GEOSPATIAL ANALYSIS OF HOW OIL AND GAS ENERGY DEVELOPMENT INFLUENCES LESSER PRARIE-CHICKEN SPATIAL ECOLOGY IN KANSAS

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ABSTRACT

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Anthropogenic changes in land use in the form of agriculture, unmanaged livestock grazing, invasive species, and energy development have reduced the viability of wildlife habitat, resulting in population declines. One group of species that may be particularly prone to stochastic and deterministic population impacts of energy development are grouse. Several grouse species native to N. America are located within the Midwest; a region containing high development densities of both wind and oil and gas (O/G). The Lesser Prairie-Chicken (Tympanuchus pallidicinctus; hereafter LPC) is a member of the prairie grouse family that has experienced significant habitat degradation and population decline due to O/G energy development since the early 1900’s. For our research, we considered the possibility that sound, produced from O/G pump jack motors, is a causal mechanism driving habitat degradation and avoidance. We collected sound pressure level (SPL) measurements at O/G pumps jack motors, nesting points, matched random, and random points throughout Gove County, KS during the 2015 LPC reproductive season. In addition, we developed an outdoor sound propagation model capable of modeling low frequency sounds from a large number of sources. We found that oil and gas pump jack motor noise had an additive effect on environmental noise out to +3,800m. We found a difference in SPL readings among nest sites, matched random, and random locations on the landscape at both low and high frequencies (p < 0.1), with nest sites and matched random points having lower SPL than random points. In addition, we found sound does not significantly influence nest success or survival. These data indicate that LPC nesting follows a hierarchical selection process where nesting habitat is constrained by sound on the landscape. Our findings
suggest that sound is an important factor influencing LPC nesting ecology and the effects of anthropogenic noise are an important component driving LPC habitat suitability.
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CHAPTER 1: SUMMARY OF RELEVANT RESEARCH INVOLVING PRAIRIE-GROUSE, SAGE GROUSE AND ENERGY DEVELOPMENT IN THE U.S.

Introduction

Prairie-grouse and sage-grouse are iconic fauna of grassland and rangeland landscapes and include species such as the Lesser Prairie-Chicken (*Tympanuchus pallidicinctus*), Greater Prairie-Chicken (*T. cupido*), Sharp-tailed Grouse (*T. phasianellus*), Attwater’s Prairie-Chicken (*T. cupido attwateri*), Gunnison Sage-Grouse (*Centrocercus minimus*), Greater Sage-Grouse (*C. urophasianus*) and the now extinct Heath-hen (*T. cupido cupido*). Currently, these species occupy ranges which extend latitudinally from Canadian territories to the Texas Gulf Coast and longitudinally from California to the Canadian east coast. (Fig. 1.1; The Cornell Lab of Ornithology 2015; Elmore et al. 2014). Prairie-grouse and sage-grouse have large home range requirements and are sensitive to anthropogenic disturbance, qualities which make them an umbrella and indicator species for rangeland management and conservation (Hagan et al. 2005; Pitman et al. 2005; Blickley et al. 2010; Patricelli et al. 2013; Hovick et al. 2014; LeBeau et al. 2014; Winder et al. 2015)

Numerous species of grouse have been petitioned for Endangered Species Act (ESA) listing due to range and population declines over the last century. Currently, the Gunnison Sage-Grouse is listed as ‘Threatened’ under provision of the ESA (ecos.fws.gov). Similarly, the Attwater’s Prairie-Chicken (APC) is listed as ‘Endangered’ under provisions of the ESA, and a recovery plan focused on the survival of the APC and conservation of its habitat is in place (U.S. Fish and Wildlife Service 1993). Unfortunately, not all imperiled grouse species have garnered the same level of conservation concern. In August of 2015, the Lesser Prairie-Chicken was delisted as ‘Threatened’ by the USFWS (ecos.fws.gov). In September of 2015, the 8th attempt to list the Greater Sage-Grouse under provision of the ESA (U.S. Department of the Interior 2015)
resulted in a “Not Warranted” ruling, which was a reversal of the previous “Warranted but Precluded” ruling (U.S. Department of the Interior 2015). In addition, across much of their range, Greater Prairie-Chickens and Sharp-tailed grouse are experiencing population declines (Westemeier et al. 1998; Svedarsky et al. 2000; Johnson et al. 2004).

Major contributors to the near ubiquitous decline in grouse abundance are anthropogenic land uses negatively affecting the availability, quality and distribution of large native rangelands (Braun 1998; Pitman et al. 2005; Francis et al. 2011; Patricelli et al. 2013; Western Association of Fish and Wildlife Agencies 2014; Winders et al. 2014; Winders et al. 2015). One particularly intensive human land use that threatens vast tracts of native grassland is high intensity energy development for oil, gas and wind resources (Copeland et al. 2011). Petroleum and natural gas extraction are large contributors to U.S. energy consumption, and because of this there is a constant trade-off between land intensive activities such as petroleum extraction (369,000-2,114,000 hectares/exajoule/year), natural gas extraction (150-880 hectares/exajoule/year) and wildlife conservation (Copeland et al. 2011). In addition, as renewable energy begins to cement itself as a relevant energy contributor, renewable resources, like wind, are expected to increase in capacity by 2025 (U.S. Departments of Interior and Geologic Survey 2015). With the large amount of development taking place in the coming decade, grouse species are likely to be further impacted by energy development across much of their home range. This review will address the conflicts derived from the spatial overlap between grouse ranges and energy development in the U.S. as well as the relevant knowledge gaps in need of further scientific investigation.

Methods

We searched for literature using online databases including ISI Web of Knowledge and Google Scholar for information relevant to grouse and energy development. All literature
searches were conducted from Dec. 2014 through April 2016 using combinations of the key words: Lesser-Prairie Chicken, Prairie Grouse, anthropogenic, sound, acoustic, chronic noise, nest success, energy development, oil and gas, wind energy, fitness, habitat, west, land use, land cover, disease, home range, nest placement, survival, mortality, U.S., energy demand, LPC, energy efficiency and GPC, Sharp tailed grouse, Gunnison Sage Grouse, attenuation, climate change, and climate prediction. Additionally, we searched government databases for unpublished technical reports regarding status and condition of grouse species. We included a total of 95 relevant publications of which 56 (58.9%) were peer-reviewed articles published in journals, 10 (10.5%) were books or book chapters, 13 (13.7%) were technical documents from various organizations including the U.S. Geologic Survey, U.S. Department of the Interior, Western Association of Fish and Wildlife Agencies, U.S. Fish and Wildlife Service and Colorado Division of Wildlife, 2 (2.10%) were meetings proceedings, 8 (8.42%) were theses or dissertations, 2 (2.10%) were related news articles and 4 (4.21%) were bulletins.

We performed two additional searches, independent of reviewed literature, using Google Scholar to compare the temporal distribution of relevant publications for prairie-grouse and sage-grouse (Fig 2). Search one used the key word “Sage Grouse” and search two used the key word “Prairie Grouse”. Each search is a distribution of the 100 most relevant publications provided by Google Scholar. The resulting distributions follow a similar pattern for each search with a gradual build up from 1950 until 2010 where it peaks, followed by a sharp drop off through 2015 (Fig. 1.2).

Of the studies included in the review, 77.9% (74/95) focused on grouse species. Of the species studied, we are categorizing Greater Sage-Grouse and Gunnison Sage-Grouse as ‘sage-grouse’ (genus Centrocercus), and we are categorizing the Greater Prairie-Chicken, Sharp
Tailed-Grouse and Lesser Prairie-Chicken as ‘prairie-grouse’ (genus *Tympanuchus*). The distribution of species studies included in the review is well dispersed between sage-grouse and prairie-grouse (Fig. 1.3).

Of our reviewed literature, 45.3% (43/95) observed the relationship between grouse species and energy development. These publications were key toward developing our summary of energy development influences on grouse. Since wind, oil and gas resources are the most abundant energy resources in grouse ranges, we focused our literature search on these energy resources. Of our reviewed literature, Greater Sage-Grouse had the most research involving oil and gas (10/26; 38.5%), while Greater Prairie-Chickens had the most research involving wind energy (8/17; 47.1%) (Fig. 1.4).

From the literature, we found a distinct increase in the publication rate of studies concerning energy development and grouse since 2000 (88.4%; 38/43). This bias might be due in part to the increasing energy demands in the U.S. (Jones et al. 2015), the 2008 EPA benchmark to reach 20% wind generated power in the U.S. by 2030 (U.S. Department of Energy 2008; Winder et al. 2015) or the attempts to list species such as the Lesser Prairie-Chicken and the Greater Sage-Grouse under provisions of the Endangered Species Act (U.S. Department of the Interior 2015).

Grouse Ranges and Overlap with Energy Development

Although grouse once inhabited much of central North America, they were unable to evade the influences of anthropogenic expansion (Patricelli and Blickley 2006; Beck 2009; Blickley et al. 2012). As grouse faced land use pressure from row crop agriculture, unmanaged cattle grazing and urbanization, grouse home ranges began to shrink (Ross 2011). At one point Greater Prairie-Chicken’s inhabited grasslands in Ohio, North Dakota and Texas (Ross 2011;
Ross et al. 2011; Elmore 2014), but are now limited to the states of Kansas, Nebraska, South Dakota, Wisconsin, Colorado, Oklahoma and Minnesota (Ross 2011; Elmore 2014). Similar stories can be told for other grouse species such as the Lesser Prairie-Chicken, which is now confined to portions of New Mexico, Oklahoma, Texas, Colorado and Kansas (Kansas Ornithological Society 2009; Oyler-McCance et al. 2016). Even the enigmatic Greater Sage-Grouse has had its distribution constricted in every state it is found in (Schroeder et al. 2004).

As grouse home ranges have decreased, researchers have been able to identify the core landscape characteristics of grouse habitat. The primary landscapes for prairie-grouse are the grasslands of the Midwest and Central Plains, which are characterized by highly abundant grass and forb species with minimal forest cover (Ryan et al. 1998; Winder et al. 2014; Lautenbach 2015). Variation in grass height and density provides ideal conditions to meet annual life cycle needs (LeBeau et al. 2014; Winder et al. 2014). Sage-grouse occupy similar habitat to their prairie-grouse relatives, but vegetative composition within their range is heavily dominated by sand-sagebrush (*Artemisia filifolia*) (Pitman et al. 2005; Doherty et al. 2006; Blickley et al. 2012; Fedy et al. 2015). Sage-grouse have been observed to have stronger selection toward sand-sagebrush vegetation than other landscape features (Pitman et al. 2005; Doherty et al. 2006; Fedy et al. 2015).

In addition to vegetative characteristics, grouse have been observed to select for gentler topography in sand-sagebrush areas (Doherty et al. 2006; Fedy et al. 2015), and prairie-grouse have been observed to utilize areas with low vegetation and high elevation relative to the surrounding landscape, such as ridgelines, for lekking activities (Gregory et al. 2011; Winder et al. 2014; Hovick et al. 2015). Patch size has also been observed to play a role in grouse populations, with persistent prairie-grouse populations occurring in 65 ha to 165 ha patches of
high-quality grassland (Ryan et al. 1998; Western Association of Fish and Wildlife Agencies 2014).

Energy development in the U.S. has expanded over the last 20 years, and since 2000, the U.S. has become more energy efficient, created new sources of energy and increased domestic production from already identified sources (American Gas Association 2005). As a result of these energy improvements, domestic energy development has expanded by adding roads, transmission lines, pipelines, wind turbines, solar panels, hydro dams, oil and gas pumps and a number of other infrastructure components associated with energy development (Jones et al. 2005). The increase in energy development has led to over 76,900,000 ha of land leased to energy development across the U.S. (Copeland 2011). Of that land, 21.3% (16,389,047/76,913,703 ha) is located in the grassland landscapes of the U.S. (Copeland 2011).

Since 2000, wind energy has been pushed to become a more important contributor to U.S. energy production (American Gas Association 2005). Estimates of wind energy for the U.S. were around 167 million MWh in 2013, which accounts for <5% of total electricity generation in the U.S. (U.S. Departments of Interior and Geologic Survey 2015). In grassland landscapes, wind energy accounts for over 200,000 ha of energy leases (Copeland 2011). As of 2014, mid-western states like Kansas, Colorado, North Dakota, Minnesota and Wyoming have an installed wind capacity of 1,000 MW- 5,000 MW (American Wind Energy Association). Due to the natural abundance of wind, infrastructure can be developed within currently or previously developed sites such as mines, agricultural fields and cities making it a high potential energy source, without additive surface disturbance (Jones et al. 2015).

Records show that 122,496 federal oil and gas drilling applications were filed from 1929-2004 in the Western U.S., with 95.7% of applications filed being authorized for development
(Connelly et al. 2004). Annual petroleum and natural gas extraction land use in the U.S. ranges from 519 ha/EJ/yr - 2994 ha/EJ/yr (Copeland 2011). High demand has resulted in oil and gas development becoming a major land use in Midwest grasslands, accounting for >60% of energy leases in grassland systems (9,971,273/16,389,047 ha; Beck 2009; Copeland 2011). The majority of oil and natural gas within U.S. federal lands resides within five geologic basins: Greater Green River, Montana Thrust Belt, Paradox-San Juan, Powder River and Uinta Piceance (U.S. Departments of Interior, Agriculture and Energy 2003). Coal bed natural gas fields (CBNG) within the Powder River Basin have become some of the most heavily developed energy fields in the U.S. (Bureau of Land Management 2003). In 2003, 29,000 CBNG wells were drilled and 37,000 wells were expected to be built within a 2.4 million hectare region (Bureau of Land Management 2003).

Currently, much of the viable grouse habitat and developed energy resources occur west of the Mississippi River and are competing land uses (U.S. Department of Interior, Agriculture and Energy 2003, Bureau of Land Management 2003). Grouse habitat completely overlaps regions with moderate- very high amounts of wind energy development (Fig. 1.5). This heavy overlap likely comes from the similarities in site selection by grouse and wind energy infrastructure (Gregory 2011; Kiesecker et al. 2011; Western Association of Fish and Wildlife Agencies 2014; Winder et al. 2015). Both grouse and wind developers search for open grasslands or shrub land as well as high elevations to minimize vertical barriers (Doherty et al. 2006; Blickley et al. 2014; Winder et al. 2014; Fedy et al. 2015; Jones et al. 2015; Winder et al. 2015). For grouse, these features help to attract females to lekking sites during the mating season (Gregory 2011; Kiesecker et al. 2011; Winder et al. 2014; Winder et al. 2015), and for wind
energy developers, these locations help to maximize energy harnessed by wind turbines (Gregory et al. 2011; Jones et al. 2015).

Similar overlap can be seen between grouse ranges and resource rich geologic basins in the Midwest (Fig. 1.6; U.S. Departments of Interior, Agriculture and Energy 2003; Schroeder et al. 2004; Harju 2010; Naugle 2011; Gregory and Beck 2014). Of particular concern is the Powder River Basin, which is situated within the Wyoming Basin and contains 25% of sage-grouse species range (Doherty et al. 2006). The sage-grouse population in the Powder River Basin is important due to its high density of sage-grouse leks, as well as acting as a bridge between populations in Wyoming, South Dakota and Montana (Doherty et al. 2006). The overlap between grouse habitat and resource rich geologic basins has resulted in thousands of hectares of grouse habitat being overlapped by high density oil and gas infrastructure (Naugle 2011; Gregory and Beck 2014).

Viable grouse habitat is heavily overlapped by wind, oil and gas development. This overlap has led to broad scale changes resulting in the degradation of grassland and shrub land ecosystems (Ryan et al. 1998; Doherty et al. 2006). Landscape alteration has caused eastern tallgrass prairies to become one of the most fragmented landscapes in the U.S., and CBNG development in the Powder River Basin has led to significant degradation of sagebrush habitat (Ryan et al. 1998; Doherty et al. 2006). This landscape alteration has resulted in species such as the Greater Sage-Grouse being extirpated from roughly 50% of their original range (Schroeder et al. 2004; Taylor et al. 2013). Competition between these land uses has resulted in grouse species being negatively affected in a multitude of ways (Wolfe 2007; Gregory 2011; Blickley and Patricelli 2012; Gregory and Beck 2014)
Direct Loss of Habitat Due to Overlap

Due to the extensive overlap between grouse habitat and energy development, there has been considerable research investigating what landscape characteristics are important for grouse and how that varies during the grouse life cycle (Ahlborn 1980; Hagen et al. 2005; Doherty et al. 2006; Gregory et al. 2011; Matthews et al. 2011; Shepherd et al. 2011). Yearly grouse activities can be separated into two categories: breeding season and non-breeding season (Sandercock et al. 2011). Previous observations have found grouse species, such as the Lesser Prairie-Chicken, have significantly higher mortality during the breeding season months of April-July (Jamison 2000; Wolfe et al. 2007). This research suggests space use during the breeding season may be more important to grouse populations than space use during the non-breeding season (Wolfe et al. 2007). This information has led to mitigation plans suggesting energy development be limited during the breeding season (Beck 2009; Kirol et al. 2015).

Grouse breeding seasons can be broken into three phases: lekking, nesting and brood rearing (Sandercock et al. 2011). As a lekking species, male grouse congregate in open grassy areas to perform courtship displays involving whooping, booming, cackling, fighting and a multitude of other behaviors in order to draw female attention (Gregory et al. 2011; Gregory et al. 2014). Lekking grounds are characterized by high elevation and low vegetation in order to ensure maximum visibility and vocalization for female attraction (Jones 1963; Copelin 1963; Giesen 1991; Dantzker et al. 1999). Researchers have observed a negative trend in lek persistence in relation to distance to wind turbine and that smaller leks have a higher probability of decreased attendance and lek abandonment; both of which have been attributed to the similarity in landscape characteristics selected for by wind energy developers and grouse lek sites (Taylor et al. 2013; Winder et al. 2014; Jones et al. 2015; Winder et al. 2015). Similarly, oil
and gas development has been observed to negatively affect grouse by decreasing male attendance by 29% - 73% and increasing lek avoidance (Blickley et al. 2010). These trends suggest a direct loss of potential lekking habitat for grouse (Blickley et al. 2010; Gregory et al. 2011; Winder et al. 2014; Winder et al. 2015).

Once a female has copulated with a lekking male, she immediately transitions into nesting mode (Sandercock et al. 2011). In general, nests and leks are within 1-5 km of each other (Blickley et al 2010; Gregory 2011; Gregory et al. 2011; Winder et al. 2015). Although they are in close proximity, the landscape characteristics of leks and nests selected for by grouse are very different. Nests are often placed in tall native grass vegetation, or within sand-sagebrush vegetation (Riley et al. 1978; Giesen 1994; Pitman et al. 2005; Shepherd et al. 2011; Fedy et al. 2015; Kirol et al. 2015). Vegetation height and visual obstruction (VOR) has been found to be important for nest survival of multiple grouse species including Greater Prairie-Chicken, Lesser Prairie-Chicken and Greater Sage-Grouse (Riley 1978; Davis et al. 1979; Pitman et al. 2005; Davis et al. 2008; McNew et al. 2013; LeBeau et al. 2014, Western Association of Fish and Wildlife Agencies 2014; Kirol et al. 2015). Tall vegetation is often selected for at nest sites in order to protect the hen and her eggs from predators during this vulnerable reproductive period (Pitman et al. 2005; McNew et al. 2013; LeBeau et al. 2014). Additionally, previous research has found a 7.1% decrease in nest failure for every 1 km increase in distance to wind turbines (LeBeau et al. 2014). This decrease may be associated with landscape alteration during construction of energy infrastructure (Braun et al. 2002). The negative trend in nest success and proximity to wind turbine as well as the required vegetative characteristics for nest sites may suggest energy development has led to a direct loss of potential nesting habitat for grouse (Pitman et al. 2005; LeBeau et al. 2014).
Following successful nest incubation, the female hens begin brood rearing (Sandercock et al. 2011). While nesting season required dense, tall and thick vegetation for protection, grouse select for less dense areas of vegetation with a greater amount of forbs when rearing broods (Jones 1964; Zwickel 1972; Riley 1978; Ahlborn 1980; Shepherd et al. 2011). These brood rearing locations provide a greater supply of insects for feeding, and easier terrain for the brood to move through (Lamison et al. 2002; Hagen et al. 2005; LeBeau et al. 2014). In landscapes with wind energy development, research has found a 38.1% decrease in brood failure per 1 km increase in distance from wind turbine (LeBeau et al. 2014). This research may suggests proximity to wind turbine is having a significant impact on grouse fecundity, and is leading to a direct loss of potential habitat (LeBeau et al. 2014).

With energy demand expected to increase every year, energy developers will be adding additional infrastructure to increase energy production (Jones et al. 2015). Placement of these infrastructure components will likely occur where developers can maximize their production of energy resources. Harnessing and extraction of wind, oil and gas resources requires the use of wind turbines, oil and gas pump jacks and compressors. Oil and gas pump jacks are found in above ground areas where known reserves are located, such as the CBNG fields within the Powder River Basin (U.S. Departments of Interior, Agriculture and Energy 2003, Bureau of Land Management 2003). To minimize the drilling distance to reach the reserve, many pump jacks are placed in valleys or flats at relatively low elevation. In contrast, wind turbine placement is optimized on high elevations, such as ridge lines, with minimal wind barriers (Winder et al. 2014; Jones et al. 2015; Winder et al. 2015). To meet energy demands, manufacturing of energy infrastructure is continually modifying infrastructure components to maximize their potential and efficiency. For example, to increase energy capacity, individual wind turbines have increased in
height, which has been positively correlated with increased fatality in avian and bat species (U.S. Departments of Interior and Geologic Survey 2015).

To make use of the extracted and harnessed energy, developers have to transport the energy to urban locations. Transport of oil and gas typically is done through oil and gas tankers hauling extracted resources, or constructing pipelines for continual resource transport. This requires thousands of miles of infrastructure including roads, which may see frequent use (LeBeau et al. 2014; Jones et al. 2015). Wind energy is converted to electricity and transported through high voltage power lines. While power lines can take a more direct route to their destination compared to roads, their construction and massive size cuts directly into wildlife habitat, resulting in negative effects on surrounding wildlife (Kroodsma 1987; Pruett et al. 2008; Walker et al. 2010).

In our assessment, direct loss of grouse habitat can be equated to the amount of physical space energy infrastructure takes up within viable grouse habitat. Vegetative composition, density and height have repeatedly been observed to be some of the most influential variables in determining nest placement, nest success, hen and brood survival and lek persistence (Oyler-McCance et al. 2001; Pitman et al. 2005; Davis et al. 2008; McNew et al. 2013; LeBeau et al. 2014; Kirol et al. 2015). Construction of energy infrastructure involving surface disturbance decreases the availability and quality of these landscape variables, resulting in reduced viability of potential habitat (Kirol et al. 2015).

Power lines, roads, turbines and pump jacks are all infrastructure components necessary for collection and transportation of energy that contribute to direct habitat loss (Walker et al. 2010; Manier et al. 2014; LeBeau et al. 2014; Winder et al. 2014; Plumb 2015; Winder et al. 2015). Similar infrastructure components are constructed across all of grouse ranges. However,
heterogeneity of grouse response to infrastructure exists. Infrastructure influence is dependent on landscape covariates such as topography, visibility, proximity and audibility (Manier et al. 2014).

Observations of the influence of energy development on Greater Sage-Grouse have estimated direct influence occurs out to 62m from the energy structure (Manier et al. 2014). Extensive infrastructure networks, such as roads and power lines, largely contribute to the loss of habitat due to their wide spatial extent (Jones et al. 2015; Mainer 2015). As energy demand increases, energy development is likely to expand to more remote locations to extract the energy, which will require additional roads and power lines (Jones et al. 2015). Taking these factors into consideration along with the near complete overlap of energy development and grouse habitat, we can estimate that there has been thousands of hectares of viable grouse habitat directly lost to energy infrastructure and many thousands more hectares may be lost in the near future (Manier et al. 2014; Western Association of Fish and Wildlife Agencies 2014).

Indirect Loss of Habitat Due to Avoidance and Fragmentation

Indirect loss of viable grouse habitat can be equated to the amount of habitat that grouse are unable to use due to the influences of energy development. Indirect differs from direct loss in that direct loss is the amount of space that can’t be used because energy development is already occupying that space, whereas indirect loss accounts for behavioral avoidance of otherwise potentially available habitat. Research findings suggest that indirect influences from energy development can cause a greater loss of habitat than direct influences as seen in Gregory et al. unpublished data, which shows roads are 4 times greater barrier to grouse movement than wind turbines, power lines are 2 times greater barrier to grouse movement than roads, and the roads and power lines together are 10 times greater barrier to grouse movement than roads alone.
One of the causes of indirect loss of grouse habitat is avoidance behavior. Studies have shown multiple grouse species including the Greater Prairie-Chicken, Lesser Prairie-Chicken and Greater Sage-Grouse avoid energy infrastructure (Pitman et al. 2005; Doherty et al. 2006; Pruett et al. 2008; Blickley et al. 2010; Dinkins 2013; Hovick et al. 2014; LeBeau et al. 2014; Manier et al. 2014; Western Association of Fish and Wildlife Agencies 2014; Winder et al. 2014; Fedy et al. 2015; Winder et al. 2015). Commonly, avoidance of infrastructure is attributed to the verticality of the structures (Pitman et al. 2005; Pruett et al. 2008; Walters et al. 2014). Grouse species have been found to avoid possible predator locations (Coates et al. 2008; Dinkins 2013; Dinkins and Conover 2014), and vertical infrastructure (power lines, wind turbines and pump jacks) provides possible perching locations for avian predators such as American Kestrels, Ravens, Swainson’s Hawks and Red-tailed Hawks (Lammers and Collopy 2007; Prather and Messmer 2010; Slater and Smith 2010). The threat of predation can cause an increase in physiologic stress, which has been observed to lead to reduced fecundity and fitness (Rubolini et al. 2005; Winder et al. 2015). An understudied cause of avoidance is the sound produced by energy infrastructure (Patricelli and Blickley 2013, Lipp et al. In Review). Studies have found that sound from energy development negatively impacts communication, fitness and reproductive success in grouse and increases avoidance (Hunt 2004; Habib et al. 2007; Slabekroon and Ripmeester 2008; Francis et al. 2011; Patricelli and Blickley 2013; Lipp et al. In Review).

As previously mentioned, not all infrastructure types will have the same magnitude of influence at all locations (Manier et al. 2014), but several studies across multiple species ranges
have observed significant avoidance of energy infrastructure by grouse (Pitman et al. 2005; Doherty et al. 2006; Pruett et al. 2008; Blickley et al. 2010; Dinkins 2013; Hovick et al. 2014; LeBeau et al. 2014; Manier et al. 2014; Winder et al. 2014; Fedy et al. 2015; Winder et al. 2015). Research has found Greater Prairie-Chickens and Lesser Prairie-Chickens avoid power lines by 100 m and buildings by >1000 m (Pruett et al. 2008). Road noise has been seen to cause lek avoidance in Greater Sage-Grouse populations (Blickley et al. 2010), as well as degrade potential Lesser Prairie-Chicken habitat (Western Association of Fish and Wildlife Agencies 2014). Alteration of habitat quality, decrease in nest success, increase in brood mortality and increased physiological stress all contribute to avoidance of wind turbines (LeBeau et al. 2014; Winder et al. 2014; Winder et al. 2015), and chronic sound exposure from oil and gas development has led to lek avoidance, decrease in clutch size and acoustical masking in several avian species (Habib et al. 2007; Blickley et al. 2010; Francis et al. 2011; Patricelli et al. 2013).

Research has estimated the range of influence for indirect effects from energy development to be 19 km (Manier et al. 2014). Additional studies found no Greater Sage-Grouse nests in areas with more than four oil and gas wells/km² (Fedy et al. 2015), and estimated a 53% reduction in Lesser Prairie-Chicken nesting habitat from avoidance behavior alone (Pitman et al. 2005). These estimates show the negative relationship and far spatial reach of indirect influences from energy development.

Habitat fragmentation is the process of spatially separating a portion of habitat into smaller pieces. Tallgrass prairie is the habitat of choice for many grouse species and has been labeled as one of the most fragmented ecosystems in North America (Ryan et al. 1998). Excessive fragmentation of tallgrass prairie has reduced patch sizes along the landscape, which negatively affects grouse, which need large intact portions of suitable habitat to sustain
populations (Ryan et al. 1998; Pitman et al. 2005; Johnson et al. 2014; Western Association of Fish and Wildlife Agencies 2014). Previous studies have observed negative impacts to grouse populations stemming from fragmentation of viable habitat. Geographic isolation has led to haplotype differences among sage-grouse populations, which resulted in increased genetic drift (Breidinger et al. 2013), and bottlenecking has led to hatch failure rates in avian species around 25.3% ± 5.0% (Briskie and Mackintosh 2004). Through natural range expansion and efforts to increase genetic diversity through recolonization of fragmented habitat have resulted in hybridization between Lesser Prairie-Chickens and Greater Prairie-Chickens (Oyler-McCance 2016). In addition, a positive relationship has been observed between fragmentation and the amount of edge habitat (Stephens et al. 2004). Many grouse predators such as coyotes and squirrels thrive in fragmented habitats (Stephens et al. 2004). The increased availability of edge provides easier traveling for grouse predators, which may lead to increased avian mortality, increased nest predation and increased brood mortality (Wolfe et al. 2007).

Indirect loss of habitat from avoidance can be linked as a potential cause of habitat fragmentation (Doherty et al. 2006; Pruett et al. 2008; Collinge 2009; LeBeau et al. 2014; Winder et al. 2014). Roads and power lines are key energy infrastructure features found to fragment grouse habitat (Doherty et al. 2006; Pruett et al. 2008; Collinge 2009; Blickley et al. 2010; Gregory 2011; LeBeau et al. 2014). Continual traffic on development access roads provides a constant deterrent to grouse space use (Gregory et al. 2011; Gregory and Beck 2014; LeBeau et al. 2014; Gregory et al. unpublished data). The massive power lines that transport electricity generated by energy development add prime avian predator positioning and dissuades grouse space use (Lammers and Collopy 2007; Pruett et al. 2009; Prather and Messmer 2010; Slater and Smith 2010; Dinkins 2013). By avoiding these abundant structures, grouse
populations are gradually boxing themselves into smaller patches of habitat. As more roads and power lines are constructed for energy transport, grouse habitat will increase in fragmentation and likely decrease in suitability (Ryan et al. 1998; Doherty et al. 2006; Pruett et al. 2008; Dinkins 2013; LeBeau et al. 2014; Winder et al. 2014).

Knowledge Gaps and Challenges for the Future

One knowledge gap that exists is a lack of any long-term data specifically collected to address how energy development is affecting grouse. Most of the research investigating the influence of energy development on grouse species has come since the early 2000’s. In this short time, there has been a good deal of progress made toward quantifying the influence of energy development on grouse, but knowledge gaps remain.

One remaining knowledge gap is how sound from energy development influences the acoustic environment. Studies investigating the influence of sound have found that sound significantly affects avian species including Lesser Prairie-Chickens, Greater Sage-Grouse, bats and Oven birds (Sparling 1983; Habib et al. 2007; Slabekroon and Ripmeester 2008; Blickley et al. 2010; Francis et al. 2011; Patricelli et al. 2013; Lipp et al. In Review). Observed affects include vocalization overlap reducing communication capabilities, decreased lek attendance, reduced reproductive success, reduced nest success, decrease in nesting habitat, decrease in clutch size, increased stress, increased mortality and avoidance (Sparling 1983; Hunt 2004; Habib et al. 2007; Slabekroon and Ripmeester 2008; Blickley et al. 2010; Francis et al. 2011; Patricelli et al. 2013; Lipp et al. In Review). Studies have estimated the amount of area influenced by oil and gas development sound to be 320m-900m; in one case, this lead to over 80% of the selected study area being affected by sound alone (Hunt 2004; Francis et al. 2011). Environmental factors such as wind, topography, temperature, humidity, barometric pressure and
vegetation will affect the intensity of sound and distance it propagates (Marten and Marler 1977; Cosens and Falls 1984; Butler et al. 2009). Height of the sound source is another factor influencing the sound propagation distance, and may be especially relevant as infrastructure components are becoming increasingly taller; e.g. wind turbines (Marten and Marler 1977; Cosens and Falls 1984).

Impacts from climate change are another area with little actual data. Average global temperature is increasing and could lead to negative results for grouse populations due to their thermal sensitivity (Root et al. 2002; Boal et al. 2014; Hovick et al. 2014). Thermal activity in nesting Lesser Prairie-Chicken has shown a negative correlation between nest success and nest temperatures (Boal et al. 2010; Hovick et al. 2014). Grouse nests were observed to be 4-6°C cooler than surrounding landscape temperatures, but doing so required constant effort by the hen (Boal et al. 2010; Hovick et al. 2014). As energy development increases, large densities of energy development may increase landscape temperatures, which has been associated with negative impact on nest placement and success (Hovick et al. 2014).

Climate change in conjunction with human land use is expected to result in a 9.0% - 21.0% decline in habitat abundance and a 3.0% - 30.0% reduction in habitat quality for Greater Prairie-Chicken (Western Association of Fish and Wildlife Agencies 2014; Gregory et al. In Press). Climate prediction models have been developed to emulate future climate scenarios, with many showing negative impacts to grouse habitat (Lyu and Sun 2013; Western Association of Fish and Wildlife Agencies 2014; Homer et al. 2015). Increased CO2 emission models predict a large decrease in the quantity and suitability of Chinese Grouse habitat over the next 60 years (Lyu and Sun 2013). Another model predicted an increase in bare ground and decrease in shrub and sagebrush litter resulting in an 11.6% loss of sage-grouse habitat by 2050 (Homer et al. 2015).
While these are predictive models of the future and not current conditions, they provide useful information for developing precautionary conservation efforts.

Energy demand is expected to increase annually (Fillipini and Hunt 2012; Jones et al. 2015). To meet the growing demand, increases in energy extraction are likely to occur. For the past 50 years, increasing energy demands have been primarily met by using fossil fuels and current information suggests that trend will continue (Jones et al. 2015). In the years 1929-2004, over 120,000 drilling applications were filed to federal agencies with <2% rejected or withdrawn (Connelly et al. 2005). Drilling permits in the Rocky Mountain West region have increased 60% as of 2005 (American Gas Association 2005), and natural gas production has risen by over 20% since 1990 (Jones et al. 2015). As a supplement to oil and gas, wind energy has had a 23-fold increase since 2000 (Jones et al. 2015), and projections estimate our current wind energy capacity of 62.3 GW will increase to 80-114 GW by 2025 (U.S. Departments of Interior and Geologic Survey 2015). Additionally, the U.S. Department of Energy has set a goal to satisfy 20% of energy demand using domestic wind resources by the year 2030 (U.S. Department of Energy 2008; Winder et al. 2015). While wind energy has been labeled as a ‘green energy source’, in 2030, its expected land requirement of 72.1 ha/TW will be 53.5 ha/TW more than natural gas and 27.4 ha/TW more than oil (McDonald et al. 2009; Jones et al. 2015).

Challenging tradeoffs arise when trying to balance the increase in energy production with conservation of grouse habitat. Interstate organizations such as the Western Association of Fish and Wildlife Agencies (WAFWA) and the Fish and Wildlife Service (FWS) are researching the highest quality potential habitat for grouse and recommending research backed management plans (Svedarsky et al. 2000; Jamison et al. 2002; Dinkins 2013; Patricelli et al. 2013; Jamison et al. 2002). Tools developed for habitat conservation like the Crucial Habitat Assessment Tool
(CHAT), which uses offset mitigation, are giving state and federal agencies the ability to locate the highest quality, potential habitat based on the defined needs of the species being conserved (WAFWA.org). Tools like the CHAT are advantageous for maximizing the quantity of high quality habitat while minimizing the constraints placed on neighboring energy development (WAFWA.org). Use of before-and-after controlled-impact (BACI) designed studies applied at the appropriate scale will offer insight into the influences brought on by energy development as well as make observations from one area comparable to observations from another (Kemp et al. 2001; Weins 2001; Stephens et al. 2003).

An additional method to minimize habitat conservation and energy development conflicts is to develop contemporary regulatory mechanisms. Mitigating sound influences could increase lek attendance, avian communication, nesting success and potential habitat for many grouse species including Lesser Prairie-Chickens, Greater Prairie-Chickens, Gunnison Sage-Grouse and Greater Sage-Grouse (Sparling 1983; Habib et al. 2007; Slabekroon and Ripmeester 2008; Blickley et al. 2011; Francis et al. 2009; Lipp et al. In Review). Regulations on development proximity and development density could reduce negative population trends in grouse, reduce noise exposure, increase nesting habitat, decrease nest failure, decrease brood mortality and increase space use (Hunt 2004; Beck 2009; Francis et al. 2011; LeBeau et al. 2014; Manier et al. 2014; Winder et al. 2014; Fedy et al. 2015; Winder et al. 2015). As more knowledge gaps are addressed, regulatory policies should be revised in order to most effectively mitigate the influence of energy development on wildlife.

While the observed impact of energy development on grouse has been primarily negative, and there are still several knowledge gaps that need to be addressed, some previously imperiled species of grouse have had recent success. Conservation efforts implemented by groups, such as
the Western Association of Fish and Wildlife Agencies, have aided in a 25% population increase in Lesser Prairie-Chicken from 2014-2015 (Western Association of Fish and Wildlife Agencies 2015). Additionally, male lek attendance of Greater Sage-Grouse has increased 63% since 2013, and the Greater Sage-Grouse still maintains an eleven state range (WAFWA 2015b). There are many threats to grouse species, but that hasn’t deterred the conservation efforts of state and federal agencies. With the help of effective management and informed conservation, it has been shown that grouse species can still persist in their native habitat even with intense energy development (WAFWA 2015a, WAFWA 2015b).

Conclusion

Energy development within grassland habitats encompasses 16,389,047 ha of land (Copeland 2011). With their collective spatial distributions occurring in the Southwest, Intermountain west, Central Plains and Midwest, grouse home ranges overlap thousands of hectares of the U.S. domestic energy development (Francis et al. 2011; Mainer 2014; Winder et al. 2014; Winder et al. 2015). Conservation of grouse habitat and energy development are both very land intensive practices (Copeland 2011; Western Association of Fish and Wildlife Agencies 2014). Supporting both land uses within this landscape calls for exceptional consideration when developing management strategies (Patricelli 2013).

Intense energy development has created an omnipresent influence across rangelands (Francis et al. 2011; Mainer 2014). Direct influences have removed thousands of hectares of potentially viable grouse habitat through large scale energy development. Indirect influences from energy development have led to negative impacts to grouse including fragmentation, decreased lek attendance, clutch size and avoidance of habitat by grouse (Briskie 2004; Pitman et al. 2005; Wolfe et al. 2007; Pruett et al. 2008; Patricelli et al. 2013; Winder et al. 2014).
Suggested guidelines based on previous observations have included: no surface occupancy within 0.4 km of a lek (Beck 2009), no development within 3.2 km of lek during breeding season (Beck 2009), no more than 10 dBA increase in noise above ambient level within grouse habitat (Patricelli et al. 2013), construct energy infrastructure in a centralized location (Francis et al. 2011) and place sound barriers around oil and gas pumps to reduce sound propagation distance (Francis et al. 2011).

Increased domestic energy production has spurred increased research on the impacts of energy development on grouse over the last few decades (Nakata 2004). As energy development is expected to increase, it will be important to address remaining knowledge gaps in order to further our understanding of grouse and their habitats. Future survival and success of grouse species will be dependent on the effectiveness of mitigation and conservation strategies incorporating both energy development and habitat conservation.
Fig. 1.1
Distribution map for common grouse species in N. America. Species distribution for nearly all
grouse in N. America has been reduced in the past century. Land alteration and degradation has
reduced the availability of habitat outside of grouse distributions, and reduced the suitability of
habitat within distributions. GIS data for Northern Sage-Grouse and Gunnison Sage-Grouse
distributions came from The Cornell Lab of Ornithology.
Fig. 1.2
Results from additional search on Google Scholar comparing relevant results from key words “Sage-Grouse” and “Prairie-Grouse”. Both searches returned similar distribution of publications per decade with a gradual increase from 1900 – 2010 where the peak occurred. The sharp drop in publications following the peak in 2010 is likely due to search year (2015) and not a decrease in research effort.
Fig. 1.3
Number of publications used in review; compared by species. Greater Sage-Grouse and Lesser Prairie-Chicken were the focal species of the greatest number of publications used in the review.
Fig. 1.4
Number of publications used in this review, compared by species and energy resource. Greater Sage-Grouse had the greatest number of publications involving any type of energy development, as well as the greatest number of publications involving oil and gas development specifically. Greater Prairie-Chickens had the greatest number of publications involving wind energy development.
**Fig. 1.5**
Map of overlap between wind resources and grouse ranges in the continental U.S. Wind resources are most abundant in the New England, Midwest and Rocky Mountain regions. Grouse ranges overlap moderate – very high wind resource areas. GIS data for wind resources obtained from the National Renewable Energy Laboratory operated by the Alliance for Sustainable Energy for the U.S. Department of Energy.
Fig. 1.6
Map of overlap between U.S. geologic basins and grouse ranges in the continental U.S. Grouse ranges overlap several large sedimentary basins including the Powder River, Williston, Greater Green River and Denver basin. Sedimentary basin GIS data obtained from U.S. Geological Survey and state agencies.
CHAPTER 2: INFLUENCE OF OIL AND GAS DEVELOPMENT NOISE ON LESSER PRAIRIE-CHICKEN NESTING ECOLOGY IN NW KANSAS

Introduction

Expansion of anthropogenic land use has resulted in negative effects on wildlife species in a variety of habitats (Pitman et al. 2005; Francis et al. 2011; Patricelli et al. 2013). Habitat conversion and loss through anthropogenic land use has caused population declines to hundreds of species worldwide, leading to what has been dubbed “the extinction crisis” (Hoekstra et al. 2005), and urbanized areas create communication barriers, leading to speciation between populations (Slabbekoorn & Ripmeester 2008; McLaughlin et al. 2013).

An understudied feature of anthropogenic land use in wildlife ecology and management is sound. Characteristics of sound, frequency, amplitude and duration, can differ between anthropogenic sources and natural sources (Blickley et al. 2012; Patricelli & Blickley 2013). Previous research has investigated the influence of sound duration on wildlife, finding that intermittent and continuous sounds, like those associated with roads and oil and gas compressors respectively, negatively affect avian species by reducing communication, fecundity, and survival (Marten & Marler 1977; Francis et al. 2011; Blickley et al. 2012; Francis & Barber 2013). Frequency and amplitude of sound also play an influential role in the effect of sound on wildlife, as these characteristics determine the distance a sound propagates from its source (Marten & Marler 1977; Cosens & Falls 1984; Bell & Bell 1994).

While previous studies have investigated the influence of duration and amplitude on wildlife (Francis & Barber 2013; Patricelli & Blickley 2013), there has been little research on the influence of sound frequency. This is especially true of research looking at the influence of extremely low sound frequencies below the audible range of most species (100 Hz-150K Hz)
These lower frequencies are capable of propagating much further distances than higher frequencies, potentially resulting in a much greater affected area (Sparling 1983).

Over the last 100 years, Lesser Prairie-Chicken (hereafter LPC; *Tympanuchus pallidicinctus*) have suffered continual population declines across their historic range (Wolfe et al. 2007). Oil and gas development is a common land use overlapping LPC distribution and has been linked to fragmentation and loss of habitat within the LPC home range (Pitman et al. 2005). With consistently declining populations and habitat pressure from competing land uses, LPC were given a ‘Threatened but Precluded’ listing under the Endangered Species Act in August of 2014 (U.S. Fish and Wildlife Service). While the listing was removed in September of 2015, LPC are still considered a species of conservation concern.

Due to the lack of research on the influence of sound on wildlife and the recent listing and delisting of LPC, our research investigates the influence of both high and low frequency sounds on LPC nest placement and nest success. In addition, we have modeled sound propagation from oil and gas pump jacks; oil and gas development exists at a high density within our study site in NW Kansas. Our model of sound propagation incorporates aspects of commercially available sound propagation software, while adapting them to work in our analyses (Lihoreau et al. 2006; Bolin 2009; Reed et al. 2009).

From previous research and observation, we predicted sound will have a negative effect on LPC nesting ecology (Francis et al. 2011; Patricelli et al. 2013). We expected LPC to avoid areas on the landscape with high sound pressure levels, leading to a loss of potential nesting habitat (Blickley et al. 2012). We also expected high sound pressure levels at nest sites to decrease nest success (Francis & Barber 2013). In addition, we expected low sound frequencies
to have a greater effect on LPC than high sound frequencies due to their physical properties propagating sound further distances (Sparling 1983). Our sound propagation model will provide a novel method of estimating sound propagation across a large area over a long period of time, from a large number of sources and at a wide array of frequencies, which has not been explored with previous modeling software.

Methods

Our study was conducted at a 3,930 km² section of NW Kansas, encompassing portions of Logan, Gove, Lane, and Scott counties (Fig. 2.1). Land uses in the region of study are primarily unmanaged livestock grazing, oil and gas development, row crop agriculture and CRP grasslands (Conservation Reserve Program). As part of the short-grass prairie/CRP ecoregion, dominant grass composition consisted of blue grama (*Bouteloua gracilis*), little bluestem (*Schizachyrium scoparium*), big bluestem (*Andropogon gerardii*), side oats grama (*Bouteloua curtipendula*), purple threeawn (*Aristida purpurea*) and sand dropseed (*Sporobolus cryptandrus*). The study landscape had little topographic complexity, with elevations ranging from 750 m-850 m. Monthly rainfall ranged from 3.73 cm – 20.8 cm with a total of 52.5 cm during the study period, and average monthly temperature fluctuated between 12.7°C – 25.9°C (NOAA).

Using a combination of walk-in traps and drop nets, LPCs were captured during the spring lekking period, lasting from 15-March until 13-May (Silvy & Robel 1967; Hamerstrom & Hamerstrom 1973). At capture, LPCs were sexed and aged by plumage (Schroeder and Robb 2005) and females were fitted with either a satellite-received transmitter (100 GPS Platform Transmitting Terminals (PTT), Microwave Telemetry Inc., Columbia, Maryland, USA) or a VHF radio transmitter (12-g necklace, Advanced Telemetry System, Isanti, Minnesota, USA). All capture and handling procedures were approved by Kansas State University Institutional
Animal Care and Use Committee under protocol #3241, and the Kansas Department of Wildlife Parks and Tourism scientific collection permit numbers SC-042-2013 and SC-079-2014.

GPS satellite tagged females were located using the GPS/Argos System with GPS locations transmitted once every two hours from 0400-2200. UTM coordinates of LPCs were retrieved using Location of a Signal software (Ecological Software Solutions, Florida, USA). Female LPCs fitted with VHF radio transmitters were located by triangulation five times per week until the hen had localized for three consecutive locations, at which time the hen was flushed to confirm nesting (Lautenbach 2015, Plumb 2015). Once nesting was confirmed, GPS coordinates of the nest were recorded; nests were revisited weekly until hatching occurred (Lautenbach 2015).

On the first day a nest was discovered, nest status was recorded and laying and hatch dates were estimated using standard float curves (McNew et al. 2009). Nest status was considered successful if ≥1 egg hatched and had a chick capable of fledging, or failed if it had been depredated, destroyed or abandoned (McNew et al. 2014; Lautenbach 2015). Immediately following nest success or failure, we measured sound pressure level (dBC) at nine frequency levels (8 Hz, 16 Hz, 32 Hz, 64 Hz, 125 Hz, 250 Hz, 500 Hz, 1000 Hz and 2000 Hz) using a Larson Davis LxT-L1 Sound pressure level Dosimeter equipped with an ultra-low frequency preamp (Larson Davis Inc. NY, NY, USA). For each nest, we measured sound at the nest bowl itself, a matched random point within 0-200 m at a bearing between 0-360° from the nest bowl and at random points throughout our study system. Random points were generated using the Create Random Point Tool in the Spatial Analyst extension of ArcGIS 10.3 (ESRI 2011. ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute). This sampling scheme yielded a balanced sample design allowing us to test the hierarchical nature of sound
influence on LPC nesting ecology. In addition, we took sound measurement at oil and gas pump jacks. Sound measurements at oil and gas pump jacks were taken 2-5m away from the pump jack motor. When taking sound measurements, we measured sound pressure level at each frequency simultaneously. We chose to measure sound pressure level at low frequencies (8 Hz – 125 Hz) because sound at low frequencies propagate further than high frequency sounds (Marten & Marler 1977; Bell & Bell 1994). We also included moderate and high frequencies in our measurements because previous research suggests the Lesser-Prairie Chicken vocalization range lies within 250 Hz - 2000 Hz (Sparling 1983). We measured sound at 50 oil and gas pump jacks, 23 nest locations, 23 nest matched random points, and 203 random points (Table 2.1). However, we used rarefaction analysis to subsample our random points for comparison with nest and matched random points. All sound measurement periods lasted 5 min, with measurements taken at a rate of 10 measurements per second at 30 cm above the ground, which is the approximate height of a LPC. When taking sound measurements, we also measured environmental covariate data (temperature, humidity, elevation, wind speed, wind direction, land cover, and barometric pressure) using a Kestrel 4500 NV Weather Station (Supp. Table 1; Kestrel Inc. 21 Creek Circle Boothwyn, PA 19061, USA). There were 1,083 oil and gas pump jacks located in our study site. Of those, we performed repeated measurements at 50 pumps that were nearest to known Lesser-Prairie Chicken habitat. To account for daily and seasonal variance in environmental conditions, sound and environmental covariates were measured at each pump 2-4 times during the study period at different times of the day and night.

All statistical analyses, unless otherwise noted, were carried out using the Stats package of Program R (R Core Team 2013).
Because our sound measurements at nest, matched random, and true random points measured sound at each frequency simultaneously, our measurements of sound pressure level may have been susceptible to inter-frequency interference (Marten & Marler 1977). To control for inter-frequency interference and colinearity among sound frequencies, we used a structured equation modeling framework, wherein we first used a Multiple Analysis of Variance (MANOVA) across all sound frequencies measured at nest, matched random, and true random points, and then a post hoc univariate analysis of variance (ANOVA) to test for the influence of individual sound frequencies on nest placement and success (McGarigal & Marks 2000; Cushman & McGarigal 2002. We used ANOVA to compare sound pressure level between nest locations, matched random locations, and true random locations. Similarly, we also used ANOVA to compare sound pressure level at successful nests, failed nests and random locations. In addition, we used linear regression to test if sound pressure level had an influence on LPC life history traits including egg volume, clutch size and % hatch success.

We initially tried to use commercially available sound propagation modeling software SPReAD GIS (Reed et al. 2009), however, SPReAD GIS is not currently capable of incorporating sound from frequencies lower than 125 Hz and is not optimized to model sound propagation from hundreds of sources (personal communication, S. Reed developer of SPReAD GIS). Consequently, we developed our own sound propagation model that could be applied using standard GIS tools and python scripts (Python Software Foundation. Python Language Reference, version 2.7). To quantify the spatial extent of oil and gas development noise, we used ArcGIS 10.3 (ESRI 2011. ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute). The first step to our sound propagation model was to create an independent distance raster for each oil and gas pump jack within the study area with a spatial resolution of

Equation 1

\[ L_p(r, f) = L_p^1(r, f) - 20 \log(r) - \frac{\alpha(f)r}{100} - (0.18 \log(f) - 0.31)r \]

\( L_p(r, f) \) is the estimated sound pressure level occurring at distance \( r \) from the source at a frequency \( f \). \( L_p^1(r, f) \) is the measured sound pressure level at a distance, \( r \), from the source at frequency, \( f \) (\( L_p^1(r, f) \) was created by averaging sound pressure levels from all oil and gas pump jack measurements using Equation 2). \( 20 \log(r) \) describes the attenuation due to natural spherical spreading of sound. Where \( r \) is the distance from the source, \( \frac{\alpha(f)r}{100} \) is the attenuation due to atmospheric absorption where \( r \) is distance from the source and \( \alpha(f) \) is the local atmospheric attenuation coefficient at a specific frequency (\( f \)) calibrated with our measured environmental covariates. \( (.18 \log(f) - .31)r \) describes the attenuation from tall grasses and shrubs at a distance from the source, \( r \), at frequency \( f \) (Bell & Bell 1994).

In addition to the sound propagation rasters around oil and gas pump jacks, we also created a constant raster at each measured frequency for the entire study area to represent baseline LPC nesting conditions at an individual frequency. We used our sound measurements at nest sites to determine our baseline sound conditions by averaging the sound pressure level at each frequency using Equation 2. We chose to use nest sites to determine our baseline sound conditions, and because energy development has been shown to reduce nest success in grouse
species (Lebeau et al. 2014), our model assumes that without oil and gas development, the entire study area is potential nesting habitat.

Equation 2

\[ L_{p\bar{x}} = 10 \times \log \left[ \frac{1}{n} \sum_{i=1}^{23} 10 \left( \frac{L_{p_i}}{10} \right) \right] \]

Equation 2 is used to average sound pressure level from multiple sources. \( L_{p\bar{x}} \) is the averaged sound pressure level from all LPC nest sites, \( L_{p_i} \) is the sound pressure level from individual measurements and \( n \) is the total number of measurements used in generating the average sound pressure level (Chan n.d.)

Once raster surfaces for each pump jack as well as baseline conditions were created, we used PyScripter 2.7 to combine all rasters, of an individual frequency on a cell by cell basis into a single soundscape raster (Equation 3; Python Software Foundation. Python Language Reference, version 2.7). This sound model can be calibrated to incorporate any measured sound frequency. We chose to use 16 Hz because our estimates predicted 16 Hz sound to propagate the furthest, and influence the largest area (Supp. Fig. 1).

Equation 3

\[ L_{p_T} = 10 \times \log \left[ \sum_{i=1}^{1084} 10 \left( \frac{L_{p_i}}{10} \right) \right] \]

Equation 3 is used to add incoherent sound pressure level from multiple sources at a single location. \( L_{p_T} \) is the total sound pressure level from all oil and gas pump jacks and \( L_{p_i} \) is the sound pressure level from an individual source (Bell & Bell 1994).

To quantify the amount of area with sound exceeding baseline conditions, we used PyScripter 2.7 to reclassify the resulting raster into a binary map of the study area showing modeled sound pressure levels above the baseline conditions, and modeled sound intensities at or
below baseline conditions (Python Software Foundation. Python Language Reference, version 2.7). Following the reclassification, we used the Cell Statistics tool within the Spatial Analyst extension for ArcGIS 10.3 to calculate the amount of area classified as above baseline within our study site (ESRI 2011. ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute).

Accuracy of our sound model was estimated using percent error calculations (Equation 4), comparing modeled sound values to measured sound values at our true random points.

Equation 4

$$PE = 100 * \frac{|(Modeled - Measured)|}{Measured}$$

Assessing percent accuracy of soundscape model. PE is percent error, Modeled refers to the modeled sound values, and Measured refers to on the ground measurements taken at true random points.

We used the Nest Survival module within Program Mark to model probability of daily nest survival as a function of day and sound pressure level (White & Burnam 1999). In the model we included the day nests were found, the last known date before success or failure of a nest, the date a nest failed or succeeded, and the nest fate and sound measurements at each nest for each measured frequencies. We used Information Theoretic Approach to select the most parsimonious model of nest fate based on AICc values (Akaike 1973).

Results

Results of MANOVA testing the effect of sound at 8, 16, 500, and 1000 Hz on nest placement were significant and indicated that simultaneous measurement of sound pressure level across these frequencies did not add inter-frequency interference to our measurements ($F_{d.f.} = 2,246$).
= 2.37 \( P=0.0168 \); Hotelling-Lawley= 0.0784). Subsequent tests comparing measured sound pressure level at nest locations, nest matched random and true random locations indicate that both nest locations and nest-match random locations occur at quieter areas than random locations on the landscape (Table 2.2). Additional ANOVA testing found a significant difference in sound pressure level measurements at successful nests, failed nests, and random locations on the landscape, with random locations being significantly louder than both successful and failed nest points (Table 2.2). Linear regression results indicate that sound had little, if any, influence on egg volume (\( P_{d.f.} = 6, 12= 0.7709, R^2= -0.1826 \)), clutch size (\( P_{d.f.} = 6, 13=0.9481, R^2=0.2556 \)) or hatch success (\( P_{d.f.} = 4, 15=0.2279, R^2= 0.1563 \)).

Comparing our measured sound values to our modeled sound values, we estimate an average error of 9.5 dBC and a percent error of 20.5% for our sound model. We accept the level of error associated with our model, due to the assumptions used in developing the model; oil and gas pump jacks represent all oil and gas development noise on our landscape, wind and temperature are variable throughout the measurement period and we are modeling average conditions throughout the entirety of the breeding season. Our sound model predicted that sound produced by an oil and gas pump jack at 16 Hz will propagate 3.83 km and cover 46.1 km² before fully attenuating (Fig. 2.2). At a distance of 5 m from a pump jack, sound is increased by 5.6 dBC, at 7 m sound is increased by 3.5 dBC, at 10 m sound is increased by 2.1 dBC, at 14 m sound is increased by 1.1 dBC and at distances ≥30 m, sound is increased by ≤1 dBC (Fig. 2.3, Supp. Fig. 1).

Based on our definition of baseline sound pressure level for LPC nesting (53.7 dBC), and in conjunction with our oil and gas sound propagation model, we calculated the amount of area on the study landscape that exceeds the baseline sound pressure level (53.7 dBC) to be 3,371 km².
(85.8% of the landscape) (Supp. Fig. 2). However, the majority of these areas (85.7% of the landscape) are <0.4 dBC above baseline.

Nest success across our landscape was low at 30.4% (7/23 nests). Of our competing models, the model utilizing just day of the nesting season (Date; $\beta = -0.0177$, SE = 0.0176) was most parsimonious. Only models utilizing mid-high frequency sounds (125 Hz-2000 Hz) were competitive, and they varied in their relationship to nest survival. 2000 Hz ($\beta = 0.0633$, SE = 0.0849) and 250 Hz ($\beta = 0.0535$, SE = 0.0734) were positively related to nest survival, and 500 Hz ($\beta = -0.0269$, SE = 0.0408) and 125 Hz ($\beta = -0.0219$, SE = 0.0657) were negatively related to nest survival. AICc scores in competing models differed by <1.0, so there is no clear best model (Table 2.3). None of the 95% CI for competing models included 0.0%. Models, excluding 500 Hz, predicted a probability of survival at or between 15.8% and 26.2% with 95% CI at or between 3.92% and 63.3% (Fig. 2.4). Probability of daily survival decreased as a f(x) of Date, indicating that a prolonged nesting season negatively influences probability of daily nest survival (Fig. 2.5).

Discussion

From our analyses, we found that sound pressure level at random locations is significantly higher than sound pressure level at LPC nest and nest matched random locations, regardless of nest fate. This suggests hierarchical constraints may be placed on selection of nesting habitat by LPC hens (Johnson 1980). Hierarchy theory, in an ecological context, bases selection of habitat features on a ranked order where higher levels constrain lower levels on a temporal and spatial scale (Turner et al. 2001). In addition, hierarchy theory implies that constraints operate at different spatial and temporal scales causing variations in landscape pattern and heterogeneity (Turner et al. 2001). Our focal level of interest is the landscape scale during a
single nesting season, where sound sources are creating large scale spatial patterns of high and low sound pressure level. Hierarchy theory suggests that if we were to look at higher levels, we would find spatial and temporal patterns independent of those at our focal level (Johnson et al. 1980; Turner et al. 2001). In contrast, if we were to look below our focal level, we would find a more intricate landscape pattern delineated by patterns at our focal level (Nixon 2001). At our focal level, sound is a constraining characteristic dictating where an LPC hen is likely to place a nest during the nesting season. At higher levels, climatic conditions and regional topography may be constraining factors in LPC home range. At lower levels, local microhabitat vegetation likely influence the precise location of an LPC nest (Riley 1978; Davis et al. 1979; Giesen 1994; Pitman et al. 2005). This has been shown by recent research that found vegetation at LPC nest sites has greater VOR, and less bare ground than both matched random and true random locations (Lautenbach 2015). Overall, our results indicate that for the duration of the nesting season, high sound pressure levels are constraining habitat availability spatially, which suggests that sound is an important feature constraining LPC habitat selection on our study landscape.

However, our data further suggests that sound does not significantly influence nest success. There are two caveats to this observation. First, nest success on this landscape was only 30.4%. Second, because all nests are placed in quieter portions of the landscape, there is little difference in terms of sound pressure level among successful and failed nests. The co-occurrence of successful and failed nests is likely the reason our nest survival analysis resulted in sound having a positive and negative relationship to nest survival, depending on frequency. Our nest survival results indicated probability of daily nest survival decreased as the nesting season progressed. Our probability of daily nest survival had a slight change in rate of decline around
the 50th day of the nesting season, which corresponds to May 20th. This follows previous research finding increased LPC mortality in May due to raptor predation (Jamison 2000).

Nests can fail for a variety of stochastic and deterministic reasons that cannot be directly explained by sound, but sound may have an indirect effect on nest success through the various other mechanisms influencing nest survival. Vigilance of a nesting hen has been shown to be a key factor in the survival of her nest (Brown 1999); as vigilance decreases, the lethality of predators will increase (Brown 1999; Lima & Dill 1990; Mitchell & Lima 2002). Additionally, vigilance of an individual is linked to the individual’s ability to perceive a threat (Slabbekoorn & Ripmeester 2008). Anthropogenic noise has been found to mask warning calls among avian populations as well as mask approaching predator noise (Slabbekoorn & Ripmeester 2008; Francis & Barber 2013). It’s possible that the masking of predator approaches and neighboring alarm calls has led to a functional reduction in vigilance in hens, thereby increasing nest depredation, resulting in low nest survival. These indirect effects of sound increase the dependence of LPC on suitable microhabitat characteristics, such as VOR, to survive the nesting period (Pitman et al. 2005).

Our results indicated oil and gas noise propagates to 85.8% of the landscape and can have negative effects on LPC nesting ecology; which supports the growing research suggesting oil and gas development is capable of negatively affect wildlife over large areas (Pitman et al. 2005; Francis et al. 2011; Patricelli et al. 2013). It should be noted that while we estimate oil and gas to propagate to 85.8% of the landscape, <1.0% of the landscape experiences an increase >1.0 dBC above our baseline conditions, meaning only a small percentage of the landscape is removed from availability. However, on a landscape with multiple stressors, a slight increase in sound may increase mortality, decrease fecundity or both.
Keys to reducing the effect of oil and gas development on grassland bird species are to reduce the sound produced by pump jacks and to reduce the visibility of infrastructure (Pitman et al. 2005; Francis et al. 2011; Patricelli et al. 2013). To accomplish this, oil and gas companies should consider clustering pump jacks in developed areas. Having a single cluster of pump jacks in a centralized location rather than hundreds of pump jacks interspersed across the landscape may reduce the visibility of pump jacks across the landscape. Clustering oil and gas pump jacks has a tradeoff associated with it in regards to sound. From our sound model, we can see that high density oil and gas pump jacks produce a greater sound pressure level than low density pump jacks, due to the additive properties of sound, which can propagate longer distances (Supp. Fig. 3; Marten & Marler 1977; Cosens & Falls 1984). This can be mitigated through the use of walls and mufflers on an interspersed portion of oil and gas pumps jacks (Fuller et al. 2007; Francis et al. 2011). By having an interspersed portion of pump jacks muffled, the effective density of sound sources would be reduced (Madhusudan & Warren 2004; Dooling & Popper 2007; Dowling et al. 2012). If oil and gas companies continue with the common practice of vertical drilling, clustering pump jacks would reduce access to oil and gas reserves. Therefore, we suggest oil and gas companies implement more directional and horizontal drilling to allow for centralized arrangements of pump jacks as well as access to oil and gas reserves on the landscape.

Spatial arrangement of oil and gas infrastructure can have an effect on several wildlife species. Non-clustered oil and gas development requires more transportation infrastructure such as roads and power lines, which previous research found to fragment grassland landscapes (Stephens et al. 2004; Pruett et al. 2009). Both Greater Prairie-Chicken and LPC have been observed to dislike crossing roads and under power lines causing isolated populations (Pruett et
al. 2009; Gregory 2011). Edge predators, such as coyote, benefit from increased fragmentation due to the associated increase in edge habitat increasing search efficiency (Wolfe et al. 2007), which in turn increases predation risk among prey species (Wolfe et al. 2007; Morris & Gilroy 2008). Grassland passerine species have also been observed to have decreased nest density near edge habitat created through fragmentation (Renfrew et al. 2005). By clustering oil and gas pump jacks, the centralized arrangement would reduce the amount of needed infrastructure and reduce the associated effects on wildlife species.

In addition to our own findings, previous research efforts have observed sound to be an important factor influencing many species across different landscapes (Habib et al. 2007; Francis et al. 2011; Patricelli & Blickley 2013; Patricelli et al. 2013). Mitigation of oil and gas development sound can be done through centralized spatial arrangements as well as through the use of mufflers (Francis et al. 2011). This mitigation approach would benefit several species by reducing oil and gas infrastructure on the landscape as well as their associated effects. To optimize this mitigation approach, future research should investigate the influence of sight and sound interactions on grassland species. Identified as two drivers of avoidance behaviors in grouse species (Pitman et al. 2005; Pruett et al. 2009; Blickley & Patricelli 2013), understanding this interaction is needed to minimize oil and gas development effects. Our study has contributed to the growing field of acoustical ecology and the study of anthropogenic influence by identifying sound as a landscape characteristic influencing hierarchical habitat selection by LPC, finding that sound does not significantly influence survival of nesting LPC and by creating an outdoor sound propagation model capable of modeling sound from a realistic distribution of energy development infrastructure.
Table 2.1
Average sound pressure level measurements at all measured frequencies from all point types.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>8 Hz (dB)</th>
<th>16 Hz (dB)</th>
<th>32 Hz (dB)</th>
<th>64 Hz (dB)</th>
<th>125 Hz (dB)</th>
<th>250 Hz (dB)</th>
<th>500 Hz (dB)</th>
<th>1000 Hz (dB)</th>
<th>2000 Hz (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>O/G Pump Jack</td>
<td>65.5 ±0.88</td>
<td>65.7 ±0.70</td>
<td>69.1 ±0.81</td>
<td>73.9 ±0.94</td>
<td>73.6 ±0.86</td>
<td>69.9 ±0.83</td>
<td>67.8 ±0.90</td>
<td>64.4 ±0.92</td>
<td>70.6 ±1.1</td>
</tr>
<tr>
<td>LPC Nest</td>
<td>56.5 ±2.2</td>
<td>53.7 ±1.9</td>
<td>51.2 ±1.5</td>
<td>47.2 ±1.1</td>
<td>44.4 ±1.1</td>
<td>39.8 ±0.89</td>
<td>39.9 ±1.0</td>
<td>38.9 ±1.1</td>
<td>38.2 ±0.85</td>
</tr>
<tr>
<td>Nest Matched Random</td>
<td>55.8 ±2.3</td>
<td>54.7 ±2.0</td>
<td>52.1 ±1.7</td>
<td>47.5 ±1.3</td>
<td>42.6 ±0.98</td>
<td>39.2 ±0.89</td>
<td>40.9 ±1.0</td>
<td>39.3 ±0.88</td>
<td>38.4 ±0.88</td>
</tr>
<tr>
<td>True Random</td>
<td>68.3 ±1.0</td>
<td>62.8 ±0.78</td>
<td>56.4 ±0.65</td>
<td>54.5 ±0.47</td>
<td>53.3 ±0.46</td>
<td>52.7 ±0.50</td>
<td>46.0 ±0.56</td>
<td>47.2 ±0.60</td>
<td>42.4 ±0.58</td>
</tr>
</tbody>
</table>

Notes: Average sound pressure level from all measurements taken; O/G n=50, LPC Nest n=23, Matched Random n=23, True Random n=203
Table 2. 2  
ANOVA series testing for differences in measured sound pressure level at multiple frequencies

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>F-value</th>
<th>df</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nests vs Matched Random vs True Random</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>3.09</td>
<td>2, 247</td>
<td>0.047*</td>
</tr>
<tr>
<td>16</td>
<td>2.65</td>
<td>2, 247</td>
<td>0.072*</td>
</tr>
<tr>
<td>500</td>
<td>4.96</td>
<td>2, 247</td>
<td>0.0077*</td>
</tr>
<tr>
<td>1000</td>
<td>3.01</td>
<td>2, 247</td>
<td>0.051*</td>
</tr>
<tr>
<td>Successful Nests vs Fail Nests vs True Random</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>3.31</td>
<td>2, 248</td>
<td>0.038*</td>
</tr>
<tr>
<td>16</td>
<td>2.88</td>
<td>2, 248</td>
<td>0.057*</td>
</tr>
<tr>
<td>500</td>
<td>5.32</td>
<td>2, 247</td>
<td>0.0054*</td>
</tr>
<tr>
<td>1000</td>
<td>3.01</td>
<td>2, 247</td>
<td>0.050*</td>
</tr>
</tbody>
</table>

Notes- Table shows significant results. ANOVA performed at all measured frequencies.  
* - significant (p < 0.10)
Table 2. 3  
Competing models of Nest Survival for Lesser Prairie-Chickens in NW Kansas in 2016. Models are ranked by differences in AICc values.

<table>
<thead>
<tr>
<th>Model</th>
<th>K</th>
<th>AICc</th>
<th>ΔAICc</th>
<th>wi</th>
<th>Deviance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Datea</td>
<td>2</td>
<td>102.22</td>
<td>0.00</td>
<td>0.210</td>
<td>98.20</td>
</tr>
<tr>
<td>2000 Hz</td>
<td>2</td>
<td>102.64</td>
<td>0.42</td>
<td>0.170</td>
<td>98.62</td>
</tr>
<tr>
<td>500 Hz</td>
<td>2</td>
<td>102.67</td>
<td>0.45</td>
<td>0.168</td>
<td>98.65</td>
</tr>
<tr>
<td>250 Hz</td>
<td>2</td>
<td>102.68</td>
<td>0.46</td>
<td>0.167</td>
<td>98.66</td>
</tr>
<tr>
<td>2000 Hz + 500 Hz</td>
<td>3</td>
<td>102.90</td>
<td>0.68</td>
<td>0.149</td>
<td>98.86</td>
</tr>
<tr>
<td>125 Hz</td>
<td>2</td>
<td>103.09</td>
<td>0.87</td>
<td>0.136</td>
<td>99.06</td>
</tr>
</tbody>
</table>

Notes: aDay of the nesting season (1-85)
Fig. 2.1
Map of study site. Study area located in 4 counties of NW Kansas; Logan, Gove, Scott and Lane Counties. Total study area was 4,000 km². Dominant land uses included row crop agriculture, cattle ranching, oil and gas development and CRP enrollment.
Fig. 2. 2
Sound propagation from 1,083 oil and gas pump jacks at 16Hz. Map shows the attenuation of sound generated by oil and gas pumps from source locations until complete attenuation. Source sound values are estimated to be 57.9 dBC at 16Hz and propagate +3800 m before attenuating to 0 dBC.
Fig. 2.3
Oil and gas development soundscape using sound propagation and baseline conditions. Smaller map shows the soundscape for the study site. At this scale, baseline sound conditions dominate the soundscape and little detail in sound propagation between pumps can be seen. The larger image shows a magnified portion of the soundscape. At this reduced scale, the additive properties of sound can be seen by the increased sound pressure level (SPL) near densely clustered pump jacks.
Fig. 2.4
Probability of nest survival between all competing models. Nest success for all models, except 500Hz, is estimated near 20%. 95% CI for all models were greater than 0.
Fig. 2.5
Daily survival rate for nest sites during the 85 day nesting season. Daily survival decreases a total of 3.90% from start to end of the nesting season.
CHAPTER 3: SUMMARY AND CONCLUSIONS

In Chapter 1 we discussed the overlap between grouse habitat and energy development in the U.S. due to the similarities in site selection characteristics. We also discussed previous research that has identified energy development as a distinct threat to grouse conservation. After reviewing the current literature, we observed 3 knowledge gaps related to grouse conservation that should be addressed. One of those 3 knowledge gaps was the influence of sound.

In Chapter 2, we sought to contribute toward filling that knowledge gap by investigating the response by Lesser Prairie-Chicken (LPC) toward sound during the nesting season. We found that LPC select nest sites based on a hierarchical selection process in which sound is an important landscape characteristic driving site selection. In addition, because of the hierarchical nature of nest site selection by LPC, we found sound did not significantly influence nest success or survival on our landscape. These findings have important implications for LPC and broad grouse conservation by identifying sound as an important landscape characteristic requiring further investigation, finding high sound levels cause avoidance behavior by LPC; which may lead to further fragmentation of grassland landscapes, and identifying the hierarchical influence of sound; which will help develop more effective and efficient management strategies.

In addition, in Chapter 1 and 2, we identified management practices to mitigate the influence of energy development on LPC. The results of my MS work support these recommendations because it shows LPC are affected by high sound levels during their breeding season, it shows how oil and gas development infrastructure can be arranged to reduce noise and visibility, and it provides information on how LPC are selecting nesting habitat.

In conclusion, my MS work has contributed to the growing research findings that anthropogenic noise is a concern for grouse conservation, and that there are several management
strategies that can be applied to mitigate the impacts of noise and other disturbances associated with energy development. Finally, I conclude with a note of hope for future of grouse conservation and the longevity of the Lesser Prairie-Chicken.
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**APPENDIX A**

**Supp. Table 1**  
Average measurements of environmental conditions taken during sound pressure level recordings.

<table>
<thead>
<tr>
<th>Metric</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (^\circ C)</td>
<td>20.4 ±0.46</td>
</tr>
<tr>
<td>Wind Speed (m/s)</td>
<td>2.2 ±0.09</td>
</tr>
<tr>
<td>% Humidity</td>
<td>53.3 ±1.28</td>
</tr>
<tr>
<td>Barometric Pressure (kPa)</td>
<td>920.9 ±2.17</td>
</tr>
</tbody>
</table>
Supp. Fig. 1
Differences in sound attenuation between high and low frequencies. High frequencies (500Hz and 1,000Hz) attenuate faster due to greater attenuation coefficients. Low frequency sounds (8Hz and 16Hz) are not affected by atmospheric and vegetative attenuation factors; this allows for greater propagation distances.
Supp. Fig. 2
Reclassified oil and gas development soundscape for entire study area. Locations above baseline have higher estimated SPL due to additive effect of oil and gas pump jack noise. >99.0% of soundscape classified as ‘Above Baseline’ is <1.0 dBC above baseline.
Supp. Fig. 3
Alternate sound propagation scenarios. ‘16Hz’ line shows current sound propagation conditions. ‘16Hz +5 dBC’ shows the distance sound is estimated to propagate if oil and gas pump jack sound is increased by 5 dBC. ‘16Hz +10 dBC’ shows similar scenario adding 10 dBC to current conditions. Adding 5 dBC nearly doubled propagation distance and adding 10 dBC tripled sound propagation distance.

Sound Attenuation from Oil and Gas Pump Jacks at 16Hz
APPENDIX B

TO: David Haekos
Biology
205 Leisure

FROM: Sally Olson, Chair
Institutional Animal Care and Use Committee

DATE OF APPROVAL: 02/11/2013
DATE OF EXPIRATION: 02/11/2016

RE: Approval of Animal Care and Use Protocol Entitled, "Lesser Prairie-Chicken Habitat Use, Survival, and Recruitment" is the primary project title, but protocol will also be applicable to the funded companion projects "Lesser Prairie-Chicken Response to USDA Conservation Practices in Kansas and Colorado" & "Outcome Based Evaluations to Determine the Benefits of Conifer Removal and Fence Marking for Lesser Prairie-Chicken Populations".

The Institutional Animal Care and Use Committee (IACUC) for Kansas State University has reviewed the protocol identified above and has approved it for three years from the date of this memo. During the period of approval, the protocol will be subject to annual monitoring, which may include the examination of records connected with the project. Announced post-approval monitoring (PAM) may be performed during the course of this approval period by a member of the University Research Compliance Office staff. Changes in the protocol affecting the care or use of animals must be reviewed by the IACUC prior to implementation. Unanticipated problems related to the humane care or use of animals must be reported to the IACUC immediately.

It is important that your animal care and use project is consistent with submissions to funding/contract entities. It is your responsibility to initiate notification procedures to any funding/contract entity of any changes in your project that affects the use of animals.
STATE OF KANSAS
Scientific, Education, or Exhibition Wildlife Permit

PERMIT EXPIRES: December 31, 2013

Permit No. SC-042-2013    Issued Jan 31, 2013
Permittee: David Haukos
Subpermittee(s): Reid Plumb, Joseph Lautenbach, John Kraft, Dan Sullins
Affiliation: KCFWRU, Division of Biology, Kansas State University
Address: 203 Leasure Hall, KSU
City Manhattan    State KS    Zip Code 66506
Phone Number 806-939-9404    E-mail: dhaukos@ksu.edu

PERMIT CONDITIONS
List of Species to be collected: Lesser Prairie Chicken
Number of specimens Mark/Release/Recapture >50 specimens
Counties to be covered by activity: Morton, Stanton, Stevens, Grant, Gove, Logan, Harper, Barber, Comanche, Kiowa
Anticipated dates of activity Collecting Purpose date of issue to 12/31/2013
Scientific Research
Collecting Method hand, trap, net, salvage
Specimen Storage N/A

This permit must be in possession while conducting the above activity.
The permit holder must notify the KDWP Regional Law Enforcement Supervisor prior to conducting activity in the counties listed above. See map for contact information.


Permission to enter any lands, either public or private, to conduct permitted activity must be obtained from the owner or manager before entry. Collecting specimens on KS Dept of Wildlife & Parks (KDWP) properties must first obtain permission from the local Public Land Manager. Permission can be obtained by writing to the address below or calling KDWP Environmental Services Section at 620-672-5911.

Subpermittees: Only the permittee and subpermittee(s) may collect. If the permittee is affiliated with an education institution, students may collect for this permit, while in the company of the permittee. Specimens collected by such students must be placed in the possession of the permittee at the collection site, for housing of the specimen at the place(s) listed on the permit. The permittee or subpermittee(s) may not acquire specimens originating in the wild from other permission (including other holders of scientific, education, or exhibition wildlife permits), without permission from the Kansas Dept of Wildlife & Parks.

Permittee Signature

512 SE 25th Ave
Pratt KS 67124
STATE OF KANSAS
Scientific, Education, or Exhibition Wildlife Permit
PERMIT EXPIRES: December 31, 2014

Permit No: SC-079-2014
Issued: Mar 4, 2014

Permittee: David Haukos
Subpermittee(s): Reid Plumb, Joseph Lautenbach, John Kraft, Dan Sullins, Samantha Robinson, Jonathan Lautenbach
Affiliation: KCPWRU - Division of Biology, Kansas State University
Address: 205 Leasure Hall, KSU
City: Manhattan
State: KS
Zip Code: 66506
Phone Number: 806-939-9404
E-mail: dhauros@ksu.edu

PERMIT CONDITIONS
List of Species to be collected: Lesser Prairie Chicken
Number of specimens to be collected: mark/release/recapture
Counties to be covered by activity: Morton, Stanton, Stevens, Grant, Gove, Logan, Harper, Barber, Comanche, Kiowa, Clark
Anticipated dates of activity: March 2014 - October 2014
Collecting Method: hand, salvage, net, trap
Specimen Storage: N/A

This permit must be in possession while conducting the above activity.
The permit holder must notify the KDWPT Regional Law Enforcement Supervisor prior to conducting activity in the counties listed above. See map for contact information.


Permittee Signature:

KDWPT Ecological Services Section
S12 SE 25th Ave
Pratt KS 67124
Protocol Cover Sheet for Collaborative Research Review
as of April 15, 2004

1. Name of the performance site: Kansas State University

2. Assurance number of the performance site: 3241

3. Title: Lesser Prairie-Chicken Habitat Use, Survival and Recruitment

4. BGSU Principal Investigator (Faculty/Staff): Andrew J. Gregory

5. Participants in Protocol

<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
<th>List Training Completed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andrew J. Gregory</td>
<td>BGSU</td>
<td>9 years experience trapping and handling prairie-chickens; 22 years trapping and handling wildlife including 11 years working with birds</td>
</tr>
<tr>
<td>Thomas Lipp</td>
<td>BGSU--graduate student</td>
<td>None; To be trained on site in Kansas</td>
</tr>
<tr>
<td>David Haukos</td>
<td>KSU</td>
<td>25 years experience working with wildlife, incl. prairie-chickens</td>
</tr>
</tbody>
</table>

6. Provide a brief description of the protocol:
Leks will be observed each morning during the breeding seasons from 1 hour prior to sunrise until ~12 noon. Observations will occur from a distance of about 20-50 meters from the leks using spotting scopes and field glasses. Prairie-Chicken vocalizations will be recorded using a Marantz PMD 861 portable solid state recorder and SPL readings will be taken with a Larson Davis Lx1-L1 SPL meter.

Birds, both Greater Prairie-Chickens (Tympanuchus cupido) and Lesser Prairie-Chickens (T. pallidicinctus), will be captured using standard walk in box traps. Birds will be handled using handling bags to minimize distress. Handling time/bird will be ~10 minutes. Basic morphometric measurements will be taken and multi-color leg bands will be placed on the legs to allow observational identification of previously captured individuals without a need to recapture them. A subset of hens will be equipped with GPS back-pack transmitters.

KSU IACUC approval attached.
KDWPT approved research permits for these activities attached.

7. Indicate how BGSU faculty/staff/students are involved in the project:
BGSU staff will primarily be observers, but will assist with banding when asked to do so by KSU staff.

8. Principal Investigator Statement:

Investigator
Protocol#
Protocol Cover Sheet for Collaborative Research Review
as of April 15, 2004

I will provide, to the BGSU IACUC in a timely fashion, copies of the performance site IACUC approval
notifications relative to addenda and annual renewals for the research activity, to be maintained in the
BGSU protocol file.

I will provide, to the BGSU IACUC in a timely fashion, documentation of significant questions or issues
brought to my/my collaborator’s attention by the performance site’s IACUC during its semiannual
program inspection of a facility housing the research activity in question, to be maintained in the protocol
file.

Andrew J. Gregory  
Investigator’s Name (print)  Investigator’s Signature  12/12/14  
Date
ADDENDUM: SOUND PROPAGATION FROM WIND TURBINES

Wind energy is similar to oil and gas development in that it is a common land use within the Lesser Prairie-Chicken species distribution (Winders et al. 2014). With wind energy development increasing in abundance (U.S. Department of Energy 2008), it is possible that negative wildlife effects may begin to be seen. Due to this, we estimated the amount of area influenced affected by sound from wind turbines at the Westar Energy Central Plains wind farm in Wichita County, KS. The wind farm spans 6,000 acres, contains 33 Vestas V90-3.0 turbines and produces 99 megawatts of energy.

To estimate the area affected by wind turbine sound, we measured sound pressure level at the base of each wind turbine using a Larson Davis LxT-L1 Sound pressure level Dosimeter equipped with an ultra-low frequency preamp (Larson Davis Inc. NY, NY, USA). Sound measurements were taken at multiple frequencies (8 Hz, 16 Hz, 32 Hz, 64 Hz, 125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz), lasted 5 minutes, and were taken at a rate of 10 measurements per second. We averaged sound measurements from wind turbines at each frequency measured (Addend. Table 1). After averaging our sound measurements, we estimated the propagation distance at each individual frequency using Equation 1, where our averaged sound values at a specific frequency are inserted as $L_{p1}$ (Addend. Fig. 1)

Equation 1

$$L_p(r, f) = L_{p1}(r, f) - 20 \log(r) - \frac{\alpha(f)r}{100} - (0.18 \log(f) - 0.31)r$$

From Addend. Fig. 1., we can see that low frequency sound at 32 Hz will propagate the furthest at a distance of 1726 m, while high frequency sound at 500 Hz, 1000 Hz and 2000 Hz propagates <100 m (Addend. Fig. 1). Due to sound at 32 Hz having the furthest
propagation distance, we decided to model the sound propagation from each wind turbine at 32 Hz frequency using the outdoor sound propagation model described in Chapter 2. Using the sound model, we estimated sound produced by wind turbines directly below the wind turbine to be 64.8 dBC, 50.8 dBC at 5 m from the turbine, 44.8 dBC at 10 m, 38.6 dBC at 20 m, 31.3 dBC at 50 m, and at distances ≥100 m, sound from turbines has attenuated to ≤ 26.4 dBC (Addend. Fig. 2).
Addend. Table 1
Average measurements of sound pressure level (dBC) from wind turbines at all measured frequencies.

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Sound Pressure Level (dBC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>58.7 ±1.18</td>
</tr>
<tr>
<td>16</td>
<td>63.9 ±1.30</td>
</tr>
<tr>
<td>32</td>
<td>64.8 ±1.22</td>
</tr>
<tr>
<td>64</td>
<td>65.7 ±1.02</td>
</tr>
<tr>
<td>125</td>
<td>62.1 ±0.62</td>
</tr>
<tr>
<td>250</td>
<td>56.8 ±0.53</td>
</tr>
<tr>
<td>500</td>
<td>55.1 ±0.48</td>
</tr>
<tr>
<td>1000</td>
<td>52.4 ±0.44</td>
</tr>
<tr>
<td>2000</td>
<td>47.9 ±0.62</td>
</tr>
</tbody>
</table>
Addend. Fig. 1
Differences in sound attenuation between all measured frequencies. High frequencies (500Hz-2,000Hz) attenuate faster due to greater attenuation coefficients. Low frequency sounds (8Hz-32Hz) are not affected by atmospheric and vegetative attenuation factors; this results in a greater propagation distances. Sound at 32 Hz is estimated to propagate the furthest at 1726 m.
Addend. Fig. 2
Sound propagation from 33 Vestas V90-3.0 wind turbines at the Central Plains wind facility in
Wichita County, KS at 32 Hz. Map shows the attenuation of sound generated by wind turbines
from source locations until complete attenuation. Source sound values are estimated to be 64.8
dBC at 32 Hz and propagate +1700 m before attenuating to 0 dBC.