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The Influence of Wind Energy Development on Columbian Sharp-Tailed Grouse (*Tympanuchus phasianellus columbianus*) Breeding Season Ecology in Eastern Idaho

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THE INFLUENCE OF WIND ENERGY DEVELOPMENT ON COLUMBIAN SHARP-TAILED GROUSE (*TYMPANUCHUS PHASIANELLUS COLUMBIANUS*) BREEDING SEASON ECOLOGY IN EASTERN IDAHO

by

Matthew C. Proett

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Wildlife Biology

Approved:

Terry A. Messmer Major Professor	Thomas C. Edwards Committee Member
Shane B. Roberts Committee Member	Mark R. McLellan Vice President for Research and Dean of the School of Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

2017

ABSTRACT

The Influence of Wind Energy Development on Columbian Sharp-tailed Grouse (*Tympanuchus phasianellus columbianus*) Breeding Season Ecology in Eastern Idaho

by

Matthew C. Proett, Master of Science

Utah State University, 2017

Major Professor: Dr. Terry A. Messmer
Department: Wildland Resources

The Columbian sharp-tailed grouse (*Tympanuchus phasianellus columbianus*; CSTG) has experienced range-wide population declines, primarily as a result of habitat loss or degradation, and currently occupies <10% of its historic range. Expansion of wind energy developments across the remaining occupied CSTG range has been identified as a potential threat to the species. To assess the potential influence of wind energy development on CSTG breeding season ecology, I captured and radio-marked 135 female CSTG during 2014-2015 at leks located between 0.1-13.8 km from wind turbines in restored grassland habitats. I subsequently monitored 147 nests and 68 broods and used an information-theoretic model selection approach to assess the potential influence of wind energy distance and density variables, multi-scale habitat features, temporal factors, and precipitation on CSTG nest site selection, daily nest survival, brood success, and chick survival. The best nest site selection model suggested a positive functional response to the amount of restored grassland habitat with >30% forb cover at the nesting core use (60 ha) scale. Daily nest survival was positively associated with visual obstruction readings at the nest and the amount of restored grassland habitat containing >30% forb cover at the core use (60 ha) scale. Nest site selection and daily nest survival were not influenced by proximity to turbines or turbine density at the core use or breeding season home range (1385 ha) scales. Early (14-day) brood success was positively influenced by post-hatch precipitation and late (42-day) brood success was positively influenced by earlier hatch dates. Chick survival to 42 days post hatch was positively influenced by post-hatch precipitation and earlier hatch dates and negatively influenced by increasing densities of wind turbines at the breeding season home range scale. The probability of an individual chick surviving to 42 days decreased by 50% when there were ≥10 turbines within 2.1 km of the nest. In restored grassland habitats, such as Conservation Reserve Program fields, I recommend plantings and management practices that will result in diverse, bunchgrass-dominated nesting habitat with residual grass cover and >30% forb canopy cover during the nesting season. My results suggest that wind turbines occurring within 2.1 km of nesting habitats (i.e., 4.8 km of occupied leks) may negatively affect CSTG recruitment.

(102 pages)

PUBLIC ABSTRACT

The Influence of Wind Energy Development on Columbian Sharp-tailed Grouse (*Tympanuchus phasianellus columbianus*) Breeding Season Ecology in Eastern Idaho

Matthew C. Proett

The Columbian sharp-tailed grouse (*Tympanuchus phasianellus columbianus*; CSTG) has experienced range-wide population declines, primarily as a result of habitat loss or degradation, and currently occupies <10% of its historic range. Expansion of wind energy developments across the remaining occupied CSTG range has been identified as a potential threat to the species. To assess the potential influence of wind energy development on CSTG breeding season ecology, I captured and radio-marked 135 female CSTG during 2014-2015 at leks located between 0.1-13.8 km from wind turbines in restored grassland habitats. Using radio-telemetry, I monitored 147 nests and 68 broods and developed models to assess the influence of wind turbines, roads, habitat features, temporal factors, and precipitation on CSTG nest site selection, nest survival, brood success, and chick survival. Female CSTG in my study selected nest sites in grassland habitats where >30% of the canopy cover in the nesting core use area was composed of forbs (i.e., broadleaf plants). The strength of selection for this habitat type increased as its availability increased on the landscape. Nest survival increased with higher visual obstruction readings (i.e., concealment) at the nest bowl and in grassland habitats where forb cover exceeded 30% in the nesting core use area. I did not detect any influence of wind turbines or roads on nest site selection or nest survival. Early brood success (i.e., ≥1 chick alive at 14 days post-hatch) was higher when precipitation readings were higher in the first 7 days after hatch. Late brood success (i.e., ≥1 chick alive at 42 days post-hatch) was higher for nests that hatched earlier in the season. Survival of individual chicks to 42 days post-hatch was positively influenced by post-hatch precipitation (days 0-7) and early hatch dates, but was negatively influenced by increasing turbine densities at the breeding season home range scale. The probability of an individual chick surviving to 42 days decreased by 50% when there were ≥10 turbines within 2.1 km of the nest. In restored grassland habitats (e.g., farm bill program fields and state wildlife management areas), I recommend plantings and management practices that will result in diverse, bunchgrass-dominated nesting habitat with residual grass cover and >30% forb canopy cover during the nesting season. My results suggest that wind turbines occurring within 2.1 km of nesting habitats (i.e., 4.8 km of occupied leks) may negatively affect CSTG recruitment.

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I would like to start by thanking Shane Roberts, committee member and principal wildlife research biologist at Idaho Department of Fish and Game, for allowing and encouraging me to pursue a graduate project in the context of full-time employment when he was my supervisor at Tex Creek Wildlife Management Area. Shane committed countless hours to the project, including grouse capture, habitat mapping, and assistance with design and analysis. He even covered my work responsibilities when I was away at class. I couldn't have asked for a better boss.

I would like to thank my advisor, Dr. Terry Messmer, for giving a 40-something year old potential Master's student the opportunity to pursue a project under his guidance at Utah State University. Hopefully my age and experience were more of an asset than a liability. Terry provided sound input related to grouse ecology and management, but ultimately gave me the freedom to make the project my own. His ability to find time to get things done (like reviewing my thesis drafts) when essentially there was no time, can't be overstated.

Several other folks in the Department of Wildland Resources are deserving of thanks as well. Tom Edwards, my final committee member, provided sound statistical advice throughout the project. Dave Koons answered so many questions pertaining to nest survival analysis, model development, and R coding that he should get credit for being my 4th committee member, when in fact, he wasn't. Dave Dahlgren provided significant help with brood monitoring and analysis techniques. Finally, Marsha Bailey deserves high praise for keeping me on track with course requirements, university deadlines, and everything in between.

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Thank you to family and friends for the encouragement; hopefully I can visit more frequently in the near future. And, thank you, Cholla, my 12 year old bird dog, for putting up with my crazy schedule the past 3.5 years and living to see this chapter of my life come to an end. I did this for the birds you love, and hopefully, if you are able, we will chase a few more down this fall.

Matthew C. Proett

CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

NEED FOR RESEARCH

The demand for clean, renewable, domestically produced energy has led to increased investment in wind energy development across the United States. Between 2005 and 2015, total wind power capacity in the United States increased from less than 10,000 megawatts (MW) to greater than 74,000 MW (Arcadia Power 2016). A 2015 Department of Energy (DOE) report predicted wind power could supply the U.S. with 10% of the country's electricity by 2020, 20% by 2030, and 35% by 2050 (American Wind Energy Association 2016*a*).

Conservationists have expressed concerns over potential impacts of wind energy development to wildlife (Drewitt and Langston 2006, Kunz et al. 2007, Kuvlesky et al. 2007) and adverse impacts have been documented, particularly bird and bat collision mortalities (Arnett et al. 2008, Strickland et al. 2011, Johnson et al. 2016). Wind energy infrastructure may also indirectly impact wildlife populations via habitat loss, habitat avoidance, and increased predation (Kuvlesky et al. 2007). Indirect impacts of wind energy development have only recently begun to receive consideration, although they may pose the greatest threat to wildlife (Kuvlesky et al. 2007)

Prairie, shrub-steppe, and other grassland landscapes throughout the western and mid-western United States have high potential for continued wind development due to the quality of wind resources available. Several plains and western states rank in the top ten in either wind potential, MW installed, or both (American Wind Energy Association 2016*b*). This raises concern over potential adverse impacts to prairie grouse species, many of which have already experienced range-wide population declines. Although collisions between galliforms and turbine blades are unlikely, indirect impacts from anthropogenic features related to wind energy development have been predicted to occur (Kuvlesky et al. 2007, Pruett et al. 2009). Indirect effects of anthropogenic features related to other forms of development are well documented for greater sage-grouse (*Centrocercus urophasianus*; sage-grouse; Holloran 2005, Aldridge and Boyce 2007, Doherty 2008) and lesser prairie-chickens (*Tympanuchus pallidicinctus*; prairie-chicken; Patten et al. 2005, Wolfe et al. 2007, Pruett et al. 2009).

Recent studies have directly addressed potential impacts of wind energy development on prairie grouse species. LeBeau et al. (2014) documented decreased nest and brood survival of sage-grouse in habitats closer to turbines in Wyoming but found no influence of turbines on adult survival rates. Prairie-chicken nest site selection, nest survival, and adult survival were not negatively influenced by proximity to turbines in Kansas (McNew et al. 2014, Winder et al. 2014*a*). However, female space use indicated avoidance of turbines during the breeding season (Winder et al. 2014*b*) and turbines negatively affected lek persistence for leks <8 km from turbines (Winder et al. 2015). In Nebraska, prairie-chicken nest and brood ecology were not influenced by proximity to a pre-existing wind farm (Harrison 2015). To date, no published studies have investigated influences of wind energy development on sharp-tailed grouse (*T. phasianellus)* ecology.

STUDY SPECIES

The Columbian sharp-tailed grouse (*T. phasianellus columbianus*; CSTG), one of six extant sharp-tailed grouse subspecies, is endemic to big sagebrush (*Artemesia tridentata*), shrub-steppe, mountain shrub, and riparian plant communities in western

North America. Once widespread, and perhaps the most abundant gallinaceous bird of the Intermountain West (Bendire 1892), it now occupies <10% of its historic range (Hoffman and Thomas 2007; Fig. 1-1) and has suffered the greatest decline in abundance of the extant sharp-tailed grouse subspecies (Hamerstrom and Hamerstrom 1961, Miller and Graul 1980). The historic range included parts of British Columbia, Washington, Idaho, Montana, Oregon, California, Nevada, Utah, and Colorado and encompassed approximately 867,000 km^2 (Hoffman and Thomas 2007). The current range encompasses only 38,400 km^2 (U.S. Department of Interior 2000), primarily in south-central British Columbia, northeast Washington, southeast Idaho, northern Utah, northwest Colorado, and south-central Wyoming. Smaller reintroduced populations also exist in northeast Nevada and northeast Oregon (Hoffman and Thomas 2007). The range-wide breeding population was estimated at 56,000 to 61,500 birds in 2000 (U.S. Department of Interior 2000).

The CSTG has been petitioned twice for listing under the Endangered Species Act, first in 1995 and again in 2004. Under both petitions, the U.S. Fish and Wildlife Service ruled that the subspecies did not warrant listing (U.S. Department of Interior 2000, 2006). The U.S. Forest Service (USFS) and the Bureau of Land Management (BLM) classify CSTG as a sensitive species wherever it occurs on lands under their jurisdiction. The CSTG is listed as threatened in Washington (Stinson and Schroeder 2012) and is classified as a species of special concern in most other states where it occurs. Currently, CSTG are legally hunted in portions of Colorado, Idaho, Utah, and British Columbia.

Primary threats to CSTG populations include conversion of native habitats to pasture or cropland, loss of Conservation Reserve Program (CRP) grasslands, overgrazing by domestic livestock, herbicide control of big sagebrush, alteration of fires regimes, invasion of exotic plants, urban and rural expansion, and energy development (Hoffman and Thomas 2007). Until recently, energy development within the range of CSTG was limited to coal mining and affected <1% of the range (Hoffman and Thomas 2007). Thus far, the only completed investigation of the relationship between CSTG ecology and energy development pertains to coal mine reclamation (Collins 2004). Recent expansion of wind energy developments into occupied CSTG habitats, and projections for growth in the wind industry, suggest a need for scientifically sound studies on responses of CSTG to wind energy development (Hoffman et al. 2015).

STUDY DESIGN

I initiated a study to examine the potential influence of a 215-turbine wind development complex in eastern Idaho on CSTG breeding season ecology. Specifically, I investigated the influence of wind energy development features—as well as habitat, temporal, and weather variables—on CSTG nest site selection, nest survival, and offspring survival.

Before-after-control-impact (BACI) study designs are recommended for assessing the effects of energy developments on wildlife (Anderson et al. 1999, Kuvlesky 2007) but may be impractical if the timing or location of developments is uncertain, which was the case in our study area. Additionally, post-development data from BACI studies must be viewed with caution because there may be a 2-10 year time lag before negative responses are detected (Walker et al. 2007, Harju et al. 2010). I assessed the influence of wind energy infrastructure along a gradient extending away from a pre-existing turbine development complex, using a combination of distance-to-turbine and turbine density metrics. Completion of turbine and road developments within the complex ranged from 4-9 years prior to the initiation of the study, which may have been sufficient to allow for detection of negative responses in the event of a time-lag effect. Density and distance metrics used in our study allowed us the opportunity to detect potential effect thresholds for wind energy development.

I captured female CSTG at 11 leks located between 0.1-13.8 km from turbines during March-May of 2014 and 2015 (Fig. 1-2). Capture leks were relatively evenly spaced along the gradient, with 6 leks located within 2 km of turbines. I radio-marked CSTG females and monitored nests and broods of marked birds from late April to late August. I developed a suite of microhabitat, macrohabitat and wind energy covariates and assessed their influence on nest site selection, nest survival, and offspring survival using an information-theoretic model selection approach (Burnham and Anderson 2002).

This thesis was written in a multiple-paper format. Chapters 1-4 follow format guidelines for the *Journal of Wildlife Management* and I use the second-person voice, we, in Chapters 2 and 3, to acknowledge the contributions of co-authors. The Appendix was previously published in the *Wilson Journal of Ornithology*.

LITERATURE CITED

Aldridge, C. L., and M. S. Boyce. 2007. Linking occurrence and fitness to persistence: habitat-based approach for endangered greater sage-grouse. Ecological Applications 17:5080-526.

American Wind Energy Association [AWEA]. 2016*a*. DOE Wind Vision, <http://www.awea.org>. Accessed 13 Jan 2017.

American Wind Energy Association [AWEA]. 2016*b*. U.S. Wind Energy State Fact Sheets, <http://www.awea.org>. Accessed 13 Jan 2017.

Anderson, R., M., Morrison, K. Sinclair, D. Strickland. 1999. Studying Wind Energy and Bird Interactions: A Guidance Document. National Wind Coordinating Collaborative (NWCC). Washington, D.C.

Arnett, E. B., W. K. Brown, W. P. Erickson, J. K Fielder, B. I. Hamilton, T. H. Henry, A. Jain, G. D. Johnson, J. Kerns, R .R. Koford, C. P. Nicholson, T. J. O'Connell, M. D. Piorkowski, and R. D. Tankersley Jr. 2008. Patterns of bat fatalities at wind energy facilities in North America. Journal of Wildlife Management 72:61-78.

Arcadia Power. 2016. A timeline of wind power in the U.S. <http://blog.arcadiapower.com>. Accessed 13 Jan 2017.

Bendire, C. 1892. Life histories of North American birds. United States National Museum Special Bulletin 1, United States Government Printing, Smithsonian Institute, Washington, D.C.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. Second addition. Springer-Verlag, New York, New York, USA.

Collins, C. P. 2004. Ecology of Columbian sharp-tailed grouse breeding in coal mine reclamation and native upland cover types in northwestern Colorado. Thesis, University of Idaho, Moscow, USA.

Doherty, K. 2008. Sage-grouse and energy development: Integrating science with conservation planning to reduce impacts. Dissertation, The University of Montana, Missoula, Montana, USA.

Drewitt, A. L., and R. H. W. Langston. 2006. Assessing the impacts of wind farms on birds. Ibis 148**:**29-42.

Hamerstrom, Jr., F.N. and F. Hamerstrom. 1961. Status and problems of North American grouse. Wilson Bulletin 3:284-293.

Harju, S. M., M. R. Dzialak, R. C. Taylor, L. D. Hayden-Wing, and J. B. Winstead. 2010. Thresholds and lag in effects of energy development on greater sage-grouse populations. Journal of Wildlife Management 74:437-448.

Harrison, J. O. 2015. Assessment of disturbance effects of an existing wind energy facility on greater prairie-chicken (*Tympanuchus cupido pinnatus*) breeding season ecology in the sandhills of Nebraska. Thesis, University of Nebraska, Lincoln, USA.

Hoffman, R. W., and A. E. Thomas. 2007. Columbian sharp-tailed grouse: a technical conservation assessment. USDA Forest Service, Rocky Mountain Region. <http://www.fs.fed.us/r2/projects/scp/assessments/columbiansharptailedgrouse.pdf>. Accessed 1 Oct 2015.

Hoffman, R. W., K. A. Griffen, J. M. Knetter, M. A. Schroeder, A. D. Apa, J. D. Robinson, S. P. Espinosa, T. J. Christianson, R. D. Northrup, D.A. Budeau, and M. J. Chutter. 2015. Guidelines for the management of Columbian sharp-tailed grouse populations and their habitats. Sage and Columbian Sharp-tailed Grouse

Technical Committee, Western Association of Fish and Wildlife Agencies, Cheyenne, Wyoming, USA.

Holloran, M. J. 2005. Greater sage-grouse (*Centrocercus urophasianus*) population response to natural gas field development in western Wyoming. Dissertation, University of Wyoming, Laramie, USA.

Johnson, D. H, R .L. Scott, K. S. Smallwood, and W. P. Erickson. 2016. Avian fatalities at wind energy facilities in North America: a comparison of recent approaches. Human-Wildlife Interactions 10:7-18.

Kunz, T. H., E. B. Arnett, W. P. Erickson, G. D. Johnson, R. P. Larkin, M. D. Strickland, R. W. Thresher, and M. D. Tuttle. 2007. Ecological impacts of wind energy development on bats: questions, research needs, and hypotheses. Frontiers in Ecology and the Environment 5:315-324.

Kuvlesky, W. P., L. A. Brennan, M. L. Morrison, K. K. Boydston, B. M. Ballard, F. C. Bryant. 2007. Wind energy development and wildlife challenges and opportunities. Journal of Wildlife Management 71:2487-2498.

Lebeau, C. W., J. L. Beck, G. D. Johnson, and M. J. Holloran. 2014. Short-term impacts of wind energy development on greater sage-grouse fitness. Journal of Wildlife Management 78:522-530.

McNew, L. B., L.M. Hunt, A. J. Gregory, S. M. Wisely, and B. K. Sandercock. 2014. Effects of wind energy development on the nesting ecology of Greater Prairie-Chickens in fragmented grasslands. Conservation Biology 28:1089-1099.

Miller, G. C. and W. D. Graul. 1980. Status of sharp-tailed grouse in North America. Pages 18-28 *in* P.A. Vohs, Jr. and F. L. Knopf, editors. Proceedings of the prairie grouse symposium. Oklahoma State University, Stillwater, OK.

Patten, M. A., D. H. Wolfe, E. Shochat, and S. K. Sherrod. 2005. Habitat fragmentation, rapid evolution, and population persistence. Evolutionary Ecology Research 7:235-249.

Pruett C. L., M. A. Patten, and D. H. Wolfe. 2009. Avoidance behavior by prairie grouse: implications for development of wind energy. Conservation Biology 23:1253-1259.

Stinson, D. W. and M. A. Schroeder. 2012. Washington state recovery plan for the Columbian sharp-tailed grouse. Washington Department of Fish and Wildlife, Olympia, USA.

Strickland, M. D., E. B. Arnett, W. P. Erickson, D. H. Johnson, G. D. Johnson, M. L., Morrison, J. A. Shaffer, and W. Warren-Hicks. 2011. Comprehensive Guide to Studying Wind Energy/Wildlife Interactions. Prepared for the National Wind Coordinating Collaborative, Washington, D.C., USA.

U.S Department of Interior. 2000. Endangered and threatened wildlife and plants; 12-month finding for a petition to list the Columbian sharp-tailed grouse as threatened. Federal Register 65:60391-60396.

U.S Department of Interior. 2006. Endangered and threatened wildlife and plants; 90-day finding on a petition to list the Columbian sharp-tailed grouse as threatened or endangered. Federal Register 71:67318-67325.

Walker, B. L., D. E. Naugle, and K. E. Doherty. 2007. Greater sage-grouse response to energy development and habitat loss. Journal of Wildlife Management 71:2644-2654.

Winder, V. L., L. B. McNew, A .J. Gregory, L. M. Hunt, S. M. Wisely, and B. K. Sandercock. 2014*a*. Effects of wind energy development on the survival of Greater Prairie-Chickens. Journal of Applied Ecology 51:395-405.

Winder V. L., L. B. McNew, A. J. Gregory, L. M. Hunt, and B. K. Sandercock. 2014*b*. Space use by female Greater Prairie-Chickens in response to wind energy development. Ecosphere 5:art3.

Winder, V. L., A. J. Gregory, L. B. McNew, and B. K. Sandercock. 2015. Responses of male Greater Prairie-Chickens to wind energy development. Condor 117:284-296.

Wolfe, D. H., M. A. Patten, E. Shochat, C. L. Pruett, and S. K. Sherrod. 2007. Causes and patterns of mortality in Lesser Prairie-Chickens and implications for management. Wildlife Biology 13:95-104.

FIGURES

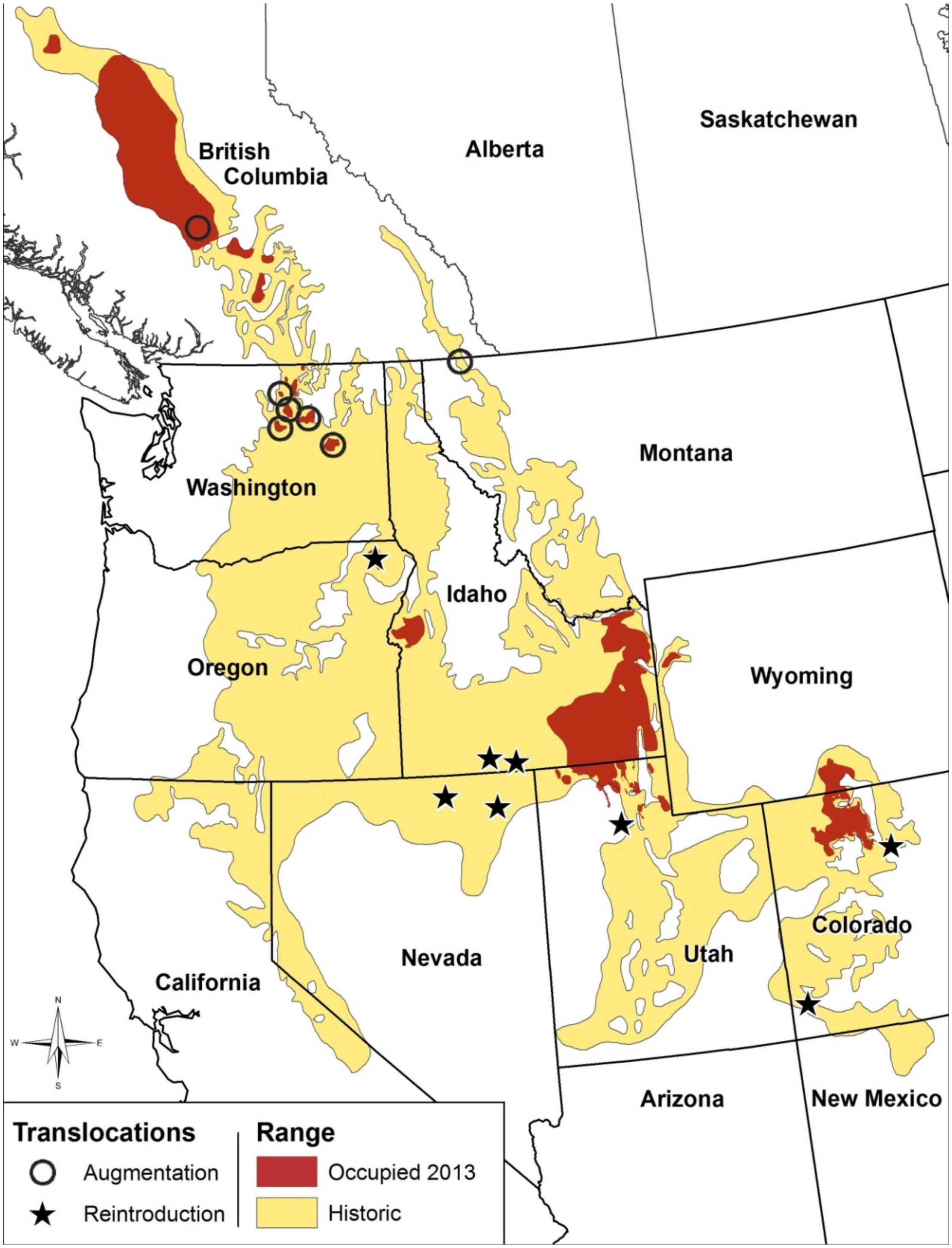

Figure 1-1. Current and historic distribution of Columbian sharp-tailed grouse (*Tympanuchus phasianellus columbianus*) in western North America. From: Hoffman et al. 2015, used with permission.

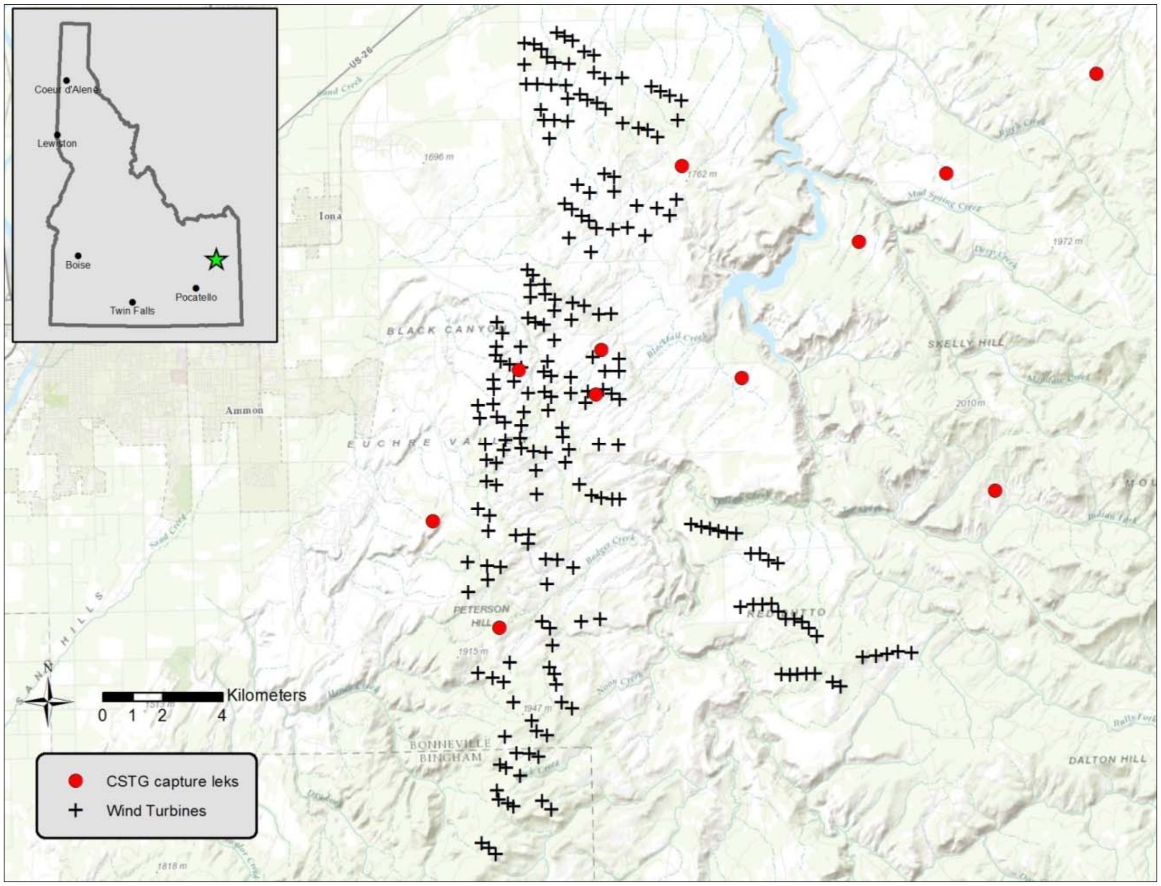

Figure 1-2. Study area east of Idaho Falls, Idaho, USA with wind turbine locations (n = 215) and Columbian sharp-tailed grouse (*Tympanuchus phasianellus columbianus*) leks (n = 11) used for capture during 2014-2015.

CHAPTER 2

THE INFLUENCE OF WIND ENERGY DEVELOPMENT ON COLUMBIAN SHARP-TAILED GROUSE NEST SITE SELECTION AND NEST SURVIVAL IN EASTERN IDAHO[1]

ABSTRACT

Negative effects of wind energy development on wildlife have been reported, particularly in migratory birds and bats. However, little is known about the effects of wind energy development on non-migratory North American Tetraonidae grouse species. We studied Columbian sharp-tailed grouse (*Tympanuchus phasianellus columbianus;* CSTG) nest site selection and nest survival from 2014-2015 in the vicinity of a 215-turbine wind energy development complex in eastern Idaho. We monitored 147 CSTG nests from females captured at leks 0.1-13.8 km from wind turbines in restored grassland habitats. We used an information-theoretic model selection approach to assess the influence of wind energy infrastructure and vegetation structure and composition on nest site selection and daily nest survival. Nest site selection and daily nest survival were influenced by vegetation structures and composition at two spatial scales. The CSTG females we studied selected nest sites with more restored grassland habitat containing >30% forb cover at the nesting core use (60 ha) scale and showed a functional response to the availability of grassland habitat containing >30% forb cover. Daily nest survival was best predicted by visual obstruction readings at the nest site and the amount of restored grassland containing >30% forb cover at the nesting core use scale. We did not

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[1] Co-authors: Shane B. Roberts and Terry Messmer

detect any influence of wind energy infrastructure on nest site selection or nest survival. We recommend wildlife managers continue to implement management practices that will provide bunchgrass-dominated grasslands with >30% forb cover in restored grassland habitats within CSTG range.

INTRODUCTION

Wind power is one of the fastest-growing sources of electricity supply in the United States. A 2015 Department of Energy (DOE) report predicted wind power could supply 10% of U.S. electricity by 2020, 20% by 2030, and 35% by 2050 (American Wind Energy Association 2016). The pace and projected growth of wind energy development raise questions about environmental impacts of this renewable energy source (Johnson et al. 2016). Bird and bat collision mortalities due to wind turbines are well documented (Arnett et al. 2008, Strickland et al. 2011, Johnson et al. 2016) and are occurring at non-trivial levels (Smallwood 2013, Loss et. al 2013, Erickson et al. 2014). Additionally, wind energy development may indirectly affect wildlife via habitat loss, avoidance, or increased predation (Kuvlesky et al. 2007), although few studies have addressed these mechanisms (Johnson et al. 2016).

The increase in wind energy development in prairie and shrub-steppe habitats raises concerns over impacts to prairie grouse (Galliformes) species, several of which are already experiencing long-term declines as a result of habitat loss and fragmentation, disease, invasive species, and increased mortality from other anthropogenic activities (North American Bird Conservation Initiative 2014, Johnson et al. 2016). Although collision mortalities from turbine strikes in galliforms are unlikely (Kuvlesky et al. 2007), wind energy development may negatively impact prairie grouse indirectly through habitat loss, increased predation, or avoidance behavior.

Few studies have directly assessed the impacts of wind energy development on prairie grouse nesting ecology. In Wyoming, greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) nest site selection was not influenced by proximity to turbines but nest survival decreased in habitats closer to turbines (LeBeau et al. 2014). Proximity to turbines did not negatively affect greater prairie-chicken (*Tympanuchus cupido pinnatus*; prairie-chicken) nest site selection or nest survival in fragmented grasslands in Kansas (McNew et al. 2014). However, within the same study area, female prairie-chicken space use during the breeding season indicated avoidance of wind turbines (Winder et al. 2014). In Nebraska, proximity to turbines did not influence prairie-chicken nest site selection, nest survival, or female space use in unfragmented grasslands (Harrison 2015).

The Columbian Sharp-tailed Grouse (*T. phasianellus columbianus*; CSTG), one of six extant subspecies of sharp-tailed grouse found in North America (Johnsgard 1973), is endemic to shrub-steppe, grassland, mountain shrub, and riparian plant communities in western North America (Connelly et al. 1998). The subspecies currently occupies <10% of its historical range and has been petitioned twice for listing under the Endangered Species Act (U.S. Department of Interior 2000, 2006). Declines in CSTG populations are commonly attributed to habitat loss resulting from conversion of native habitats to cropland, overgrazing by livestock, shrub control, altered fire regimes, invasion of exotic plants, and urban and rural development (Hoffman and Thomas 2007). Until recently, energy development affected <1% of the occupied CSTG range (Hoffman and Thomas

2007). The only published research related to effects of energy development on CSTG pertained to coal mine reclamation (Collins 2004). Recent expansion of wind energy development into occupied CSTG range, combined with recent projections for wind energy growth, will require a better understanding of the relationship between wind energy development and CSTG ecology to mitigate the potential for impacts (Hoffman et al. 2015).

We initiated this study to investigate the potential effects of wind energy infrastructure on the nesting ecology of CSTG in restored grassland habitats in eastern Idaho. The study was conducted near four pre-existing wind energy facilities, the last of which was completed in 2012. We examined multiple hypotheses related to nest site selection and nest survival. First, we hypothesized that female CSTG would avoid wind turbines when selecting nest sites, thereby decreasing availability of otherwise suitable habitat, as predicted by Pruett et al. (2009). We also hypothesized that CSTG nest survival would be lower in habitat closer to wind turbines as a result of habitat fragmentation and subsidization of nest predators (Dijak and Thompson 2000, Chalfoun et al. 2002). Finally, we hypothesized that habitat structure and vegetation composition would influence CSTG nest site selection and nest survival (Meints 1991, Boisvert 2002, Collins 2004) and may be more influential to nesting ecology than the proximity or density of wind turbines (e.g., McNew et al. 2014).

STUDY AREA

Our study area was located in Bonneville County, Idaho, USA approximately 10 km east of the city of Idaho Falls. Land ownership included Bureau of Land Management (BLM), Bureau of Reclamation (BOR), Idaho Department of Lands (IDL), Idaho Department of Fish and Game (IDFG), and private lands. The four wind energy facilities located within the study area included: 1) Wolverine Creek Wind Farm, a 64-megawatt (MW) facility consisting of 43, 1.5 MW turbines (completed in 2005); 2) Goshen North Wind Farm, a 64 MW facility consisting of 83, 1.5 MW turbines (completed in 2010); 3) Horse Butte Wind Farm (Phase 1), a 60 MW facility consisting of 32, 1.8 MW turbines (completed in 2012); and 4) Meadow Creek Wind Farm, a 120 MW facility consisting of 57, 2.1 MW turbines (completed in 2012). Additional wind facility infrastructure included gravel access roads, maintenance buildings, electrical substations, and a small number of overhead transmission lines (most lines were buried). The four wind energy facilities within the study area were developed on leased portions of private agricultural lands, and excluding turbine pads and associated infrastructure, lands within the turbine complexes were actively farmed or enrolled in the Conservation Reserve Program (CRP) at the time of our study. The IDFG documented 39 active CSTG leks within the study area in 2013 (IDFG, unpublished data).

The landscape in the study area is characterized by bench lands intersected by steep-sloped canyons. Elevations range from 1,500 m in the Willow Creek drainage to 2,200 m near Mt. Baldy. The two most commonly occurring soils are Ririe silt loam and Torriorthents-rock outcrop complex (Web Soil Survey 2016). Privately-owned bench lands were primarily used for agriculture or were enrolled in CRP. On Tex Creek Wildlife Management Area (TCWMA), a 14,000-ha big game winter range managed by IDFG situated roughly in the center of the study area, historically-farmed bench lands have been converted to perennial vegetation, and are similar in composition and structure to CRP fields. Common native vegetation across the study area included big sagebrush

(*Artemisia tridentata spp*), antelope bitterbrush (*Purshia tridentata*), rabbitbrush (*Chrysothamnus spp),* serviceberry (*Amelanchier spp*), snowberry (*Symphoricarpos spp),* aspen (*Populus tremuloides*)*,* and willow (*Salix spp*). Vegetation commonly occurring in CRP fields and TCWMA fields included smooth brome (*Bromus inermis*), intermediate wheatgrass (*Thinopyrum intermedium*), crested wheatgrass (*Agropyron cristatum*), bluebunch wheatgrass (*Pseudoroegneria spicata*), big bluegrass (*Poa secunda*), basin wild rye (*Leymus cinereus*), cheatgrass (*B. tectorum*), alfalfa (*Medicago sativa*), yellow sweet clover (*Melilotus officinalis),* sanfoin (*Onobrychis viciifolia*.), small burnet (*Saguisorba minor*), blue flax (*Linum lewisii*), and yarrow (*Achillea millefolium*). The regional climate is classified as continental with a mean annual precipitation of 30.8 cm and average temperatures ranging from 0.2 C to 14.8 C (Western Regional Climate Center 2016).

METHODS

Capture and Monitoring

We captured female CSTG during March-May of 2014 and 2015 using walk-in traps and drift fences (Schroeder and Braun 1991). Females were captured from 11 leks, with 7 leks used in both years of the study. The 11 capture leks locations ranged from 0.1-13.8 km from wind turbines (Fig. 2-1). We selected leks based on size (count of ≥10 birds the previous year) and proximity to turbines, to maximize capture efficiency and disperse our sample of radio-marked hens evenly along the ~14-km gradient from wind turbines. Once captured, females were aged (adult vs. yearling) based on shape and wear of outer primaries (Ammann 1944), weighed to the nearest 5 g, and banded with uniquely numbered aluminum leg bands. We fitted females with a 9-g (<1.5% of body mass) necklace-style radio-transmitter equipped with a mortality switch (Model RI-2D, Holohil Systems, Ltd., Carp, ON, Canada) and released birds at the capture site immediately after processing. The animal capture and handling protocols were approved by the Utah State University Institutional Animal Care and Use Committee (Protocol #2286).

We monitored radio-marked females from the ground 2-3 times per week during the nesting period, beginning in late April, using portable telemetry receivers and handheld Yagi antennas. To estimate locations, observers circled radio-marked females using directional telemetry signals, maintaining a 30-50 m buffer around each grouse. This technique ensured precise ground locations while minimizing disturbance to radio-marked females. We recorded the estimated distance and bearing to each female, as well as the observer's coordinates, using handheld Garmin eTrex global positioning systems (GPS; Garmin International, Inc., Olathe, KS, USA). We conducted fixed-wing aerial telemetry flights, as needed, to locate radio-marked females that we were unable to locate using ground telemetry methods.

When radio-marked females were found in the same location on consecutive visits, we presumed they had initiated nests. Using telemetry, we verified the nest location and flushed the female from the nest to obtain a clutch count. After recording the GPS coordinates of each nest, we monitored nests 2-3 times per week by telemetry from >50 m. We monitored nests from a GPS point, rather than using visual markers, and only approached nests on the initial inspection and to determine nest fate when telemetry indicated the female had left the nest. We classified nests as successful if ≥1 egg hatched, based on inspection of eggshell remains (Reardon 1951).

Microhabitat Variables

We measured microhabitat characteristics at each nest within 3 days of ascertaining nest fate. We recorded visual obstruction readings (VOR) at the nest by placing a Robel pole in the nest bowl and recording concealment in decimeters (dm) from a distance of 4 m and a height of 1 m (Robel et al. 1970). We randomly assigned a bearing for the first reading; obtained 3 additional readings at 90, 180, and 270 degrees from the initial bearing; and averaged measurements across the 4 transects. We measured overhead concealment at the nest bowl by placing a 16-cm diameter cover board, which we modified from Roersma (2001), in the nest bowl and estimating percent concealment to the nearest 5% when viewed from 1 m above the nest. We estimated canopy coverage of total standing grass (live or residual), bunchgrass, crested wheatgrass, rhizomatous grass (smooth brome and intermediate wheatgrass), forb, shrub, litter, and bare ground by averaging 12, 20 x 50-cm Daubenmire frame readings (Daubenmire 1959). We estimated cover on an overlapping basis, allowing total composition to exceed 100%. Frames were read at 0, 3, and 6 m from the nest, along transects separated by 90 degrees.

Macrohabitat Variables

We also evaluated the influence of habitat composition on CSTG nesting ecology at two macrohabitat scales. To facilitate analyses while considering habitat changes (primarily CRP field conversions) between years, we developed year-specific, land-cover type layers of the study area within a geographic information system (GIS; ArcGIS 10.3, ESRI, Redlands, CA, USA). We used 2013 and 2015 National Agriculture Imagery Program (NAIP) imagery to manually digitize land cover types within 5 km of capture leks. We expanded the GIS map, where necessary, to incorporate nest and brood locations that extended beyond 5 km of capture leks. When land cover identification from NAIP imagery was uncertain, we used field observations to verify land cover types. We incorporated roads using U.S. government open source road data layers (U.S. General Services Administration 2015) and manually digitized roads, using NAIP imagery, where road layers were incomplete. We incorporated wind turbine locations using a 2014 U.S. Geological Survey onshore wind turbine location data layer (U.S. Geological Survey 2015).

We further categorized restored grasslands (primarily CRP and TCWMA fields) with on-the-ground visual assessments of dominant grass type and forb and shrub canopy cover. We chose to conduct simple, field-based classifications rather than use seeding records because seeding records may not have accurately represented the vegetation composition of fields at the time of our study (particularly in the case of older CRP plantings that included rhizomatous grasses). For each unique patch of restored grassland habitat, we classified the dominant grass into one of the following categories: bunchgrass, rhizomatous grass (smooth brome or intermediate wheatgrass), crested wheatgrass, or cheatgrass. These grass categories were developed to test hypotheses related to grass structure and CSTG nesting ecology and were representative of grass types commonly found in CRP in Idaho. Next, we recorded visual estimates of forb and shrub canopy cover within each patch. To account for potential error due to visual estimation, we categorized forb and shrub cover estimates for each patch in to one of five bins: <2%, 2%-10%, 11%-20%, 21%-30%, and >30% cover. We manually digitized each unique habitat patch within the restored grassland habitat type using hand drawn polygons from field maps as reference. We attributed each polygon with forb and shrub cover estimates, using the mean value of the previously assigned bin (e.g., 11%-20% = 15%).

We evaluated the influence of macrohabitat variables on nest site selection and daily nest survival at two spatial scales relevant to the nesting ecology of sharp-tailed grouse: nesting core use (60 ha) and breeding season home range (1,385 ha). The nesting core use scale represented habitat associated with the home range of a female during laying and incubation. Habitat characteristics at this scale have been previously reported to influence prairie grouse nesting ecology (Manzer and Hannon 2005, McNew et al. 2014). Because we did not obtain incubation recess locations during our study, we used recess distances from Manzer and Hannon (2005) to delineate the 60-ha core use area of nesting females. The breeding season home range scale was based on nest-to-brood distances obtained from females that successfully reared broods to 42 days post-hatch during this study. Ninety percent of females that reared a successful brood stayed within 2,100 m of the nest (1,385 ha area). Previous studies of CSTG nesting ecology have not assessed the importance of habitat composition at this spatial scale.

Analysis and Model Selection

We developed resource selection functions (RSF; Manly et al. 2002) for nesting female CSTG by contrasting measurements of each variable at nest sites (use) and available sites with mixed-effects logistic regression using package lme4 (Bates et al. 2014) in R (R Version 3.3.1, www.r-project.org). We defined available nesting habitat as grassland or sage-steppe habitat with <30% slope (Hoffman et al. 2015) within 2.7 km of the lek of capture, since ninety percent of nests fell within a 2.7-km radius of the lek of capture. We then generated 1 point/25 ha of available nesting habitat, resulting in 31-75 available points within each 2.7 km lek buffer. Available points were generated using the Generalized Random Tessellation Stratified Sampling (GRTS) scheme in the package spsurvey (Kincaid and Olsen 2016) in R. This sampling scheme ensured that points defining availability were dispersed in a spatially balanced manner. To account for variation in habitat composition and available nesting habitat between years, and because availability of nesting habitat was constrained by lek of capture, we fit a random "lek-year" intercept in all models.

We employed a multi-step, information-theoretic approach (Burnham and Anderson 2002) to evaluate candidate models for nest site selection using seven macrohabitat variables and two wind energy variables (Table 2-1). First, we evaluated models within the two macrohabitat scale groupings: core use and breeding season home range. Each candidate model consisted of a of single habitat variable combined with a random effect of lek-year. If a model performed ≥2.0 AIC_c units better than the intercept-only model, we considered the variable to have acceptable explanatory power (i.e., supported). Next, we compared supported univariate models and multivariate models constructed from supported variables to determine the most explanatory habitat models. To avoid multicollinearity, no correlated variables ($r \geq 0.65$) were included in the same model at any stage. When variables were supported at both spatial scales, we used the lower AIC_c score to select the best spatial scale for the given variable. To assess the influence of wind energy development, we added wind turbine density variables to each habitat model within 2.0 AIC_c units of the top model to determine if the addition of wind turbine variables improved model fit (*sensu* Dinsmore et al. 2002, Webb et al. 2012). Although all models within 2.0 AIC_c units of the top model were presumed to have similar ability to explain nest site selection (Burnham and Anderson 2002), we considered the most parsimonious model within 2.0 AIC_c units of the top model to be best model. Finally, to extend applicability of our results beyond our study area, we constructed generalized functional response models (GFR; Matthiopoulos et al. 2011) using variables from our best additive model and then compared the GFR models to the additive model.

We employed the same multi-step approach to assess the influence of habitat features and wind energy development on daily nest survival (DNS). In addition to the variables used in our nest site selection analysis, we also developed candidate models with 10 microhabitat variables and an additional wind energy variable (Table 2-1). We estimated the effects of explanatory variables on DNS using generalized linear models in the RMark package (Laake 2014) in R, which implements program Mark (White and Burnham 1999). Before initiating our hierarchical modeling approach we explored both linear and quadratic relationships between microhabitat variables and nest survival. We then selected only the best term for each microhabitat covariate using the lowest AIC_c score. Step 1 of our nest survival modeling compared variation between years to a null model. In step 2 we compared univariate habitat models within three spatial scale groupings. In step 3 we compared supported univariate models with additive models incorporating supported habitat variables. And finally, in step 4 we compared top habitat models with and without the addition of wind energy variables. We used the same model evaluation criteria as in our nest site selection analyses.

The initial steps in our hierarchical model building process allowed us to examine the influence of habitat variables related to the composition and structure of vegetation typically found in CRP plantings in eastern Idaho. To avoid data dredging, we chose to identify top performing models at each spatial scale and then identify top performing multi-scale habitat models using supported variables from our univariate model comparisons. The final step allowed us to identify the relative importance of wind energy variables while accounting for the variation in nest site selection and DNS explained by the vegetation composition and structure that occurred within the landscape. We acknowledge that a statistically superior model could be identified by considering all possible covariate combinations (Bromaghin et al. 2013), but given the tendency of AIC_c to favor models with spurious effects (Aho et al. 2014), we opted for a more ecologically-based and parsimonious approach to model building and selection (Franklin et al. 2000).

RESULTS

We monitored 147 nests (119 first nests and 28 renests) during 2014 and 2015. Sixty-eight nests hatched at least one egg and 79 nests failed. Six hens were killed while incubating nests. Nests of hens that were killed during incubation were considered failed nests in our analyses. Fifty-two percent of nests were located under grass, 27% were located under forbs, and 21% were located under shrubs.

Nest Site Selection

We evaluated 107 nests in our nest site selection analyses. To avoid potential biases, we did not include either renests or second year nest attempts of females radio-marked in the first year of the study because lek attendance for these females was unknown. At the core use scale, the single most important factor influencing nest site selection was the amount (ha) of restored grassland habitat containing >30% forb cover

(Table 2-2). The second most explanatory factor for nest site selection at the core use scale was the amount (ha) of restored grassland habitat where bunchgrasses were the dominant grass type. Although not a top model, the amount (ha) of restored grassland habitat containing <2% forb cover at the core use scale had more explanatory power than a null model and was therefore included in multivariate habitat models. At the breeding season home range scale, the best predictor of nest site selection was also the amount (ha) of restored grassland habitat containing >30% forb cover. No other models fell within 2.0 AIC_c units of the top model at this scale, although four additional variables had support for inclusion in multivariate habitat models.

Next, we evaluated seven candidate models constructed from the best scale for each of three supported habitat variables in the previous step: hectares of restored grassland containing >30% forb cover (core use scale), hectares of restored grassland containing <2% forb cover (breeding season home range scale), and hectares of grassland containing <2% shrub cover (breeding season home range scale). Bunchgrass dominance and the amount of restored grasslands with >30 % forb cover at the core use scale were correlated, and therefore were not included together in any multivariate model. We found support for four models and each included the amount of restored grasslands with >30% forb cover variable at the core use scale. The most parsimonious model within 2.0 AIC_c units of the top model was a univariate model containing the amount of restored grasslands with >30% forb cover at the core use scale.

We then evaluated a set 15 models that included our top four habitat models, two univariate wind energy models, eight additive models constructed by adding wind energy variables to our top habitat models, and an intercept-only model. The two univariate wind energy models ranked 14th and 15th and below the intercept-only model. The top model included a wind energy variable but the 95% confidence interval around the coefficient estimate for the wind energy covariate included zero. The most parsimonious model within 2.0 AIC_c units of the top model included the amount of restored grassland with >30% forb cover at the core use scale.

In the final step of our nest site selection analysis, a GFR model with interactions and first order expectations of the amount of restored grassland with >30% forb cover at the core use scale performed 2.7 AIC_c units better than a model containing only the habitat variable. That model suggests selection for restored grasslands with >30% forb cover at the core use scale was stronger as availability of that habitat type increased (Fig. 2-2, Table 2-4).

Nest Survival

Our DNS analysis included 147 nests (119 first nests and 28 renests). Apparent nest success for the 2-year study period was 46% (45% for first nests and 50% for renests). We evaluated DNS over a 27-day incubation period. Our DNS estimate was 0.97 and did not differ between years (Table 2-3).

At the microhabitat scale, we did not find support for modeling any variables as quadratic effects; all variables were modeled as linear effects. The top microhabitat predictor of DNS was VOR and we also found support for percent overhead concealment at the nest (Table 2-3). At the core use scale, the best predictor of DNS was the amount (ha) of restored grassland habitat containing >30% forb cover. We also found support for a negative relationship between DNS and the amount (ha) of crested wheatgrass dominated grasslands at the core use scale.

Our multi-scale habitat models were constructed using microhabitat and core use scale variables; we found no support for effects of home range scale variables on DNS. We constructed models using all possible combinations of the following variables: VOR, overhead concealment, the amount of restored grassland habitat with >30% forb at the core use scale, and the amount of restored grassland dominated by crested wheatgrass at the core use scale. The most explanatory model was an additive model containing VOR and the amount (ha) of grassland containing >30% forb cover at the core use scale.

The candidate model set for assessing wind energy effects on DNS included the four best habitat models, models adding each of the three wind energy variables to each of the four best habitat models, three univariate wind energy models, and an intercept-only model. We did not find support for an influence of wind energy development on DNS. Models containing wind energy covariates did not perform better than a more parsimonious habitat model and all three univariate wind energy models performed worse than an intercept-only model.

The best model for DNS was the model including VOR and amount of grassland with >30% forb cover at the core use scale. This model suggests that DNS increased from .96 (33% nest success) at a visual obstruction reading of 2 dm to .98 (59% nest success) at a visual obstruction reading of 8 dm, and from .97 (44% nest success) to .98 (59% nest success) when the portion of the core use area containing restored grasslands with greater than 30% forb cover increased from 0% to 60% (Fig. 2-3, Table 2-4).

DISCUSSION

Our study is the first to examine the potential effects of wind energy development on CSTG nesting ecology. We found no evidence to support an influence of wind energy infrastructure on CSTG nest site selection or nest survival. The primary factors contributing to variation in nest site selection and nest survival were related to vegetation structure and composition. Female CSTG selected nest sites in grassland habitat with higher forb cover at the core use scale. Nest survival was positively influenced by visual obstruction readings at the nest site and grassland habitat with higher forb cover at the core use scale.

Our nest site selection results are similar to those of Harrison (2015) and McNew et al. (2014) who reported no influence of wind energy development on nest site selection in prairie-chickens. Similarly, LeBeau et al. (2014) found no influence of wind energy development on nest site selection in sage-grouse. Our results do not support the prediction of Pruett et al. (2009) that prairie grouse would avoid wind turbines and differ from studies by Pittman et al. (2005) and Holloran et al. (2005) that documented avoidance of energy-related infrastructure by prairie-chickens and sage-grouse, respectively.

Prairie grouse responses to energy development may vary based on differences in associated infrastructure. Oil and gas developments may trigger predator avoidance behaviors because those infrastructure types provide potential perches or nesting platforms for raptors and corvids (Prather and Messmer 2010, Messmer et al. 2013). Wind turbines in our study lacked suitable surfaces for perching or nesting and likely did not subsidize avian predators. Overhead transmission lines and their associated towers/poles may also serve as perches for raptors and corvids but transmission lines associated with the wind facilities in our study were mostly buried.

Disturbance levels associated with roads may vary among different forms of energy development as well (Messmer et al. 2013). Prairie-chickens in Kansas avoided major roads when nesting (McNew et al. 2014) and sage-grouse lek attendance was negatively influenced by road noise associated with gas-field access roads (Blickley et al. 2012). Wind turbine access roads in our study were lightly traveled, as operational turbines required little maintenance and public access was typically restricted by wind companies or private landowners. Our results suggest that CSTG may not perceive wind energy infrastructure as a threat when selecting nest sites and that nest site selection is driven by vegetation characteristics within grassland habitats.

Nest microhabitat characteristics selected by CSTG have been well documented (e.g., McDonald 1998, Meints 1991, Boisvert 2002, Collins 2004, Stonehouse et al. 2015). Columbian sharp-tailed grouse tend to select nest sites with higher grass canopy cover (McDonald 1998, Boisvert 2002, Collins 2004, Stonehouse et al. 2015), higher visual obstruction (Meints 1991, Boisvert 2002, Collins 2004), less bare ground (Meints 1991, Collins 2004) and taller forbs (Stonehouse et al. 2015). Selection of nest sites with more vegetation cover suggests that decisions made by CSTG when selecting nest micro-habitat may be related to concealment from visually oriented predators (Lima 2009).

Animals may select different habitat components at different spatial scales and patterns detected at one scale cannot always reliably be “scaled up” or “scaled down” (Wiens 1989, Schneider 1994). To detect patterns that may occur at larger spatial scales and provide reliable, management-oriented results, we assessed CSTG nest site selection at two broader, biologically-relevant spatial scales: 1) the core use area of nesting hens and 2) the breeding season home range. Our top nest site selection model indicates that

CSTG hens select for grassland habitat patches with >30% forb cover at the core use scale and show a functional response to forb cover, with the strength of selection increasing relative to availability (Mysterud and Ims 1998).

Our study is the first to document the importance of forb cover to sharp-tailed grouse nest site selection at the nesting core use scale. Goddard et al. (2009) documented sharp-tailed grouse selecting shrub-steppe habitats over residual grass at the patch scale (250 m radius) for first-nest attempts in fragmented habitats of northeastern British Columbia. They attributed selection of that habitat type to the concealment attributes provided by shrubs. Forb cover in our study may provide similar concealment benefits, but we suspect that the benefit of higher forb cover to incubating hens goes beyond concealment. The core use scale we evaluated represents the assumed extent of habitat available to hens during incubation recess movements. Nesting season diets of CSTG consist primarily of grasses and forbs, with forbs dominating as the season progresses (Hoffman and Thomas 2007). The CSTG females we studied may have selected grassland patches with higher forb abundance to meet the nutritional requirements of egg-laying and incubation.

Bunchgrass dominance and the amount of restored grasslands with >30% forb cover at the core use scale were highly correlated. As such, we cannot rule out the possibility that bunchgrass cover or a combination of bunchgrass dominance and forb cover is what actually drove nest site selection in our study. The structural attributes of bunchgrasses, relative to sod-forming exotic grasses, may provide a variety of benefits to CSTG, including: better residual cover for nest concealment, diverse thermal environments (Carroll et al. 2015), or improved mobility resulting from greater interspacing between plants.

Our best performing model did not include breeding season home range-scale predictors. The best predictor of nest site selection at the breeding season home range scale performed better at the core use scale. We hypothesized that CSTG would select nest sites within breeding season home ranges that minimized potential demographic impacts of nest predators, similar to McNew et al. (2014). Our results suggest CSTG may not make nest site decisions at the home range scale or the variables we considered were not important at that spatial scale.

Our results indicate that wind energy infrastructure did not influence CSTG nest survival. These results are similar to those of Harrison (2015) who found no influence of wind energy on prairie-chicken nest survival near a wind facility in Nebraska and McNew et al. (2014) who found no effect of proximity to wind turbines on prairie-chicken nest survival in Kansas. Both studies found nest survival to be influenced by vegetation rather than wind energy infrastructure. Our results differ from those of LeBeau et al. (2014) who documented decreased nest survival in sage-grouse as distance to turbines decreased at a wind energy facility in Wyoming. We hypothesized that CSTG nest survival would decrease near turbines due to increased predation resulting from anthropogenic features or habitat fragmentation. Increased numbers of corvids could occur near turbines if collision mortalities resulted in subsidized food resources and meso-carnivores could benefit from either subsidized food resources or improved access resulting from turbine roads (Tigas et al. 2002). However, we found that nest survival of CSTG at this study site was influenced more by vegetation structure and composition.

Similar to our habitat selection results, nest survival models including wind turbine variables performed poorly and additive models with turbine and habitat variables did not outperform more parsimonious habitat models.

Our top model suggests CSTG nest survival was affected by visual obstruction at the microhabitat scale and forb cover within restored grassland habitat at the core use scale. Previous studies have also documented higher visual obstruction readings associated with successful CSTG nests (McDonald 1998, Boisvert 2002, Collins 2004), indicating the importance of concealment from visually-oriented predators at the microhabitat scale. At the core use scale, nest survival increased with an increasing amount of restored grassland habitat containing >30% for cover. To our knowledge, no published study has documented a relationship between percent forb cover within restored grasslands and CSTG daily nest survival rates, at any spatial scale.

We also found support for effects of two additional variables on nest survival: percent overhead concealment at the micro-habitat scale (positive relationship) and amount of crested wheatgrass-dominated grassland at the core use scale (negative relationship). The influence of increased overhead concealment on nest survival suggests that avian predators may play a significant role in nest predation in our study area. We assessed the influence of three grass types on daily nest survival: bunchgrasses, rhizomatous grasses (smooth brome and intermediate wheatgrass) and crested wheatgrass. We hypothesized that the structural differences in these grass types may influence CSTG movements or concealment from nest predators. We found that core use areas with a higher amount of crested wheatgrass had lower nest survival. The structural attributes of crested wheatgrass may provide inadequate concealment to CSTG females during incubation and recess movements, and therefore, may facilitate increased nest predator efficiency.

MANAGEMENT IMPLICATIONS

Our findings suggest that CSTG nesting ecology in eastern Idaho was not impacted by wind energy development. Our results, combined with those of recent studies, indicate that nesting prairie grouse may be less sensitive to wind energy development than other forms of energy development. We explored the relationship between CSTG and wind energy near pre-existing wind farms over a two year post-development period and recommend future researchers consider long-term studies to better assess potential behavioral changes and demographic responses of sharp-tailed grouse following wind energy development. Efforts to manage CSTG nesting habitats in eastern Idaho should focus on maintaining parcels of high-quality, bunchgrass-dominated, perennial grasslands with >30% forb canopy cover. The CSTG nests in our study area occurred primarily in CRP fields, or other restored grasslands similar in vegetation structure and composition to CRP fields, as opposed to native habitats or agricultural fields. Apparent nest success of CSTG in CRP and similar restored grasslands in our study (46%) was higher than previous studies. Our results suggest that CRP can provide suitable nesting cover for CSTG in eastern Idaho and plantings or programs resulting in higher forb cover (e.g., CRP-SAFE) should provide additional benefits to nesting CSTG.

LITERATURE CITED

American Wind Energy Association, http://www.awea.org, accessed 13 July 2016.

Ammann, G. A. 1944 Determining the age of pinnated and sharp-tailed grouse. Journal of Wildlife Management 8:170:171.

Aho, K., D. Derryberry, and T. Peterson. 2014. Model selection for ecologists: the worldviews of AIC and BIC. Ecology 95:631-636.

Arnett, E. B., W. K. Brown, W. P. Erickson, J. K Fielder, B. I. Hamilton, T. H. Henry, A. Jain, G. D. Johnson, J. Kerns, R. R. Koford, C. P. Nicholson, T. J. O'Connell, M. D. Piorkowski, and R. D. Tankersley Jr. 2008. Patterns of bat fatalities at wind energy facilities in North America. Journal of Wildlife Management 72:61-78.

Bates, D, M. Maechler, B. Bolker, and S. Walker. 2014. lme4: Linear mixed-effects models using Eigen and S4. R package version 1.1-10, http://CRAN.R-project.org/package=lme4.

Blickley, J. L., D. Blackwood, and G. L. Patricelli. 2012. Experimental evidence for the effects of chronic anthropogenic noise on abundance of greater sage-grouse at leks. Conservation Biology 26:461-471.

Boisvert, J. H. 2002. Ecology of Columbian sharp-tailed grouse associated with Conservation Reserve Program and reclaimed surface mine lands in northwestern Colorado. Thesis, University of Idaho, Moscow, USA.

Bromaghin, J. F., T. L. McDonald, and S. C. Amstrup. 2013. Plausible combinations: an improved method to evaluate the covariate structure of Cormack-Jolly-Seber mark-recapture models. Open Journal of Ecology 3:11-22.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. Second addition. Springer-Verlag, New York,New York, USA.

Carroll, J. M., C. A. Davis, R. D. Elmore, S. D. Fuhlendorf, and E. T. Thacker. 2015. Thermal patterns constrain diurnal behavior of a ground-dwelling bird. Ecosphere 6(11):222. http://dx.doi.org/10.1890/ES15-00163.1.

Chalfoun A. D., F. R. Thompson III, and M. J. Ratnaswamy. 2002. Nest predators and fragmentation: a review and meta-analysis. Conservation Biology 16:306-318.

Collins, C. P. 2004. Ecology of Columbian sharp-tailed grouse breeding in coal mine reclamation and native upland cover types in northwestern Colorado. Thesis, University of Idaho, Moscow, USA.

Connelly, J. W., M. W. Gratson, and K. P. Reese. 1998. Sharp-tailed Grouse (*Tympanachus phasianellus*). *In:* A. Poole and F. Gill, editors. The Birds of North America, Number 354. The Birds of North America, Inc., Philadelphia, PA.

Dijak, W. D., and F. R. Thompson III. 2000. Landscape and edge effects on the distribution of mammalian predators in Missouri. Journal of Wildlife Management 2000:209-216.

Dinsmore, S. J., C. G. White, and F. L. Knopf. 2002. Advanced techniques for modeling avian nest survival. Ecology 83:3476-3488.

Daubenmire, R. 1959. A canopy-coverage method of vegetation analysis. Northwest Science 33:43-64.

Erickson, W. P., M. M. Wolfe, K. J. Bay, D. H. Johnson, and J. L. Gehring. 2014. A comprehensive analysis of small-passerine fatalities from collision with turbines at wind energy facilities. PLOS ONE 9(9): e107491.

Franklin, A. B., D. R. Anderson, R. J. Gutierrez, and K. P. Burnham. 2000. Climate, habitat quality, and fitness in northern spotted owl populations in northwestern California. Ecological Monographs 70:539-590.

Goddard, A. D., R. D. Dawson, and M. P. Gillingham. 2009. Habitat selection by nesting and brood rearing sharp-tailed grouse. Canadian Journal of Zoology 87:326-336.

Harrison, J. O. 2015. Assessment of disturbance effects of an existing wind energy facility on greater prairie-chicken (*Tympanuchus cupido pinnatus*) breeding season ecology in the sandhills of Nebraska. Thesis, University of Nebraska, Lincoln, USA.

Hoffman, R. W., and A. E. Thomas. 2007. Columbian sharp-tailed grouse: a technical conservation assessment. USDA Forest Service, Rocky Mountain Region. <http://www.fs.fed.us/r2/projects/scp/assessments/columbiansharptailedgrouse.pdf>.Accessed 1 Oct 2015.

Hoffman, R. W., K. A. Griffen, J. M. Knetter, M.A. Schroeder, A. D. Apa, J. D. Robinson, S. P. Espinosa, T. J. Christianson, R. D. Northrup, D.A. Budeau, and M. J. Chutter. 2015. Guidelines for the management of Columbian sharp-tailed grouse populations and their habitats. Sage and Columbian Sharp-tailed Grouse TechnicalCommittee, Western Association of Fish and Wildlife Agencies, Cheyenne, Wyoming, USA.

Holloran, M. J. 2005. Greater sage-grouse (Centrocercus urophasianus) population response to natural gas field development in western Wyoming. Dissertation, University of Wyoming, Laramie, USA.

Johnsgard, P. A. 1973. Grouse and quails of North America. Universityof Nebraska Press, Lincoln, NE.

Johnson, D. H, R. L. Scott, K. S. Smallwood, and W. P. Erickson. 2016. Avian fatalities at wind energy facilities in North America: a comparison of recent approaches. Human-Wildlife Interactions 10:7-18.

Kincaid, T. M. and Olsen, A. R. 2016. spsurvey: Spatial Survey Design and Analysis. R package version 3.3.

Kuvlesky, W. P., L. A. Brennan, M. L. Morrison, K. K. Boydston, B. M. Ballard, F. C. Bryant. 2007. Wind energy development and wildlife challenges and opportunities. Journal of Wildlife Management 71:2487-2498.

Laake, J. L. 2014. RMark: An R Interface for Analysis of Capture-Recapture Data with MARK. R package version 3.1.1

LeBeau, C. W., J. L. Beck, G. D. Johnson, and M. J. Holloran. 2014. Short-term impacts of wind energy development on greater sage-grouse fitness. Journal of Wildlife Management 78:522-530.

Lima, S. L. 2009. Predators and the breeding bird: behavioral and reproductive flexibility under the risk of predation. Biological Reviews 84: 485-513.

Loss, S. R., T. Will, and P. P. Marra. 2013. Estimates of bird collision mortality at wind facilities in the contiguous United States. Biological Conservation 168:201-209.

Manly, B. F. J., L. L. McDonald, D. L. Thomas, T. L. McDonald, and W. P. Erickson. 2002. Resource selection by animals: statistical analysis and design for field studies. Second Edition. Kluwer, Boston, Massachusetts, USA.

Manzer, D. L., and S. J. Hannon. 2005. Relating grouse nest success and corvid density to habitat: a multi-scale approach. Journal of Wildlife Management 69:110-123.

Matthiopoulos, J., M. Hebblewhite, G. Aarts, and J. Fieberg. 2011. Generalized functional responses for species distributions. Ecology 92:583-589.

McDonald, M. W. 1998. Ecology of Columbian sharp-tailed grouse in eastern Washington. Thesis, University of Idaho, Moscow, USA.

McNew, L. B., L.M. Hunt, A. J. Gregory, S. M. Wisely, and B. K. Sandercock. 2014. Effects of wind energy development on the nesting ecology of Greater Prairie-Chickens in fragmented grasslands. Conservation Biology 28:1089-1099.

Meints, D. R. 1991. Seasonal movements, habitat use, and productivity of Columbian sharp-tailed grouse in southeastern Idaho. Thesis, University of Idaho, Moscow, USA.

Messmer, T. A., R. Hasenyager, J. Burruss, and S. Liguori. 2013. Stakeholder contemporary knowledge needs regarding the potential effects of tall-structures on sage-grouse. Human-Wildlife Interactions 7:273-298.

Mysterud, A., and R. A. Ims. 1998. Functional responses in habitat use: availability influences relative use in trade-off situations. Ecology 79:1435-1441.

North American Bird Conservation Initiative, U.S. Committee. 2014. The State of the Birds 2014 Report. U.S. Department of Interior, Washington, D.C. 16 pages.

Pittman, J. C., C. A. Hagen, R. J. Robel, T. M. Loughin, and R. D. Applegate. 2005. Location and success of Lesser Prairie-Chicken nests in relation to vegetation and human disturbance. Journal of Wildlife Management 69:1259-1269.

Prather, P. R., and T. A. Messmer. 2010. Raptor and corvid response to power distribution line perch deterrents in Utah. Journal of Wildlife Management 74:796-800.

Pruett C. L., M. A. Patten, and D. H. Wolfe. 2009. Avoidance behavior by prairie grouse: implications for development of wind energy. Conservation Biology 23:1253-1259.

Rearden, J .D. 1951. Identification of waterfowl nest predators. The Journal of Wildlife Management 386-395.

Robel, R. J., J. N. Briggs, A. D. Dayton, and L. C. Hulbert. 1970. Relationships between visual obstruction measurements and weight of grassland vegetation. Journal of Range Management 23:295-297.

Roersma, S. J. 2001. Nesting and brood rearing ecology of plains sharp-tailed grouse (*Tympanuchus phasianellus jamesi*) in a mixed-grass/fescue ecoregion of southern Alberta. Thesis, University of Manitoba, Winnepeg, Canada.

Schneider, D. C. 1994. Quantitative ecology: spatial and temporal scaling. Academic Press, Toronto, Ontario.

Schroeder, M. A., and C. E. Braun. 1991. Walk-in traps for capturing greater prairie chickens on leks. Journal of Ornithology 62:378-385.

Smallwood, K. S. 2013. Comparing bird and bat fatality-rate estimates among North American wind-energy projects. Wildlife Society Bulletin 37:19-33.

Stonehouse, K. F., L. A. Shipley, J. Lowe, M. T. Atamian, M. E. Swanson, and M. A. Schroeder. 2015. Habitat selection and use by sympatric, translocated greater sage-grouse and Columbian sharp-tailed grouse. Journal of Wildlife Management 79:1308-1326.

Strickland, M.D., E.B. Arnett, W.P. Erickson, D.H. Johnson, G.D. Johnson, M.L., Morrison, J.A. Shaffer, and W. Warren-Hicks. 2011. Comprehensive Guide to Studying Wind Energy/Wildlife Interactions. Prepared for the National Wind Coordinating Collaborative, Washington, D.C., USA.

Tigas, L. A., D. H. Van Vuren, and R. M. Sauvajot. 2002. Behavioral responses of bobcats and coyotes to habitat fragmentation and corridors in an urban environment. Biological Conservation 108:299-306.

U.S. Department of the Interior. 2000. Endangered and threatened wildlife and plants; 12-month finding for a petition to list the Columbian sharp-tailed grouse as threatened. Federal Register 65:60391-60396.

U.S. Department of the Interior. 2006. Endangered and threatened wildlife and plants; 90-day finding on a petition to list the Columbian sharp-tailed grouse as threatened or endangered. Federal Register 71:67318-67325.

U.S. General Services Administration. 2015. <https://catalog.data.gov/dataset/tiger-roads-2014>. Accessed 7 Aug 2015.

U.S. Geological Survey. 2015. <https://pubs.usgs.gov/ds/817/>. Accessed 10 Jan 2015.

Weins, J. A. 1989. Spatial scaling in ecology. Functional Ecology 3:385-397.

Web Soil Survey. 2016. <http://websoilsurvey.nrcs.usda.gov>. Accessed 1 Sept 2016.

Webb, S. L., C. V. Olson, M. R. Dzialak, S. M. Harju, J. B. Winstead, and D. Lockman. 2012. Landscape features and weather influence nest survival of a ground-nesting bird ofconservation concern, the greater sage-grouse, in human-altered environments. Ecological Processes 1:4.

Western Regional Climate Center. 2016. <http:// www.wrcc.dri.edu>. Accessed 1 Sept 2016.

White, G. C., and K. P. Burnham. 1999. Program MARK: survival estimation from populations of marked animals. Bird Study 46:120-138.

Winder, V. L., L. B. McNew, A .J. Gregory, L. M. Hunt, S. M. Wisely, and B. K. Sandercock. 2014. Space use of female Greater Prairie-Chickens in response to wind energy development. Ecosphere 5:art3.

TABLES AND FIGURES

Table 2-1. Predictor variables used to model nest site selection and daily nest survival of Columbian sharp-tailed grouse (*Tympanuchus phasianellus columbianus*) in eastern Idaho, 2014-2015.

Variable	**Description**	**Scale**[a]
Habitat		
VOR[b]	Visual obstruction at 4 m from nest (dm)	M
Over[b]	Overhead concealment 1 m above nest (%)	M
Grass[b]	Total live and residual grass canopy cover (%)	M
Bunch_m[b]	Bunchgrass canopy cover (%)	M
Crest_m[b]	Crested wheatgrass canopy cover (%)	M
Rhizo_m[b]	Rhizomatous grass canopy cover (%)	M
Forb[b]	Forb canopy cover (%)	M
Shrub[b]	Shrub canopy cover (%)	M
Litter[b]	Litter (%)	M
Bare[b]	Bare ground (%)	M
Bunch	Restored grassland dominated by bunchgrass (ha)	CU, HR
Crest	Restored grassland dominated by crested wheatgrass (ha)	CU, HR
Rhizo	Restored grassland dominated by rhizomatous grass (ha)	CU, HR
Forb<2	Restored grassland with <2% forb cover (ha)	CU, HR
Forb>30	Restored grassland with >30% forb cover (ha)	CU, HR
Shrub>2	Restored grassland with >2% shrub cover (ha)	CU, HR
Roads	Road density (ha)	CU, HR
Wind Energy		
Turb_dist	Distance to turbine (m)	N/A
Turb_dens	Number of turbines within buffer	CU, HR

[a] Abbreviations: M = microsite (6 m radius); CU = core use (437 m radius); HR = breeding season home range (2100 m radius)

[b] Variables used only for nest survival analysis

Table 2-2. Model selection results[a] for resource selection models describing Columbian sharp-tailed grouse (*Tympanuchus phasianellus columbianus*) nest site selection in eastern Idaho, 2014-2015.

Step[b]	**Group[c]**	**Model[d]**	***K***	**Dev**	**AIC_c**	**ΔAIC_c**	***w***
I	Core Use	Forb>30_CU	3	697.9	703.9	0.0	0.61
		Bunch_CU	3	698.9	704.9	1.0	0.38
		Forb<2_CU	3	706.7	712.7	8.8	0.01
		Intercept-only	2	712.5	716.5	12.5	0.00
	Home Range	Forb>30_HR	3	701.5	707.5	0.0	0.69
		Forb<2_HR	3	704.7	710.7	3.2	0.14
		Bunch>HR	3	706.3	712.3	4.8	0.06
		Crested_HR	3	706.7	712.7	5.2	0.05
		Shrub>2_HR	3	707.7	713.7	6.2	0.03
		Intercept-only	2	712.5	716.5	8.9	0.01
II	Habitat Combined	Forb>30_CU + Forb<2_HR	4	695.5	703.5	0.0	0.37
		Forb>30_CU	3	697.9	703.9	0.5	0.29
		Forb>30_CU + Shrub>2_HR	4	697.1	705.9	1.6	0.16
		Forb>30_CU + Shrub>2_HR + Forb<2_HR	5	695.2	705.2	1.7	0.16
		Intercept-only	2	712.5	716.5	13.0	0.00
III	Habitat + Wind	Forb>30_CU + Forb<2_HR + Turb_dens_CU	5	693.1	703.1	0.0	0.17
		Forb>30_CU + Forb<2_HR	4	695.5	703.5	0.4	0.15
		Forb>30_CU	3	697.9	703.9	0.8	0.12
		Forb>30_CU + Turb_dens_CU	4	696.1	704.1	1.0	0.11
		Forb>30_CU + Forb<2 + Turb_dens_HR	5	694.8	704.8	1.7	0.08
		Forb>30_CU + Shrub>2_HR + Forb<2_HR + Turb_dens_CU	6	692.9	704.9	1.8	0.07
		Intercept-only	2	712.5	716.5	13.4	0.00
		Turb_dens_HR	3	711.0	717.0	13.9	0.00
		Turb_dens_CU	3	712.3	718.3	15.2	0.00

Table 2-2. continued

IV	GFR	Forb>30_CU + Forb>30_CU^{e} + Forb>30_CU:Forb>30_CU^{e}	5	691.2	701.2	0.0	0.79
		Forb>30_CU	3	697.9	703.9	2.7	0.21

[a] K = number of parameters, Dev = deviance, AIC_c =Akaike's Information Criterion with second-order bias correction, ΔAIC_c = difference between model of interest and most explanatory model with second-order bias correction, w = Akaike weight.

[b] Step I compared models (n = 16) consisting of a single habitat covariate within 2 spatial scale groupings . Step II compared univariate models (n = 24) within 3 spatial scale groupings. Step II compared additive, multi-scale habitat models (n = 8) using supported variables from steps I (models ≥ 2 AIC_c units less than intercept-only model). Step III compared top 4 models from step III (models within 2 AIC_c of top model) to same 4 models with wind energy variables added, univariate wind energy models, and an intercept-only model (n = 15). Step IV compared the top overall habitat model to a functional response model.

[c] GFR = Generalized functional response.

[d] All models include a random "lek-year" intercept.

Table 2-3. Model selection results[a] for generalized linear models describing daily nest survival of Columbian sharp-tailed grouse (*Tympanuchus phasianellus columbianus*) nests (n = 147) in eastern Idaho, 2014-2015.

Step[b]	**Group**[c]	**Model**	***K***	**Dev**	**AIC$_c$**	**ΔAIC$_c$**	***w***
I	Annual Variation	Intercept-only	1	523.6	525.6	0.0	0.58
		Year	2	522.2	526.2	0.6	0.42
II	Micro-habitat	VOR	2	517.5	521.5	0.0	0.41
		Over	2	517.8	521.8	0.3	0.36
		Intercept-only	1	523.6	525.6	4.1	0.05
	Core use	Forb>30_CU	2	518.9	522.9	0.0	0.32
		Crest_CU	2	519.5	523.5	0.5	0.24
		Intercept-only	1	523.6	525.6	2.6	0.09
III	Habitat Combined	VOR + Forb>30_CU	3	510.8	516.8	0.0	0.20
		VOR + Forb>30_core + Crest_CU	4	508.9	516.9	0.1	0.19
		VOR + Forb>30_CU + Over	4	509.4	517.4	0.5	0.15
		VOR + Forb>30_CU + Crest_CU + Over	5	507.7	517.7	0.9	0.13
		Intercept-only	1	523.6	525.6	8.7	0.00
IV	Habitat + Wind	VOR + Forb>30_CU	3	510.8	516.8	0.0	0.12
		VOR + Forb>30_CU + Crest_CU	4	508.9	516.9	0.1	0.11
		VOR + Forb>30_CU + Over	4	509.4	517.4	0.5	0.09
		VOR + Forb>30_CU + Turb_dist	4	509.6	517.7	0.8	0.08
		VOR + Forb>30_CU + Over + Turb_dist	5	507.7	517.7	0.9	0.08
		VOR + Crest_CU + Forb>30_CU + Over	5	507.7	517.7	0.9	0.07
		VOR + Forb>30_CU + Turb_dens_HR	4	510.0	517.9	1.2	0.07
		VOR + Forb>30_CU + Over + Turb_dens_HR	5	508.2	518.2	1.4	0.06
		VOR + Forb>30_CU + Crest_CU + Turb_dist	5	508.4	518.5	1.6	0.05
		VOR + Forb>30_CU + Crest_CU + Turb_dist	5	508.5	518.5	1.7	0.05

Table 2-3. continued

VOR + Forb>30_CU + Turb_dens_CU	4	510.8	518.8	2.0	0.04
Intercept-only	1	523.6	525.6	8.7	0.00
Turb_dens_HR	2	522.6	526.6	9.8	0.00
Turb_dist	2	523.4	527.4	10.6	0.00
Turb_dens_HR	2	523.5	527.5	10.7	0.00

[a] K = number of parameters, Dev = deviance, AIC_c =Akaike's Information Criterion with second-order bias correction, ΔAIC_c = difference between model of interest and most explanatory model with second-order bias correction, w = Akaike weight.

[b] Step I compared variation between years to an intercept-only model. Step II compared univariate models ($n = 24$) within 3 spatial scale groupings. Step III compared additive, multi-scale habitat models ($n = 15$) using supported variables from steps I and II (models ≥ 2 AIC_c units less than intercept-only model). Step IV compared top 4 models from step III (models within 2 AIC_c of top model) to same 4 models with wind energy variables added, univariate wind energy models, and an intercept-only model ($n = 20$).

[c] Analyses grouped by biological theme. Factors examined at the home range scale did not have support and therefore were not included in this table.

Table 2-4. Coefficient estimates (β) and standard errors (SE) from the best models describing nest site selection and daily nest survival of Columbian sharp-tailed grouse (*Tympanuchus phasianellus columbianus*) in eastern Idaho, 2014-2015.

Variable	**β**	**SE**
Nest site selection		
Forb>30_CU	0.372	0.178
Forb>30_CU^e	-0.865	0.377
Forb>30_CU: Forb>30_CU^e	0.349	0.285
Nest survival		
VOR	0.158	0.060
Forb>30_CU	0.016	0.007

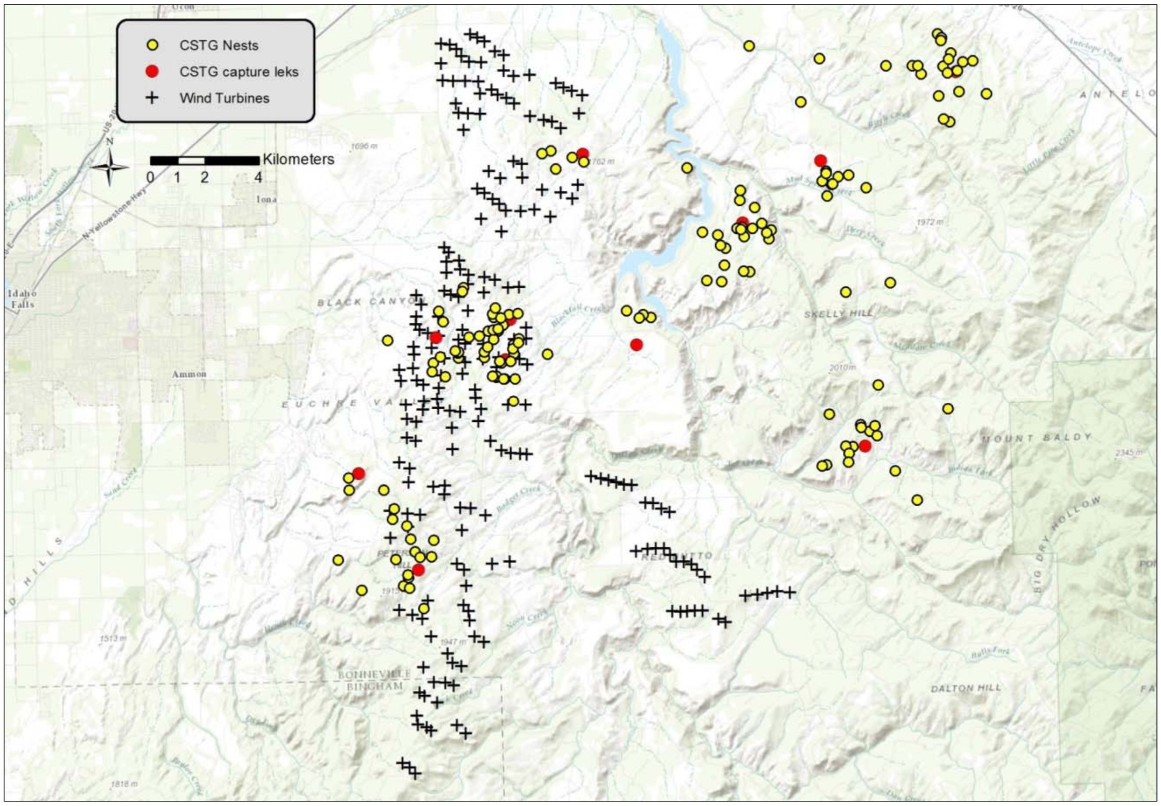

Figure 2-1. Locations of Columbian sharp-tailed grouse (*Tympanuchus phasianellus columbianus*) nests (*n* = 147) relative to capture leks (*n* = 11) and wind turbines (*n* = 215) in eastern Idaho study area, 2014-2015.

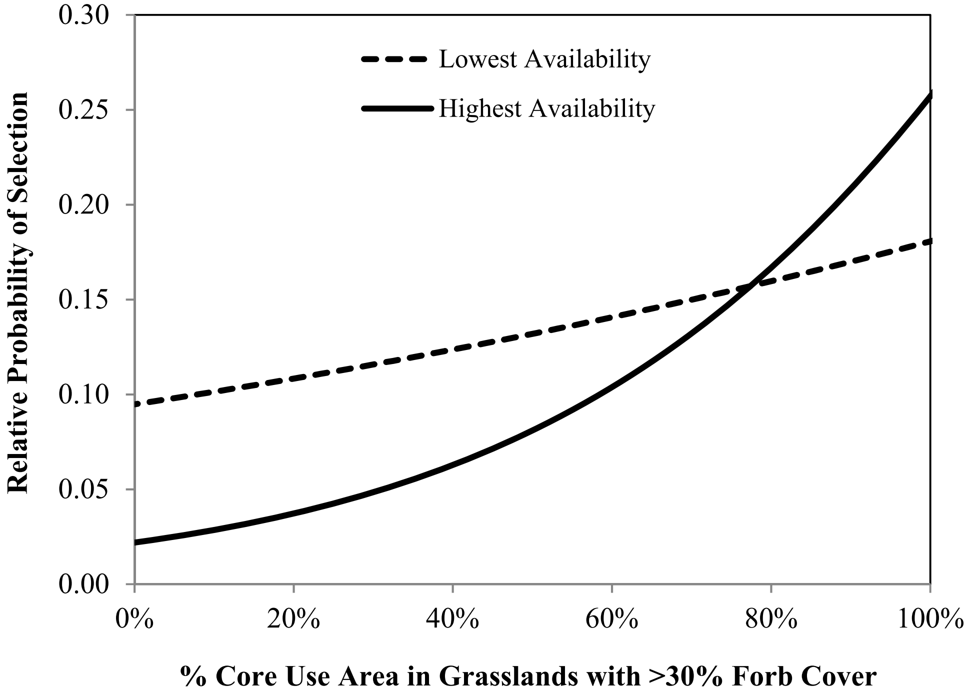

Figure 2-2. Relationship between nest site selection probability and the portion of the core use area in restored grasslands containing >30% forb cover, for CSTG leks with the highest and lowest availability of that habitat type, for Columbian sharp-tailed grouse (*Tympanuchus phasianellus columbianus*) in eastern Idaho, 2014-2015.

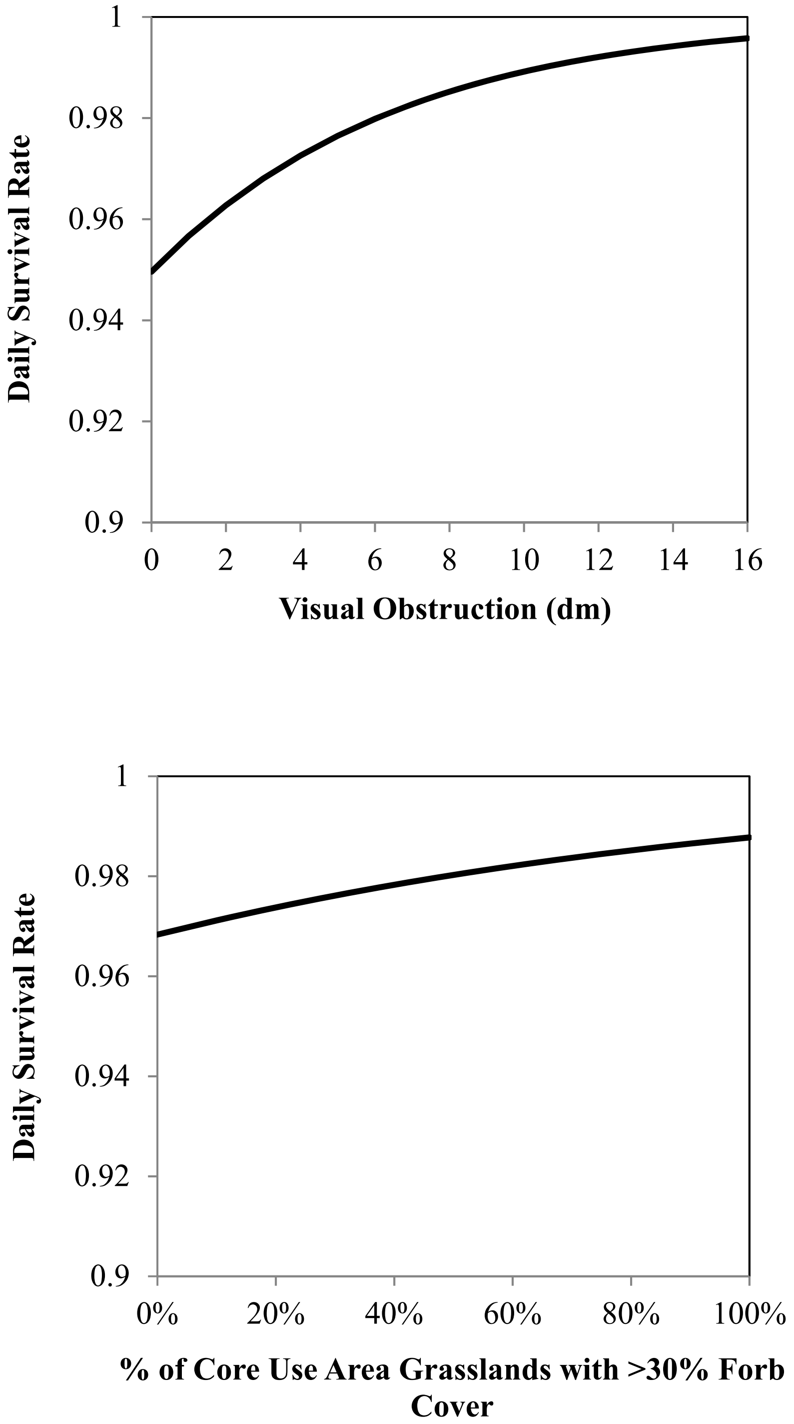

Figure 2-3. Effects of visual obstruction (top) and percent of core use area in grasslands containing >30% forb cover (bottom) on daily nest survival rates of Columbian sharp-tailed grouse (*Tympanuchus phasianellus columbianus*) in eastern Idaho, 2014-2015. All covariates not plotted were held constant at their means to show variation in the covariate of interest.

CHAPTER 3

COLUMBIAN SHARP-TAILED GROUSE BROOD SUCCESS AND CHICK SURVIVAL RELATIVE TO WIND ENERGY DEVELOPMENT IN EASTERN IDAHO[2]

ABSTRACT

The Columbian sharp-tailed grouse (*Tympanuchus phasianellus columbianus;* CSTG) has experienced range-wide population declines, primarily as a result of habitat loss or degradation, and currently occupies <10% of its historic range. Expansion of wind energy developments across the remaining occupied CSTG range has been identified as a potential threat to the species. To assess the potential effects of wind energy development on CSTG offspring vital rates, we monitored 68 broods of radio-marked females captured at 11 leks in restored grassland habitats within 14 km of a 215-turbine wind energy development complex in eastern Idaho. We assessed the influence of wind turbine density, habitat features, temporal factors, and precipitation on CSTG brood success and chick survival using an information-theoretic model selection approach. Wind turbine density did not influence early (14 day) or late (42 day) brood success but chick survival to 42 days post-hatch was negatively affected by increasing turbine density at the breeding season home range scale. The probability of an individual chick surviving to 42 days decreased by 50% when there were ≥10 turbines within 2,100 m of the nest. Habitat features such as vegetation composition in restored grasslands were poor predictors of offspring survival. Post-hatch precipitation positively influenced early brood success and chick survival. Late brood success and chick survival increased

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with earlier hatch dates. Management for high-quality, early spring nesting cover in restored grassland habitats may help offset negatives effects of late hatch dates on offspring survival.

INTRODUCTION

Wind energy supplied 4.7% of the total electricity generated in the U.S. in 2015 and may supply 10% by 2020 (American Wind Energy Association 2016). Projections for rapid growth in the wind energy industry raise concerns over potential impacts to avian wildlife species, as negative effects have been documented in waterfowl, passerines, and raptors (Kuvlesky et al. 2007). However, little is known about the effects of wind energy development on North American Tetraonidae grouse species, many of which are currently in decline (Storch 2007). Prairie grouse species may be among the most vulnerable to wind developments because prairie and shrub-steppe habitats are frequently targeted for development (Lopez et al. 2012). Potential negative impacts to prairie grouse species may include collision mortality, habitat loss, or decreased fitness.

Few studies have directly addressed the influence of wind energy development on prairie grouse ecology. In particular, little information is available on potential impacts to grouse broods and chicks. LeBeau et al. (2014) documented decreased greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) brood survival as distance to wind turbines decreased in Wyoming. In Nebraska, Harrison (2015) found no effects of a wind energy facility on greater prairie-chicken (*T. cupido pinnatus*; prairie-chicken) brood site preference or survival in unfragmented grasslands. Life-stage simulation analyses in sage-grouse by Taylor et al. (2012) demonstrated the importance of chick survival to population growth.

The Columbian sharp-tailed grouse (*T. phasianellus columbianus*; CSTG), one of six extant subspecies of sharp-tailed grouse found in North America (Johnsgard 1973), is endemic to shrub-steppe, grassland, mountain shrub, and riparian plant communities in western North America (Connelly et al. 1998). The subspecies currently occupies <10% of its historical range and has been petitioned twice for listing under the Endangered Species Act (U.S. Department of Interior 2000, 2006). Declines in CSTG populations have been attributed to habitat loss resulting from conversion of native habitats to cropland, overgrazing by livestock, shrub control, altered fire regimes, invasion of exotic plants, and urban and rural development (Hoffman and Thomas 2007). Until recently, energy development affected <1% of occupied CSTG range (Hoffman and Thomas 2007) and the only research related to effects of energy development on CSTG pertained to coal mine reclamation (Collins 2004). Recent expansion of wind energy development into occupied CSTG range, combined with recent projections for wind energy growth, suggests a better understanding of the relationship between wind energy development and CSTG ecology is needed (Hoffman et al. 2015).

We investigated the effects of wind energy development on CSTG brood success and chick survival in restored grassland habitats of eastern Idaho. We hypothesized that brood success and chick survival would be lower in habitats with higher wind turbine density and/or road density because similar impacts have been documented for sage-grouse in the vicinity of wind developments (LeBeau et al. 2014). We also explored additional hypotheses related to female age, hatch date, precipitation, and habitat composition and structure.

STUDY AREA

Our study area was located in Bonneville County, Idaho, USA approximately 10 km east of the city of Idaho Falls. Land ownership included Bureau of Land Management (BLM), Bureau of Reclamation (BOR), Idaho Department of Lands (IDL), Idaho Department of Fish and Game (IDFG), and private lands. The four wind energy facilities located within the study area, included: 1) Wolverine Creek Wind Farm, a 64-megawatt (MW) facility consisting of 43, 1.5 MW turbines (completed in 2005); 2) Goshen North Wind Farm, a 64 MW facility consisting of 83, 1.5 MW turbines (completed in 2010); 3) Horse Butte Wind Farm (Phase 1), a 60 MW facility consisting of 32, 1.8 MW turbines (completed in 2012); and 4) Meadow Creek Wind Farm, a 120 MW facility consisting of 57, 2.1 MW turbines (completed in 2012). Additional wind facility infrastructure included gravel access roads, maintenance buildings, electrical substations, and a small number of overhead transmission lines (most lines were buried). The wind energy facilities within our study area were developed on leased portions of private agricultural lands, and excluding turbine pads and associated infrastructure, lands within the turbine complexes were actively farmed or enrolled in the Conservation Reserve Program (CRP) at the time of our study. The IDFG documented 39 active CSTG leks within the study area in 2013 (IDFG, unpublished data).

The landscape in our study area is characterized by bench lands intersected by steep-sloped canyons. Elevations ranged from 1,500 m in the Willow Creek drainage to 2,200 m near Mt. Baldy. The two most commonly occurring soils are Ririe silt loam and Torriorthents-rock outcrop complex (Web Soil Survey 2016). Privately-owned bench lands were primarily used for agriculture or were enrolled in CRP. On Tex Creek

Wildlife Management Area (TCWMA), a 14,000-ha big game winter range managed by IDFG and situated roughly in the center of the study area, historically-farmed bench lands have been converted to perennial vegetation, and are similar in composition and structure to CRP fields. Common native vegetation across the study area included big sagebrush (*Artemisia tridentata spp*), antelope bitterbrush (*Purshia tridentata*), rabbitbrush (*Chrysothamnus spp),* serviceberry (*Amelanchier spp*), snowberry (*Symphoricarpos spp),* aspen (*Populus tremuloides*), and willow (*Salix spp*). Vegetation commonly occurring in CRP fields and TCWMA fields included smooth brome (*Bromus inermis*), intermediate wheatgrass (*Thinopyrum intermedium*), crested wheatgrass (*Agropyron cristatum*), bluebunch wheatgrass (*Pseudoroegneria spicata*), big bluegrass (*Poa secunda*), basin wild rye (*Leymus cinereus*), cheatgrass (*B. tectorum*), alfalfa (*Medicago sativa*), yellow sweet clover (*Melilotus officinalis),* sanfoin (*Onobrychis viciifolia* Scop.), small burnet (*Saguisorba minor*), blue flax (*Linum lewisii*), and yarrow (*Achillea millefolium*). The regional climate is classified as continental with a mean annual precipitation of 30.8 cm and average temperatures ranging from 0.2 C to 14.8 C (Western Regional Climate Center 2016).

METHODS

Capture and Monitoring

We captured female CSTG during March-May of 2014 and 2015 using walk-in traps with drift fences (Schroeder and Braun 1991). We selected 11 leks for capture, seven of which were used in both years of the study. The 11 capture leks locations ranged from 0.1-13.8 km from wind turbines. We selected leks based on size (count of

≥10 birds the previous year) and proximity to turbines to maximize capture efficiency and disperse our sample of radio-marked females evenly along the 14 km gradient from wind turbines. Once captured, females were aged (adult vs. yearling) based on shape and wear of outer primaries (Ammann 1944), weighed to the nearest 5g, banded with uniquely numbered aluminum leg bands, fitted with a 9-g (<1.5% of body mass), necklace-style radio-transmitter equipped with a mortality switch (Model RI-2D, Holohil Systems, Ltd.,Carp, ON, Canada) and released at the capture site immediately after processing. Our animal capture and handling protocols were approved by the Utah State University Institutional Animal Care and Use Committee (Protocol #2286).

We monitored radio-marked females from the ground 2-3 times per week, beginning in late April, using portable telemetry receivers and handheld Yagi antennas. When a female was found in the same location on consecutive visits she was presumed to have begun incubation. Using telemetry, we verified the nest location and flushed the female from the nest to obtain a clutch count. After recording nest locations with a Garmin eTrex handheld global positioning system (GPS; Garmin International, Inc., Olathe, KS, USA), we monitored nests 2-3 times per week by telemetry from a distance of >50 m. We monitored nests from a GPS point rather than using visual markers and only approached nests on the initial inspection and to determine nest fate when telemetry indicated the female had left the nest. At the final nest inspection, we recorded the number of hatched and unhatched eggs for all successful nests.

We monitored females with broods by telemetry 2-3 days per week between the hours of 0700 and 1000, homing to within 30 meters and taking care to not flush or disturb females or chicks. At 14 days post-hatch, we approached the brood female to check for presence of a brood (i.e., ≥1 chick alive) by either observing or hearing chicks. Once brood status had been documented, we immediately left the area to minimize disturbance to the brood. We continued to monitor brood females and record locations until 42 days post-hatch. At 42 days post-hatch we again verified brood status and conducted chick counts using 1-2 trained pointing or flushing dogs, following protocols outlined by Dahlgren et al. (2010). If no chicks were found with the female during the flush count, we repeated the protocol within 2-3 days, in the event that chicks were separated from the female and went undetected on the initial attempt.

Model Development and Analyses

We evaluated the influence of habitat composition on CSTG brood success and chick survival at two macrohabitat scales. To facilitate analyses, while considering habitat changes (primarily CRP field conversions) between years, we developed year-specific, land-cover type layers of the study area within a geographic information system (GIS; ArcGIS 10.3, ESRI, Redlands, CA, USA). We used 2013 and 2015 National Agriculture Imagery Program (NAIP) imagery to manually digitize land cover types within 5 km of capture leks. We expanded the GIS map, where necessary, to incorporate nest and brood locations that extended further than 5 km from capture leks. When land cover identification from NAIP imagery was uncertain, we used field observations to verify land cover types. We incorporated roads using U.S. government open source road data layers (U.S. General Services Administration 2015) and manually digitized roads from NAIP imagery where road layers were incomplete. We incorporated wind turbine locations from a 2014 U.S. Geological Survey onshore wind turbine location data layer (U.S. Geological Survey 2015).

We further categorized restored grasslands (primarily CRP and TCWMA fields) with on-the-ground visual assessments of dominant grass type and forb canopy cover. We chose to conduct simple, field-based classifications rather than use seeding records because seeding records may not have accurately represented the vegetation composition of fields at the time of our study (particularly in the case of older CRP plantings that included rhizomatous grasses). For each unique patch within restored grassland habitats, we classified the dominant grass type into one of the following categories: bunchgrass, rhizomatous grass (smooth brome or intermediate wheatgrass), and crested wheatgrass. These grass categories were used to test hypotheses related to the effects of grass structure on CSTG brood success and chick survival and were representative of grass types commonly found in CRP in Idaho. Next, we visually estimated forb canopy cover within each patch. To account for potential error due to visual estimation, we categorized forb cover estimates for each patch in to one of five bins: <2%, 2%-10%, 11%-20%, 21%-30%, and >30% cover. We manually digitized each unique habitat patch within the restored grassland habitat type using hand drawn polygons from field maps for reference. We attributed each polygon with forb cover estimates using the mean value of the previously assigned bin (e.g., 11%-20% = 15%).

We used three measures of offspring survival in our analyses: early brood success, late brood success, and chick survival. We defined early brood success as ≥1 chick surviving through 14 days post-hatch and late brood success as ≥1 chick surviving to 42 days post-hatch. To assess chick survival, we first examined egg shell remains during our nest fate assessments to determine the number chicks hatched per successful nest. At 42 days post-hatch, we conducted brood flush counts with trained dogs to determine the number of surviving chicks for each female that nested successfully (i.e., ≥1 hatched egg). We then subtracted the number of surviving chicks for each successfully-nesting female from the number of hatched eggs in her nest to determine the number of chicks per successful nest that did not survive. Dog flush counts are an effective method for accurately determining brood size and provide a cost-effective option for assessing productivity and recruitment (Dahlgren et al. 2010). They also provide a potentially improved alternative to standard measures of brood success (e.g., ≥1 chick surviving) that do not assess population recruitment.

We developed a suite of *a priori* variables to explain variation in survival of CSTG broods and chicks (Table 3-1). Previous studies of prairie grouse ecology have documented the influence of weather variables on brood and chick survival (Goddard and Dawson 2009, Guttery et al. 2013). Therefore, we modeled precipitation in the 10 days prior to hatch, with the hypothesis that precipitation in this interval would positively affect success/survival by increasing food availability and abundance for chicks (Flanders-Wanner et al. 2004, Goddard and Dawson 2009). We also considered precipitation in the 7 days following hatch because wet weather during the first week of life, when chicks are unable to thermoregulate, may negatively affect chick survival (Mendenhall and Milne 1995, Goddard and Dawson 2009). Daily weather data were obtained from the Bureau of Reclamation (BOR) Rire Dam weather station that lies within the study area (BOR 2016). We also developed variables to assess the influence of habitat composition (vegetation features within restored grasslands), anthropogenic features (roads and wind turbines), and agriculture on CSTG offspring survival. Finally, we modeled two additional variables known to influence offspring survival in grouse: 1) within-season hatch date and 2) brood-rearing female age (e.g., Guttery et al. 2013, Dahlgren et al. 2016).

We assessed the influence of vegetation, anthropogenic features, and agriculture on CSTG offspring survival at two biologically relevant spatial scales. Factors hypothesized to influence early brood success were assessed at a 284-ha scale because 90% of broods in this study used locations within 950 m of the nest during the first 14 days post-hatch. Factors hypothesized to influence late brood success were assessed at a 1,385 ha scale because 90% of broods in this study used locations within 2,100 m of the nest during the first 42 days post-hatch. We assessed individual chick survival using measurements of habitat variables at both spatial scales. We assessed offspring survival at spatial scales related to the nest location because selection of nesting habitat may be based on its qualities as brood rearing habitat (Gibson et al. 2016).

We modeled early and late brood success using logistic regression in R (Version 3.1.1, www.r-project.org) and chick survival with mixed-effects logistic regression in R package lme4 (Bates et al. 2014). We included "brood" as a random intercept effect in all chick survival models to account for non-independence of individual chicks. To avoid multicollinearity, we did not include correlated variables ($r \geq 0.65$) in any single model. We employed a multi-step, information-theoretic approach (Burnham and Anderson 2002) to evaluate candidate models describing brood success and chick survival. First, we compared a model for variation between study years to an intercept-only model. If the "year" model performed ≥2.0 AIC_c units better than an intercept-only model, we included year as a fixed-effect in all models. Next, we evaluated models consisting of either a single *a priori* variable or *a priori* variables combined with the fixed-effect of year. We considered models to have support when they performed ≥2.0 AIC_c units better than a more parsimonious intercept-only or year model. We then constructed and compared multivariate additive models using variables from supported *a priori* models. We considered all models within 2.0 AIC_c units of the top model to have some support for explaining variation in brood success or chick survival. To assess the influence of wind energy development, we then added a wind energy variable (turbine density) to each supported model to determine if the addition of this variable improved model performance (*sensu* Dinsmore et al. 2002, Webb et al. 2012).

RESULTS

We monitored 68 broods during 2014-2015 (2014 = 31, 2015 = 37). The average number of chicks hatched was 10.7 (SD = 1.8, n = 51) for first nests and 7.4 (SD = 1.9, n = 13) for re-nests. We censored two broods that moved to inaccessible private lands. We censored nine broods from 14- and 42-day brood survival analyses because the brood females were killed in the first 14 days post-hatch. We censored three additional broods from our 42-day brood survival analysis due to brood female mortalities or radio-collar failures between 14 and 42 days post-hatch. In 2014, 84% of broods survived to day 14 (n = 25) and 60% of broods survived to day 42 (n = 25). In 2015, 59% of broods survived to day 14 (n = 32) and 45% of broods survived to day 42 (n = 29). We included 529 chicks from 54 nests in our chick survival analysis. Ninety-one chicks (17%) survived to 42 days post-hatch.

The top model for 14-day brood success included year and precipitation occurring in days 0-7 post hatch (Table 3-2). We did not find support for an effect of wind turbine density on 14-day brood success. The model combining precipitation in the 10 days preceding hatch with turbine density fell within 2.0 AIC_c units of the top model but did not outperform more parsimonious models. Additionally, the univariate wind turbine density model performed worse than an intercept-only model.

The top model for 42-day brood success combined hatch day and turbine density but confidence intervals on the turbine density coefficient estimate overlapped zero. The univariate turbine density model performed worse than the intercept-only model. We did not find support for an effect of wind turbine density on 42-day brood success. The most parsimonious model within 2.0 AIC_c units of the top model was hatch day.

The top model of 42-day chick survival combined hatch day, precipitation occurring in days 0-7 post-hatch, and turbine density at the 1,385 ha scale (Table 3-3). Confidence intervals on the coefficient estimate for the turbine density variable in this model did not overlap zero, indicating a negative effect of turbine density at the 1,395 ha scale on 42-day chick survival. This model outperformed the second best model (hatch day + post-hatch precipitation + turbine density at the 284-ha scale) by 5.8 AIC_c units.

DISCUSSION

We found no evidence that wind turbine density at our eastern Idaho study area negatively influenced early or late brood success. However, chick survival was negatively influenced by turbine density at the 1,385 ha scale. Early and late brood success in our study were influenced by precipitation and hatch day, respectively. Chick survival was best predicted by post-hatch precipitation, hatch day, and turbine density at the 1,385 ha scale. Vegetation features and agriculture were poor predictors of brood success and chick survival.

Our findings that brood success was not influenced by wind energy development are similar to those of Harrison (2015) who found no influence of a wind farm on prairie-chicken brood survival, but differ from those of LeBeau et al. (2014) who found lower sage-grouse brood survival near wind turbines. LeBeau et al. (2014) attributed decreased brood survival to a possible increase in predation following wind energy development. We included chick survival as an additional measure of offspring survival in our study. Chick survival has not previously been measured in prairie grouse-wind energy studies. We assessed chick survival because negative effects on recruitment could be masked by traditional brood success and survival measures, where success or survival is defined as ≥ 1 chick alive, particularly for species with larger clutch and brood sizes. We found chick survival to be negatively influenced by turbine density at the 1,385 ha scale, indicating an impact of wind energy development on CSTG recruitment. The probability of an individual chick surviving to 42 days decreased by 50% when there were ≥10 turbines within 2,100 m of the nest (Fig. 3-1). Although we did not determine the cause of chick mortality in our study, chick survival may have been lower with increasing turbine density if turbine access roads facilitated mammalian predation on chicks. Manzer and Hannon (2008) found mammals to be the primary predators of radio-marked sharp-tailed grouse chicks in the first 30 days post-hatch.

Lower offspring survival may have been expected if habitat features know to influence brood ecology were of poorer quality in the vicinity of wind turbines. Good brood habitats allow chicks to move easily through vegetation, provide protection from predators and adverse weather, and provide adequate food resources (Bergerud and Gratson 1998). Columbian sharp-tailed grouse broods are known to select habitats with higher grass and forb cover than random sites (Apa 1998, Boisvert 2002, Collins 2004) and may experience decreased fitness in less diverse vegetative cover types (Boisvert 2002, Gillette 2014). We assessed the influence of vegetation attributes typically found in CSTG habitats in our study area for two reasons: 1) to account for potential differences in habitat quality between locations with and without turbines, and 2) to determine vegetation attributes important to CSTG offspring fitness in the context of CRP and other restored grassland habitats. We found no relationships between offspring survival and the vegetation attributes we characterized.

Forb cover and associated insects likely benefit grouse chicks by providing the nutritional requirements necessary soon after hatch (Kirsch 1974, Horak and Applegate 1998). We modeled forb cover as a functional group and did not collect data at the plant species level. We may have failed to detect an influence of forb cover on offspring survival if particular forb species provide better habitat for either CSTG chicks or the insects they forage on. Grass functional groups hypothesized to influence chick movement, concealment, or thermal cover were also not influential to offspring survival.

Similar to Goddard and Dawson (2009) and Guttery et al. (2013), we found weather and temporal variables to be the best predictors of offspring survival. Pre-hatch weather conditions can influence chick survival by positively influencing food and cover resources (Erikstad 1985), but cool, wet post-hatch conditions may negatively influence chick survival during the first week of life when chicks are unable to thermoregulate. We found weak support for an increase in early brood success and 42-day chick survival with increasing precipitation in the first seven days after hatch (Table 3-4). These results are contrary to those of Goddard and Dawson (2009) who documented increased sharp-tailed grouse chick survival in northern British Columbia with inclement pre-hatch weather and decreased chick survival with inclement post-hatch weather. Our weather variables included only precipitation, whereas variables used by Goddard and Dawson (2009) included precipitation and temperature, possibly explaining the differences in results.

Latitudinal variation in temperature and precipitation patterns between northern British Columbia and eastern Idaho may also explain the difference in results. Eastern Idaho experiences hot, dry summers with most spring-summer precipitation occurring prior to hatch. Post-hatch precipitation in eastern Idaho may stimulate forb and insect production necessary for CSTG hatchling survival without negatively affecting thermoregulation.

Hatch date was also an important predictor of offspring survival. Both late brood success and 42-day chick survival were associated with nests hatching earlier in the season, contrary to results from Goddard and Dawson (2009) for sharp-tailed grouse in British Columbia. Decreased offspring survival later in the season has been documented in prairie-chickens (Fields et al. 2006, Matthews et al. 2011) and may be attributable to declining female condition as the season progresses (Thogmartin and Johnson 1999), heat stress and water loss (Fields et al. 2006), or decreased food availability as suggested by Matthews et al. (2011). Columbian sharp-tailed grouse chicks in eastern Idaho may benefit from early hatches because of detrimental effects of decreased moisture and increased temperature as the breeding season progresses.

MANAGEMENT IMPLICATIONS

Our study is the first to examine the influence of wind energy development on CSTG brood success and chick survival. Our results suggest that increasing wind turbine density at the breeding season home range (1385 ha) scale negatively affected chick survival. The current Western Association of Fish and Wildlife Agencies (WAFWA) guidelines for the management of CSTG populations and their habitats recommend a stipulation for no surface occupancy (NSO) of energy developments within 2 km of occupied leks. Our models suggest that increasing wind turbine density within 2.1 km of nests may negatively affect chick survival. Most nests in our study were located within 2.7 km of the lek of capture, suggesting wind energy development within 4.8 km of occupied leks could negatively impact CSTG recruitment. The low chick survival we observed across both years of this study (17%) is concerning. Longer-term research is needed to truly understand the relationship between CSTG recruitment, weather variation, wind energy, and habitat. We recommend that future research in energy-developed habitats consider relationships between CSTG chick predators and habitat fragmentation to better identify the mechanisms influencing chick survival. We also recommend plantings and management actions that will result in diverse vegetation cover for chicks and residual grass cover that may facilitate earlier hatch dates.

LITERATURE CITED

American Wind Energy Association [AWEA]. 2016. DOE Wind Vision, <http://www.awea.org>. Accessed 13 Jan 2017.

Ammann, G. A. 1944. Determining the age of pinnated and sharp-tailed grouse. Journal of Wildlife Management 8:170-171.

Apa, A. D. 1998. Habitat use and movements of sympatric sage and Columbian sharp-tailed grouse in southeastern Idaho. Dissertation, University of Idaho, Moscow, USA.

Bates, D, M. Maechler, B. Bolker, and S. Walker. 2014. lme4: Linder mixed-effects models using Eigen and S4. R package version 1.1-10, http://CRAN.R-project.org/package=lme4.

Bergerud, A. T., and M. W. Gratson. 1988. Survival and breeding strategies of grouse. Pages 473-577 *in* A. T. Bergerud and M. W. Gratson, editors. Adaptive strategies and population ecology of northern grouse, volume II: theory and synthesis. University of Minnesota Press, Minneapolis, USA.

Boisvert, J. H. 2002. Ecology of Columbian sharp-tailed grouse associated with Conservation Reserve Program and reclaimed surface mine lands in northwestern Colorado. Thesis, University of Idaho, Moscow, USA.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. Second addition. Springer-Verlag, New York, New York, USA.

Collins, C. P. 2004. Ecology of Columbian sharp-tailed grouse breeding in coal mine mine reclamation and native upland cover types in northwestern Colorado. Thesis, University of Idaho, Moscow, USA.

Connelly, J. W., M. W. Gratson, and K. P. Reese. 1998. Sharp-tailed Grouse (*Tympanachus phasianellus*). *In:* A. Poole and F. Gill, editors. The Birds of North America, Number 354. The Birds of North America, Inc., Philadelphia, PA.

Dahlgren, D. K., T. A. Messmer, E. T. Thacker, and M. R. Guttery. 2010. Evaluation of brood detection techniques: recommendations for estimating greater sage-grouse productivity. Western North American Naturalist 70:233-237.

Dahlgren, D. K., M. R. Guttery, T. A. Messmer, R. D. Elmore, R. Chi, D. Caudill, and D. N. Koons. 2016. An Evaluation of Vital-Rate Contributions to the Dynamics of a Robust Greater Sage-Grouse Population. Ecosphere 7:e01249. DOI: 10.1002/ecs.2.1249.

Dinsmore, S. J., C. G. White, and F. L. Knopf. 2002. Advanced techniques for modeling avian nest survival. Ecology 83:3476-3488.

Erikstad, K. E. 1985. Growth and survival of willow grouse chicks in relation to home range size, brood movements, and habitat selection. Ornis Scandinavica 16:181-190.

Fields, T. L., G. C. White, W. C. Gilbert, and R. D. Rodgers. 2006. Nest and brood survival of lesser prairie-chickens in west-central Kansas. Journal of Wildlife Management 70:931-938.

Flanders-Wanner, B. L., White, G. C., and L. L. McDaniel. 2004. Weather and prairie grouse: dealing with effects beyond our control. Wildlife Society Bulletin 32:22-34.

Gibson, D., E. J. Blomberg, M. T. Atamian, and J. S. Sedinger. 2016. Nesting habitat selection influences nest and early offspring survival in Greater Sage-Grouse. The Condor 118:689-702.

Gillette, G. L. 2014. Ecology of Columbian sharp-tailed grouse in southern Idaho: evaluating infrared technology, the Conservation Reserve Program, statistical population reconstruction, and the olfactory concealment theory. Dissertation. University of Idaho, Moscow, USA.

Goddard, A. D., and R. D. Dawson. 2009. Factors influencing the survival of neonate sharp-tailed grouse *Tympanuchus phasianellus*. Wildlife Biology 15:60-67.

Guttery, M. R. et al. 2013. Effects of landscape scale environmental variation on greater sage-grouse chick survival. PLoS ONE 8:e65582.

Harrison, J. O. 2015. Assessment of disturbance effects of an existing wind energy facility on greater prairie-chicken (*Tympanuchus cupido pinnatus*) breeding season ecology in the sandhills of Nebraska. Thesis, University of Nebraska, Lincoln, USA.

Hoffman, R. W., and A. E. Thomas. 2007. Columbian sharp-tailed grouse: a technical conservation assessment. USDA Forest Service, Rocky Mountain Region. <http://www.fs.fed.us/r2/projects/scp/assessments/columbiansharptailedgrouse.pdf>. Accessed 1 Oct 2015.

Hoffman, R. W., K. A. Griffen, J. M. Knetter, M. A. Schroeder, A. D. Apa, J. D. Robinson, S. P. Espinosa, T. J. Christiansen, R. D. Northrup, D.A. Budeau, and M. J. Chutter. 2015. Guidelines for the management of Columbian sharp-tailed grouse populations and their habitats. Sage and Columbian Sharp-tailed Grouse Technical Committee, Western Association of Fish and Wildlife Agencies, Cheyenne, Wyoming, USA.

Horak, G. J., and R. D. Applegate. 1998. Greater prairie chicken management. <http://www.emporia.edu/ksn/v451-sept1998/index.html>. Accessed 9 Jan 2017.

Johnsgard, P. A. 1973. Grouse and quails of North America. Universityof Nebraska Press, Lincoln, NE.

Kirsch, L. M. 1974. Habitat management considerations for prairie chickens. Wildlife Society Bulletin 2:124-129.

Kuvlesky, W. P., L. A. Brennan, M. L. Morrison, K. K. Boydston, B. M. Ballard and F. C. Bryant. 2007. Wind energy development and wildlife challenges and opportunities. Journal of Wildlife Management 71:2487-2498.

Lebeau, C. W., J. L. Beck, G. D. Johnson, and M. J. Holloran. 2014. Short-term impacts of wind energy development on greater sage-grouse fitness. Journal of Wildlife Management 78:522-530.

Lopez, A., B. Roberts, D. Heimiller, N. Blair, and G. Porro. 2012. U.S. renewable energy technical potentials: A GIS-based analysis. NREL/TP- 6A20-5946. Golden, CO: National Renewable Energy Laboratory.

Manzer D. L., and S. J. Hannon. 2008. Survival of sharp-tailed grouse *Tympanuchus phasianellus* chicks and hens in a fragmented landscape. Wildlife Biology 14:16-25.

Matthews, T. W., A. J. Tyre, J. S. Taylor, J. J. Lusk, and L. A. Powell. 2011. Habitat selection and brood survival of greater prairie-chickens, in B. K. Sandercock, K. Martin, and G. Segelbacher, eds., Ecology, conservation, and management of grouse, pp. 179-191. Studies in Avian Biology (no. 39). University of California Press, Berkeley, CA.

Mendenhall, V. M. and H. Milne. 1985. Factors affecting duckling survival of eiders *Somateria mollissima* in northeast Scotland. Ibis 127:148-158.

Schroeder, M. A., and C. E. Braun. 1991. Walk-in traps for capturing greater prairie chickens on leks. Journal of Ornithology 62:378-385.

Storch. 2007. Conservation status of grouse worldwide: an update. Wildlife Biology 13:5-12

Taylor, R. L., B. L. Walker, D. E. Naugle, and L. S. Mills. 2012. Managing multiple vital rates to maximize greater sage-grouse population growth. Journal of Wildlife Management 76: 336-347.

Thogmartin, W. E., and J. E. Johnson. 1999. Reproduction in a declining population of Wild Turkeys in Arkansas. Journal of Wildlife Management 63:1281-1290.

U.S Department of Interior. 2000. Endangered and threatened wildlife and plants; 12-month finding for a petition to list the Columbian sharp-tailed grouse as threatened. Federal Register 65:60391-60396.

U.S Department of Interior. 2006. Endangered and threatened wildlife and plants; 90-day finding on a petition to list the Columbian sharp-tailed grouse as threatened or endangered. Federal Register 71:67318-67325.

U.S. Geological Survey. 2015. <https://pubs.usgs.gov/ds/817/>. Accessed 10 Jan 2015.

U.S. General Services Administration. 2015. <https://catalog.data.gov/dataset/tiger-roads-2014>. Accessed 7 Aug 2015.

Web Soil Survey. 2016. <http://websoilsurvey.nrcs.usda.gov>. Accessed 1 Sept 2016.

Western Regional Climate Center. 2016. <http:// www.wrcc.dri.edu>. Accessed 1 Sept 2016.

Webb, S. L., C. V. Olson, M. R. Dzialak, S. M. Harju, J. B. Winstead, and D. Lockman. 2012. Landscape features and weather influence nest survival of a ground-nesting bird of conservation concern, the greater sage-grouse, in human-altered environments. Ecological Processes 1:4.

TABLES AND FIGURES

Table 3-1. Variables used to model survival of Columbian sharp-tailed grouse (*Tympanuchus phasianellus columbianus*) broods and chicks in eastern Idaho, 2014-2015

Covariate	**Description**
Year	Study year (2014 or 2015)
Hatch_day	Hatch day
Hen_age	Age of brood rearing hen (adult or immature)
Prev_precip	Cumulative precipitation 10 days prior to hatch
Post_precip	Cumulative precipitation days 0-7 post-hatch
Bunch	Restored grassland dominated by bunchgrass (ha)
Rhizo	Restored grassland dominated by smooth brome or intermediate wheatgrass (ha)
Crest	Restored grassland dominated by crested wheatgrass (ha)
Forb >30	Restored grassland with >30 percent forb cover (ha)
Forb <2	Restored grassland with <2 percent forb cover (ha)
Ag	Amount of agriculture (ha)
Roads	Road density (ha)
Turb_284	Number of turbines in 284 ha buffer surrounding hatched nest
Turb_1385	Number of turbines in 1385 ha buffer surrounding hatched nest

Table 3-2. Model selection results[a] for logistic regression models describing brood success of Columbian sharp-tailed grouse (*Tympanuchus phasianellus columbianus*) in eastern Idaho 2014-2015.

Model[b]	***K***	**AIC$_c$**	**ΔAIC$_c$**	***w***
14 day brood success				
Year + Post_precip	3	67.2	0.0	0.20
Year + Pre_precip	3	67.4	0.3	0.18
Year + Post_precip + Pre_precip	4	68.5	1.3	0.11
Year + Pre_precip + Turb_284	4	68.8	1.6	0.09
Year + Post_precip + Turb_284	4	69.3	2.1	0.07
Year + Pre_precip + Turb_1385	4	69.4	2.2	0.07
Year	2	69.4	2.3	0.06
Year + Post_precip + Turb_1385	4	69.5	2.3	0.06
Year + Pre_precip + Post_precip + Turb_284	5	70.2	3.0	0.04
Year + Pre_precip + Post_precip + Turb_1385	5	70.7	3.5	0.03
Year + Turb_284	3	71.5	4.4	0.02
Intercept-only	1	71.5	4.4	0.02
Year + Turb_1385	3	71.7	4.5	0.02
Turb_284	2	73.6	6.4	0.01
Turb_1385	2	73.7	6.5	0.01
42 day brood success				
Hatch_day + Turb_1385	3	74.2	0.0	0.34
Hatch_day	2	74.8	0.6	0.25
Hatch_day + Turb_284	3	75.1	1.0	0.21
Intercept-only	1	76.9	2.7	0.09
Turb_1385	2	77.5	3.3	0.06
Turb_284	2	78.2	4.1	0.04

[a] *K* = number of parameters, AIC$_c$ = Akaike's Information Criterion with second-order bias correction, ΔAIC$_c$ = difference between model of interest and most explanatory model with second-order bias correction, *w* = Akaike weight.

[b] Post_precip = precipitation occurring days 0-7 post-hatch, Pre_precip = precipitation occurring 10 days prior to hatch, Hatch_day = within season hatch day (based on date of first hatched nest for entire study period), Turb_284 = turbine density at 284-ha scale, Turb_1385 = turbine density at 1385-ha scale.

Table 3-3. Model selection results[a] for logistic regression models describing chick survival of Columbian sharp-tailed grouse (*Tympanuchus phasianellus columbianus*) in eastern Idaho, 2014-2015.

Model[b]	***K***	**AIC$_c$**	**ΔAIC$_c$**	***w***
Hatch_day + Post_precip + Turb_1385	5	414.4	0.0	0.64
Hatch_day + Post_precip + Roads_1385	5	417.2	2.8	0.26
Hatch_day + Post_precip + Turb_284	5	420.2	5.8	0.06
Hatch_day + Post_precip	4	421.6	7.2	0.03
Turb_1385	3	436.4	22.0	0.00
Roads_1385	3	437.0	22.6	0.00
Intercept-only	2	441.2	26.9	0.00
Turb_284	3	442.1	27.7	0.00

[a] *K* = number of parameters, AIC$_c$ = Akaike's Information Criterion with second-order bias correction, ΔAIC$_c$ = difference between model of interest and most explanatory model with second-order bias correction, *w* = Akaike weight.

[b] Post_precip = precipitation occurring days 0-7 post-hatch, Hatch_day = within season hatch day (based on date of first hatched nest for entire study period), Turb_284 = turbine density at 284 ha scale, Turb_1385 = turbine density at 1385 ha scale, Roads_1385 = road density at the 1385 ha scale.

Table 3-4. Coefficient estimates (β) and standard errors (SE) for variables from the best models describing Columbian sharp-tailed grouse (*Tympanuchus phasianellus columbianus*) brood success and chick survival in eastern Idaho, 2014-2015

Covariate	**B**	**SE**
14 day brood success		
Year (2015)	-1.708	0.693
Post_precip	2.630	1.429
42 day brood success		
Hatch_day	-0.047	0.024
42 day chick survival		
Hatch_day	-0.073	0.021
Post_precip	1.485	0.796
Turb_1385	-0.076	0.025

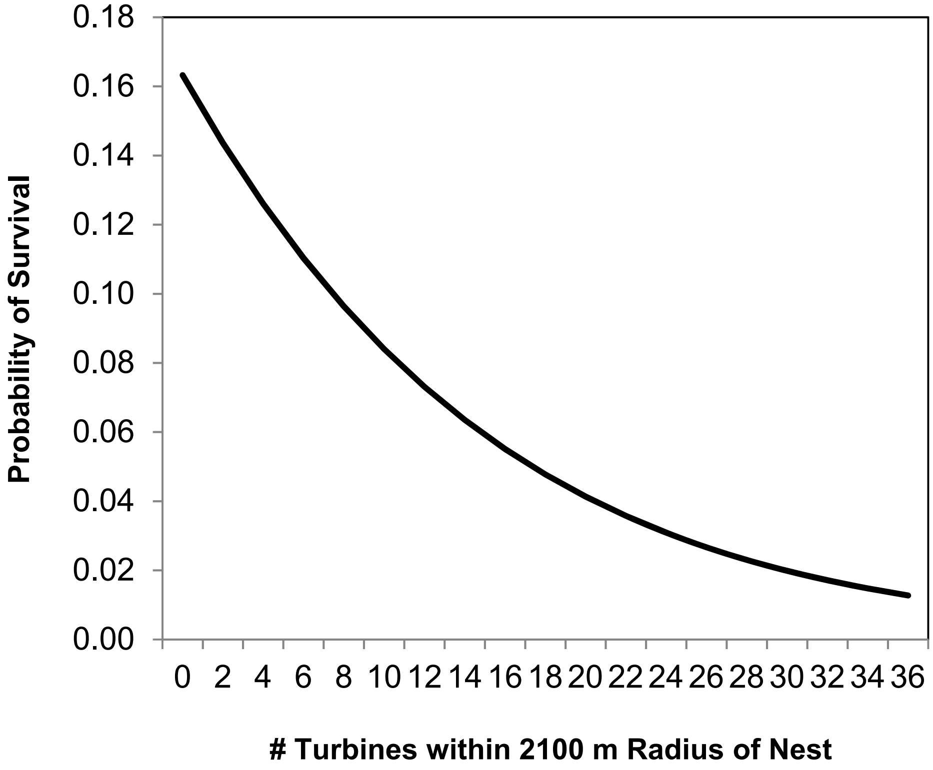

Figure 3-1. Relationship between the probability of survival and wind turbine density at the 1,385 ha scale for Columbian sharp-tailed grouse chicks (*n* = 529) in eastern Idaho, 2014-2015.

CHAPTER 4

CONCLUSIONS

The Columbian sharp-tailed grouse (*Tympanuchus phasianellus columbianus*; CSTG), one of six extant subspecies of sharp-tailed grouse in North America, has been petitioned twice for listing under the Endangered Species Act (U.S Department of Interior 2002, 2006). Population declines are primarily attributed to anthropogenic activities that have resulted in loss, degradation, and fragmentation of native habitats (Hoffman et al. 2015). Despite rulings that the subspecies did not warrant listing, CSTG remain a bird of conservation concern throughout their range, and several agencies have prepared conservation, management, and recovery plans for CSTG. The Idaho Department of Fish and Game (IDFG) management plan for CSTG identifies human development, including wind energy development, among the many threats to the species (IDFG 2015). Increasing demands for clean, renewable energy have resulted in rapid expansion of wind energy development across the United States, including occupied CSTG habitats in Idaho. To assess the influence of wind energy development on CSTG, I captured and radio-marked 135 females during 2014-2015 from 11 leks 0.1-13.8 km from a wind energy development complex in eastern Idaho.

In Chapter 2, I examined the influence of wind energy infrastructure on CSTG nesting ecology using a sample of 147 nests from radio-marked females. I constructed resource selection function (RSF) models combining habitat and wind energy variables to examine the drivers of CSTG nest site selection at multiple spatial scales. I also used generalized linear models to assess the influence of habitat and wind energy variables on daily nest survival at multiple spatial scales. Female CSTG selected nest sites with higher amounts of restored grassland habitat containing >30% forb canopy cover within 60 ha of the nest (i.e., the nesting core use area) and the strength of this selection increased as the availability of this habitat type increased on the landscape (functional response). Nest survival was positively influenced by higher visual obstruction readings at the nest site and higher amounts of restored grassland habitat containing >30% forb canopy cover within the nesting core use area. I did not detect an influence of wind energy infrastructure on CSTG nest site selection or nest survival.

In Chapter 3, I examined the influence of wind energy infrastructure on CSTG offspring survival. I developed logistic regression models to assess the influence of wind turbine density, road density, habitat features, hen age, hatch date, and precipitation on early brood success (14 day), late brood success (42 day) and 42 day chick survival. The effects of turbines, roads, and habitat variables were assessed at two biologically relevant spatial scales. Early brood success was positively influenced by precipitation in the first 7 days after hatch. Late brood success was influenced by hatch date; broods that hatched earlier more successful than later hatching broods. Chick survival to 42 days post-hatch was positively influenced by post-hatch precipitation and earlier hatch dates and negatively influenced by wind turbine density at the breeding season home range scale. The probability of an individual chick surviving to 42 days decreased by 50% when there were ≥10 turbines within 2.1 km of the nest.

Results from this study provide important information regarding the management of CSTG breeding season habitats. In restored grassland habitats, I recommend plantings and management practices that will result in bunchgrass-dominated nesting habitat containing >30% forb canopy cover. Earlier hatch dates benefit CSTG chicks and may be achieved if residual nesting cover is available at the onset of the breeding season. Our models suggest that increasing wind turbine density within 2.1 km of nests may negatively affect chick survival. Most nests in our study were located within 2.7 km of the lek of capture, suggesting wind energy development within 4.8 km of occupied leks could negatively impact CSTG recruitment.

LITERATURE CITED

Hoffman, R. W., K. A. Griffen, J. M. Knetter, M. A. Schroeder, A. D. Apa, J. D. Robinson, S. P. Espinosa, T. J. Christiansen, R. D. Northrup, D.A. Budeau, and M. J. Chutter. 2015. Guidelines for the management of Columbian sharp-tailed grouse populations and their habitats. Sage and Columbian Sharp-tailed Grouse Technical Committee, Western Association of Fish and Wildlife Agencies, Cheyenne, Wyoming, USA.

Idaho Department of Fish and Game. 2015. Management plan for the conservation of Columbian sharp-tailed grouse in Idaho 2015-2025. Idaho Department of Fish and Game, Boise, USA.

U.S Department of Interior. 2000. Endangered and threatened wildlife and plants; 12-month finding for a petition to list the Columbian sharp-tailed grouse as threatened. Federal Register 65:60391-60396.

U.S Department of Interior. 2006. Endangered and threatened wildlife and plants; 90-day finding on a petition to list the Columbian sharp-tailed grouse as threatened or endangered. Federal Register 71:67318-67325.

APPENDIX: DOUBLE BROODING OBSERVED IN A COLUMBIAN SHARP-TAILED GROUSE (*TYMPANUCHUS PHASIANELLUS COLUMBIANUS*) IN IDAHO[3]

ABSTRACT.—Double brooding is rare in Galliformes and has only been reported twice in grouse species (subfamily Tetraoninae). To our knowledge, a grouse species producing a second brood within a single breeding season that survived >12 days has not been documented in the published literature. We report the case of a Columbian Sharp-tailed Grouse (*Tympanuchus phasianellus columbianus*) in eastern Idaho (438 340 28.3434’’ N, 1118 360 47.988’’ W) that successfully re-nested after initial brood loss and had two chicks survive to 42 days post-hatch during the 2015 breeding season. Early brood loss, in conjunction with favorable environmental conditions that contributed to early nest initiation and increased food availability, may have contributed to this female’s ability to produce a successful second brood.

KEY WORDS: double brooding, Idaho, renesting, Sharp-tailed Grouse, *Tympanuchus phasianellus columbianus*.

The term ‘double brooding’ is frequently used in avian ecology to describe the production of a second clutch or brood, after a successful first brood, within a single breeding season. However, it has also been used to describe the production of two successful nests during a single breeding season, regardless of brood success (Fredrickson and Hansen 1983). Double-brooding, although common in many bird

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[3] Co-authors: Shane B. Roberts and Terry Messmer

species (Martin 1987) has only been reported twice in grouse (Kirby and Smith 2005, McNew and White 2012). In both cases, second broods were produced after initial broods failed within 10 days of hatch. Kirby and Smith (2005) reported two female Red Grouse (*Lagopus lagopus scotica*) in Scotland producing second broods with chicks that were estimated to be < 12 days of age (based on primary feathers). The authors did not document survival of the chicks beyond that point. More recently, McNew and White (2012) reported a second brood in a Greater Prairie-Chicken (*Tympanuchus cupido*) in Kansas, which failed during the pre-fledgling period (first 14 days after hatch).

The Columbian Sharp-tailed Grouse (*T. phasianellus columbianus*), one of six extant subspecies of sharp-tailed grouse in North America (Johnsgard 1973), is a ground-nesting species ranging from south-central British Columbia to northwest Colorado (Hoffman and Thomas 2007). Columbian Sharp-tailed Grouse may re-nest after failure (reported re-nesting rates range from 24–80%) and may re-nest multiple times within a season (Hoffman and Thomas 2007). However, there is no published documentation of a female successfully re-nesting and rearing a brood after her initial brood failed. We report the case of a Columbian Sharp-tailed Grouse radio-marked in eastern Idaho that re-nested after her initial brood failed within 3 days of hatch, and successfully raised two chicks to 42 days of age.

METHODS

We used walk-in traps to capture 65 female Columbian Sharp-tailed Grouse from nine leks between 25 March and 21 April 2015 as part of a comprehensive study evaluating the influence of habitat composition and anthropogenic development on sharp-tailed grouse ecology in Bonneville, County, Idaho (Schroeder and Braun 1991). Each captured female was aged, weighed, and fitted with a 9 g necklace-style radio-transmitter (Model RI-2D, Holohil Systems Ltd., Carp, ON, Canada). We monitored radio-marked females by homing with handheld VHF receivers and Yagi antennas 2–3 days per week from late April through August. We flushed females from nests to obtain an egg count when telemetry locations indicated incubation had begun. Nests were monitored 2–3 days per week using telemetry from .50 m until hatch or failure. Broods were located 2–3 days per week (without flushing) by homing from .30 m. We checked for brood survival at 14 days post-hatch (based on seeing or hearing chicks with the female) and again at 42 days post-hatch using trained bird dogs to locate chicks (Dahlgren et al. 2010).

OBSERVATIONS

On 10 April 2015, we captured and fitted an adult female Columbian Sharp-tailed Grouse (mass = 730 g) with a uniquely numbered aluminum leg band (#246) and radio-transmitter. We located the female 2–3 times per week beginning in late April. On 5 May, when consecutive telemetry locations indicated she had initiated incubation, we flushed the female from a nest with 12 eggs that was located 1.7 km from the lek where she was captured. We used telemetry to monitor the nesting female 2–3 days per week throughout the incubation period. On 1 June, when telemetry indicated the female had left the nest, we approached the nest and visually inspected the remains. We confirmed a minimum of seven hatched eggs in the nest by examining eggshell remains (Rearden 1951). Immediately following nest inspection, we homed to the female's location ~50 m from the nest. On 3 June, we located the female 770 m from her previous location. As we attempted to home in on the female, she flushed and continued flying, suggesting brood failure. We continued monitoring the hen without flushing until 14 days post-hatch. On 16 June, when we approached the female to check for chicks, we found her incubating a new nest of seven eggs. The distance between her first and second nests was 104 m. We continued to remotely monitor (>50 m from nest) the female until 10 July, when her location indicated she had left the nest. When we inspected the nest we found four hatched eggs, shell fragments, and signs of physical disturbance suggesting post-hatch scavenging. We re-located the female 168 m from the hatched second nest. On 13 July, we incidentally observed the female and she displayed aggressive behavior toward the observer, suggesting she was brooding chicks. On 24 July, we approached the female to document 14-day brood survival and observed three chicks with the female. We conducted a flush count using a trained pointing dog on 21 August to document 42-day brood survival. We flushed two chicks within 5 m of the female. We conducted a thorough search of the surrounding area and found no other chicks or adult birds within 100 m of the female's flush location.

DISCUSSION

Double brooding is a life-history strategy that may increase an individual's annual and lifetime productivity (Geupel and DeSante 1990, Holmes et al. 1992, Stearns 1992). The reproductive efforts of a female Columbian Sharp-tailed Grouse in eastern Idaho resulted in a second brood that survived to at least 42 days post-hatch, a point at which chicks could survive without parental care (Goddard and Dawson 2009). To our knowledge, this is the first published case of a Columbian Sharp-tailed Grouse re-nesting and producing a brood after her first brood failed, and the first published case of a grouse species successfully rearing a second brood after failure of an initial brood. Although we did not visually observe the first brood, our telemetry locations verify the female was incubating her initial nest for a minimum of 24 days, consistent with the incubation period of sharp-tailed grouse which has been reported as 21– 26 days (Connelly et al. 1998, Boisvert 2002), and egg shell remains indicated that at least seven chicks successfully hatched. We documented the female incubating a second nest 13 days after we suspected failure of her first brood. Columbian Sharp-tailed Grouse can start to lay eggs 1–3 days after copulation and lay eggs at a rate of 1–2 eggs/day (Connelly et al. 1998). Sufficient time had elapsed between our observations of brood failure and re-nesting for the female to copulate and lay a clutch of 7 eggs. Double brooding may be influenced by a variety of factors including length of breeding season (Monroe et al. 2008), variation in food availability (Moore and Morris 2005, Nagy and Holmes 2005), female age (Geupel and DeSante 1990, Holmes et al. 1992, Mulvihill et al. 2009), brood mortality rates (McNew and White 2012), and parental care (Blancher and Robertson 1982). Double brooding is rare in North American gallinaceous birds (Gates 1966, Dumke and Pils 1979, Keegan and Crawford 1993, Pope and Crawford 2001, Sandercock et al. 2008) and has only been documented once in a North American grouse species (McNew and White 2012). McNew and White (2012) suggested that double-brooding is likely rare in Greater Prairie-Chickens because of the duration of uniparental care required for both incubation and brood rearing. Columbian Sharp-tailed Grouse have incubation and brood rearing requirements similar to Greater Prairie-Chickens. Of the 18 radio-marked females we monitored between 2014 and 2015 which lost their first broods during the pre-fledging period, only one re-nested and produced a second brood. McNew and White (2012) proposed that double brooding in Greater Prairie-Chickens may be more common in the Flint Hills since the breeding season there is long, and brood mortality is high. We lack data to suggest that Columbian Sharp-tailed Grouse in eastern Idaho experience a long breeding season relative to other portions of their range, but warm, early spring temperatures in 2015 may have accelerated nest initiation. The female in our study also experienced early brood failure (<3 days post-hatch), increasing the time available for her to find a mate and produce a second nest and brood. Early nest failure increases the likelihood of re-nesting in Greater Sage-Grouse, *Centrocercus urophasianus* (Schroeder 1997) and Lesser Prairie-Chickens, *Tympanuchus pallidicinctus* (Pitman et al. 2006); similar mechanisms may have contributed to our observation. McNew and White (2012) also observed double brooding only after early brood failure (<2 days post-hatch), suggesting early brood loss may be required for double brooding to occur in these two species. Finally, energetic benefits from increased food availability in 2015 may also have contributed to the ability of this female to produce a second nest and brood. Body condition has been linked to re-nesting rates in Greater Sage-Grouse in Nevada and Oregon (Gregg et al. 2006). In May 2015, precipitation across our study area was >200 % of average, likely resulting in increased forb and insect abundance. Double brooding in grouse has only been observed when initial broods have failed within 10 days of hatch. Breeding season length, incubation period length, and parental care requirements in grouse likely prohibit the production of two successful broods in a single season, and prior to our observation, no grouse species had been documented rearing a second brood to independence after a failed first brood. Our observation confirms the viability of Columbian Sharp-tailed Grouse attempting a second brood after initial brood failure, under optimal environmental conditions.

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LITERATURE CITED

Blancher, P. J., and R. J. Robertson. 1982. A double-brooded Eastern Kingbird. Wilson Bulletin 94:212-213.

Boisvert, J. H. 2002. Ecology of Columbian Sharp-tailed Grouse associated with Conservation Reserve Program and reclaimed surface mine lands in northwestern Colorado. Thesis. University of Idaho, Moscow.

Connelly, J. W., M. W. Gratson, and K. P. Reese. 1998. Sharp-tailed Grouse (*Tympanachus phasianellus*). *In:* A. Poole and F. Gill, editors. The Birds of North America, Number 354. The Birds of North America, Inc., Philadelphia, PA.

Dahlgren, D. K., T. A. Messmer, E. T. Thacker, and M. R. Guttery. 2010. Evaluation of brood detection techniques: recommendations for estimating greater sage-grouse productivity. Western North American Naturalist 70:233-237.

Dumke, R. T. and C. M. Pils. 1979. Renesting and dynamics of nest site selection by Wisconsin pheasants. Journal of Wildlife Management 43:705-716.

Fredrickson, L. H. and J. L. Hansen. 1983. Second broods in Wood Ducks. Journal of Wildlife Management 47:320-326.

Gates, J. M. 1966. Renesting behavior in the Ring-necked Pheasant. Wilson Bulletin 78:309-315.

Gregg, M. A., M. R. Dunbar, J. A. Crawford, and M. D. Pope. 2006. Total plasma proteinand renesting by Greater Sage-Grouse. Journal of Wildlife Management 70:472-478.

Geupel, G. R., and D. F. DeSante. 1990. Incidence and determinants of double brooding in Wrentits. Condor 92:67-75.

Goddard, A. D., and R. D. Dawson. 2009. Factors influencing the survival of neonate sharp-tailed grouse *Tympanuchus phasianellus*. Wildlife Biology 15:60-67.

Hoffman, R. W., and A. E. Thomas. 2007. Columbian sharp-tailed grouse: a technical conservation assessment. USDA Forest Service, Rocky Mountain Region. <http://www.fs.fed.us/r2/projects/scp/assessments/columbiansharptailedgrouse.pdf>.Accessed 1 Oct 2015.

Holmes, R. T., T. W. Sherry, P. P. Marra, and K. E. Petit. 1992. Multiple brooding and productivity of a Neotropical migrant, the Black-throated Blue Warbler (*Dendroica caerulescens*), in an unfragmented temperate forest. Auk 109:321-333.

Johnsgard, P. A. 1973. Grouse and quails of North America. University of Nebraska Press, Lincoln, NE.

Keegan, T. W. and J. A. Crawford. 1993. Renesting by Rio Grande Wild Turkeys after brood loss. Journal of Wildlife Management 57:801-804.

Kirby, A. D. and A. A. Smith. 2005. Evidence of re-nesting after brood loss in Red Grouse *Lagopus lagopus scoticus*. Ibis 147:221.

Martin, T. E. 1987. Food as a limit on breeding birds: A life-history perspective. Annual Review of Ecology and Systematics 18:453-487.

McNew, L. B. and W. J. White. 2012. First case of renesting after brood loss by a Greater Prairie-Chicken. Wilson Journal of Ornithology 124:185-187.

Monroe, A. P., K. K. Hallinger, R. L. Brasso, and D. A. Cristol. 2008. Occurrence and implications of double brooding in a southern population of Tree Swallows. The Condor 110:382-386.

Moore, D. J. and R. D. Morris. 1995. The production of second clutches in the Common Tern: proximate effects of timing and food supply. Waterbirds 28:458-467.

Mulvihill, R. S., S. C. Latta, and F. L. Newell. 2009. Temporal constraints on the incidence of double brooding in the Louisiana Waterthrush. Condor 111:341-348.

Nagy, L. R., and R. T. Holmes. 2005. To double-brood or not? Individual variation in the reproductive effort of Black-throated Blue Warblers (*Dendroica caerulescens*). Auk 122:902-914.

Pitman, J. C., C. A Hagen, B. E. Jamison, R. J. Robel, T. M. Loughin, and R. D. Applegate. 2006. Nesting ecology of Lesser Prairie-Chickens in sand sagebrush prairie of southwestern Kansas. The Wilson Journal of Ornithology 118:23-35.

Pope, M. D. and J. A. Crawford. 2001. Male incubation and biparental care in Mountain Quail. Condor 103:865-870.

Rearden, J. D. 1951. Identification of waterfowl nest predators. The Journal of Wildlife Management 386-395.

Sandercock, B. K., W. E. Jensen, C. K. Williams, and R. D. Applegate. 2008. Demographic sensitivity of population change in Northern Bobwhite. Journal of Wildlife Management 72:970-982.

Schroeder, M. A., and C. E. Braun. 1991. Walk-in traps for capturing greater prairie chickens on leks. Journal of Field Ornithology 62:378-385.

Schroeder, M. A. 1997. Unusually high reproductive effort by Sage Grouse in a fragmented habitat in north-central Washington. Condor 99:933-941.

Stearns, S. C. 1992. The evolution of life histories. Oxford University Press, Oxford.