AGENDA ITEM or FINAL CONTRACT REVIEW SUBMITTAL FORM

Agenda Item: Ratification of Section 368 Energy Corridor Commen

Action Requested: Board of County Commissioners' Signature

Parties to the Agreement:

Term Begins: **Term Ends:** **Grant Contract #:**

Summary:

Ratification of Section 368 Energy Corridor Comments

Fiscal Impact:

Submitted by: Lauren Hibbard **Submitter's Email Address:** lhibbard@gunnisoncounty.org

Finance Review: ○ Required ◉ Not Required

Comments:

Reviewed by: Discharge Date:

County Attorney Review: ◉ Required ○ Not Required

Comments:
ok db 10/9/19

Reveiwed by: Discharge Date: 10/9/2019 Certificate of Insurance Required

Yes ○ No ◉

County Manager Review:

Comments:

Reveiwed by: GUNCOUNTY1\mbirnie Discharge Date: 10/9/2019

◉ Consent Agenda ○ Regular Agenda ○ Worksession Time Allotted: 0

Agenda Date: 10/15/2019

Revised April 2015

September 20, 2019

Jeremy Bluma
Bureau of Land Management
jbluma@blm.gov

Reggie Woodruff
U.S. Forest Service
Reginal.woodruff@usda.gov

Re: Section 368 Energy Corridor Review, Regions 2 and 3; August 2019; Gunnison, Colorado

Sirs:

The Board of County Commissioners of Gunnison County, Colorado ("Gunnison County") has the authority to protect and promote the health, welfare and safety of the people of Gunnison County, and the authority to regulate land use planning and environmental quality and protection (including wildlife) in Gunnison County, including activities on private and federal lands. Pursuant to these authorities, the Gunnison County Commissioners have duly adopted policies and regulations including the review, approval, conditioning or denial of certain proposed activities and users of public and private land and natural resources.

It is based on that authority – and the responsibilities that authority places on Gunnison County – that Gunnison County offers these comments on the Section 368 Energy Corridor Review, Regions 2 and 3, (the "Review") relevant to Gunnison County, Colorado. These comments are explicitly the type of new and significant information requested in the notice, August 22, 2019, from the West-wide Energy Corridor Information Center.

I. AUTHORITY OF GUNNISON COUNTY

It is important to note that among the authorities relied upon by Gunnison County in making these comments are those granted to Gunnison County pursuant to Colorado Revised Statute 24-65.1-101 et seq., which include the authority "to designate areas and activities of state interest and, after such designation, [to] administer such areas and activities of state interest and promulgate guidelines for the administration thereof." (See: C.R.S. 24-65.1-101 (2)(b)). Among the areas of state interest included in that grant of authority are:

1. Areas around "key facilities" in which development may have a material effect upon the key facility or the surround community. (See: C.R.S. 24-65.1-201.) "Key facilities" include "major facilities of public utility," include "transmission lines…of electrical utilities…pipelines (of) utilities providing natural gas or other petroleum derivatives." (See: C.R.S. 24-65.1-104(7)). Among the activities of state interest included in that grant of authority is "site selection and construction of major facilities of a public utility." (See C.R.S. 24-65.1-203 (1)(f)). Gunnison County has and will continue to rely on these authorities regarding the subject proposed corridor.
2. Areas containing or having a significant impact upon, historical, natural, or archaeological resources of statewide importance and;
3. Natural hazard areas.

The proposed corridor has implications for all of those areas and activities of state interest for which Gunnison County has legal authority.

It must be noted that Gunnison County comments submitted February 23, 2018 were neither referenced nor addressed in the Review. (Those comments are attached as Appendix A.)

All of this current comment letter is the type and quality of information requested for a Regional Review.

II. GUNNISON SAGE-GROUSE

The Section 368 Energy Corridor Regional Reviews – Region 2, dated May, 2018, notes regarding Gunnison Sage-grouse ("GuSG"):

"Settlement Agreement. RFI: re-route to avoid GuSG habitat. GIS Analysis: critical habitat located within the corridor. Comment on abstract: between MP 77 to MP 86 the only way to avoid GuSG critical habitat would be to shift the corridor north. Corridor maintenance practices/results can fragment GuSG habitat. Recommend a review of all maintenance and repair practices to reduce impacts; conformance with the Gunnison Basin GuSG Conservation Agreement on Federal Lands is a mandatory part of all corridor practices in the Gunnison Basin. There is already existing energy infrastructure that has been identified as having an adverse impact on GuSG; development of the corridor would further jeopardize the vitality [of] the species." The Review further notes: "There is an opportunity to consider revising the corridor in the GMUG National Forest, including shifting the corridor between MP 77 and MP 86 to avoid GuSG critical habitat while still encompassing the existing transmission line. (2) Given the wide expanse of the critical habitat along the other areas where the corridor intersects GuSG critical habitat, alternate routes would still require siting through GuSG critical habitat. Further analysis and consultation with the USFWS to determine the presence of the GuSG and its proposed

critical habitat within the area would be required prior to authorizing development in the corridor, but further analysis is not a consideration for corridor-level planning."

There are a number of significant detrimental consequences presented for the species GuSG by the proposed corridor.

A. Preamble.

Gunnison County offers two preambles regarding GuSG –which should be read consistently with each other. The first preamble is that it is of utmost importance to remember seminal federal actions that greatly contributed to the massive and permanent elimination of unique and unrecoverable GuSG habitat in the Gunnison Basin. These federal actions included creation of the Blue Mesa Reservoir, which resulted in a loss of at least 50 linear miles of brood-rearing habitat, multiple leks and significant nesting/winter habitat. The second preamble is the fundamental disconnect between ongoing federal, state, local and private efforts to sustain and enhance the GuSG populations and habitat, and federal planning efforts and activities on the ground such as the corridor that would actually continue to jeopardize the species and its habitat. The Review neither recognizes nor reconciles these conflicts.

B. The GuSG is a formally designated "threatened species."

As the Agency knows, the GuSG has been formally designated pursuant to the Endangered Species Act as a "threatened species." That is, GuSG are a natural resource of federal, state and local importance. In the initial review process of the proposed corridor, Gunnison County knew that the designated corridor in Gunnison County (87-277) crossed a large amount of GuSG habitat, but the species was not listed at that time and Gunnison County did not yet have its scientifically based and empirically tested GuSG Habitat Prioritization Tool

("HPT") to help analyze potential impacts of the corridor on GuSG habitat. Gunnison County now has that tool and will share the tool and its application with the Agency.

C. Spatial Relationship of Corridor to GuSG Elements.

Please note the following regarding the corridor as proposed within the Gunnison Basin:

1. GuSG occupied habitat (area and linear feet/miles) crossed by the corridor in the Gunnison Basin: 26,141 acres, roughly 56 miles long.
2. GuSG Tier 1 habitat (area and lineal feet/miles) crossed by the corridor in the Gunnison Basin: 15,927 acres, 42.5 miles long.
3. Number of GuSG leks within 0.6 miles of the corridor in the Gunnison Basin: 24
4. Number of GuSG leks within 2.0 miles of the corridor in the Gunnison Basin: 30

D. The proposed corridor detrimentally impacts the unique habitat most valuable to GuSG.

A primary task of significance not adequately performed in the Review is to correlate the corridor with GuSG habitat. A necessary beginning of that task is to understand the relative values of GuSG habitat – of which "Tier 1" habitat is the least fragmented, least impacted, and most valuable of GuSG habitat available in the species' entire environment.

The definition of Tier 1 habitat as adopted by the Gunnison Basin Sage-grouse Strategic Committee is that habitat scoring 15 or higher using the following scoring characteristics.

1. Active lek = 15
2. Unknown (status) lek = 10
3. Inactive lek = 8
4. Historic lek = 1
5. Brood rearing habitat = 14 (updated from the 2018 score in 2019)

6. Nesting/summer/fall/winter habitat < 750 from brood rearing and winter habitat = 15
7. Nesting/summer/fall/winter habitat > 750 from brood rearing and winter habitat = 10
8. Areas within active leks and < 2 miles from the edge of active leks = 5
9. Areas inside the occupied habitat polygon regardless of habitat = 1

Scores can be additive. As an example, there may be nesting/summer/fall/winter habitat within an active lek polygon <750 from brood rearing and winter habitat: 15 + 15 = 30

There is also negative scoring from "impacts":

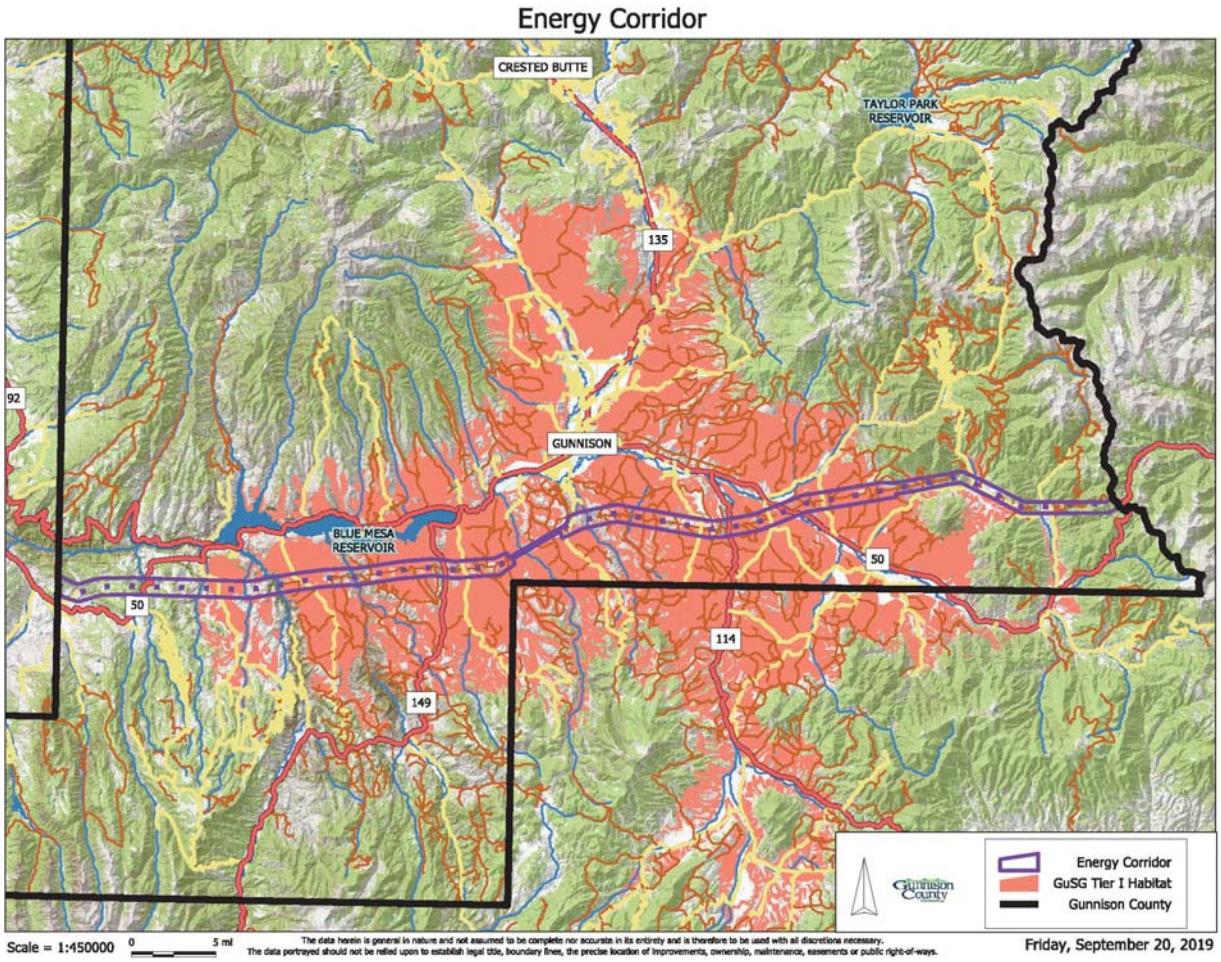
1. Areas within 300 ft of a house point (GIS location) = -5
2. Areas where there are 3 house points within 1000 ft (of each other) = -20
3. <150 ft from the centerline of an improved road = -4
4. <50 ft from the centerline of a double track = -3
5. <25 ft from the centerline of a single track (trail) = -2
6. <25 ft from the centerline of a closed route = 0
7. 0 to 820 ft from an above ground transmission powerline (WAPA) (the line that centers the Energy Corridor) = -3
8. 820 ft to 1,640 ft from an above ground transmission powerline (WAPA) (-1)
9. 4,920 ft to 6,560 ft from an above ground transmission powerline (WAPA) = 0
10. 150 ft to 450 ft from GCEA above ground distribution powerline = -1
11. <150 ft from a GCEA above ground distribution powerline = (-2)
12. Landfill boundary = -30
13. <500 ft from the landfill boundary = -30
14. UMTRA site = -30
15. Gunnison County Airport = -30

16. Large areas of open water = -30 (Blue Mesa Reservoir)

17. Large historic gravel pits = -30

It must be noted that the proposed corridor follows the route of an existing WAPA electric transmission line. An example score for a location in summer habitat, near a lek and along existing WAPA powerline with a double track road under it, would be: +15 +15 -3 -3 = 24. It would still be Tier 1 habitat unless further "impacts" were introduced.

Please see the following illustrative map:



E. <u>Gunnison Sage-grouse Habitat Prioritization Tool, 2018 Update</u>.

The document titled "Gunnison Sage-grouse Habitat Prioritization Tool, 2018 Update," attached hereto as Appendix B, provides a spatial model that can be used on the broad scale of the Review for planning and rough habitat assessment; any further consideration of projects and development would require onsite assessment on a project-by-project basis. It is important to note that this model was developed through collaborative efforts of the Gunnison Basin Sage-grouse Strategic Committee with specific guidance from Gunnison County, the U.S. Fish and Wildlife Service, the U.S. Bureau of Land Management, the U.S. Forest Service, Colorado Parks and Wildlife, the U.S. National Park Service, the Natural Resources Conservation Service, the Gunnison Conservation District, and other interested stakeholders. Of significance, Appendix B notes, on P. 9, "Power lines pose a potential risk for habitat degradation due to predation and fragmentation. There is a significant distinction between WAPA lines and Gunnison County Electric Association ("GCEA") lines. WAPA lines do have large structures, high lines, and improved road associated with them. GCEA lines are smaller primary and secondary lines that usually do not have roads associated with them." And, "Exponential decay out to about 2.5 km is more probably the direct influence of power lines. This would reflect the impact of predation on the grouse, from perching predators. (Aldridge, 2011b.)"

F. Academic Research.

Two recent and significant research papers provide additional concern regarding the corridor vis-à-vis GuSG; both papers are the type of new information requested by the Agency.

1. Kohl MT, Messmer TA, Crabb BA, Guttery MR, Dahlgren DK, Larson RT, et al. (2019) The effects of electric power lines on the breeding ecology of greater sage-grouse. PLoS One

14(1) – e 0209968. https://doi.org/10.1371/journal. pone.0209968. (Attached hereto as Appendix C.)

In greatly condensed summary, the paper concludes that anthropogenic infrastructure can negatively affect wildlife through direct mortality and/or displacement behaviors. Some tetranoids (grouse spp.) species are particularly vulnerable to tall anthropogenic structures because they evolved in ecosystems void of vertical structures. The paper recommends a hierarchical approach for avoiding and minimizing the potential impacts of power lines on sage-grouse. New transmission power lines should be placed in existing utility or transportation corridors where feasible.[1]

2. Lebeau, C., Smith K., Holloran, M., Beck, J., Kaufman, M., Johnson, G., Greater Sage-Grouse Habitat Function Relative to 230-kV Transmission Lines. The Journal of Wildlife Management 1-14; 2019; DOI: 10.1002 (Attached hereto as Appendix D.)

In greatly condensed summary, the paper concludes that the effect of transmission lines on habitat function extended 1.0 km from a transmission line in habitats within 3.1 km of an occupied lek compared to 0.50 km from a transmission line in habitats beyond 3.1 km from occupied leks. The paper suggests that future power line placement relative to GuSG nesting, brood-rearing, and summer habitats consider potential effects GuSG habitat selection and demography, and that effects can be minimized by incorporating design features that discourage avian predator perching and siting power lines on habitats with lower suitability and in habitats beyond 3.1 km from occupied leks.

[1] The initial Regional Review recognized a "de facto" pipeline corridor adjacent to State Highway 50. This was not addressed in the current Review.

G. Potential Partial Solution.

The U.S. Fish and Wildlife Service is urging local electric utilities to bury their distribution lines. Following this logic, and applying a cascading rubric of avoid, then minimize, then remediate, there ought be a requirement that – when transmission lines, other utilities and infrastructure can be located to not impact GuSG, they should be so located. When these elements must of necessity be located in the corridor, to require those components should be required to be buried.

H. Water-Body Crossings

The Section 368 Energy Corridor Regional Reviews – Region 2, dated May, 2018, notes regarding Water Body Crossings:

The proposed corridor crosses at least the following water bodies in Gunnison County:

- Tomichi Creek
- Cochetopa Creek
- South Beaver Creek
- Willow Creek
- Cebolla Creek
- Big Blue Creek

The corridor has consequences to these water bodies and their tributaries, as well as downstream impacts to the waters of the Curecanti NRA and Black Canyon of the Gunnison River.

The Review provides only the following scant analysis: "1. Projects proposed in the corridor would be reviewed during their ROW application review process and would adhere to Federal laws, regulations, and policy." And, "2. Confirm existing corridor best meets siting principles." This analysis should be performed – now – at the programmatic state – rather than deferred to a later state when fundamental decisions already have been made.

I. Stubbs Gulch

The Section 368 Energy Corridor Regional Reviews – Region 2, dated May, 2018, notes regarding Stubbs Gulch:

"There is an opportunity to shift the corridor to avoid or minimize the intersections with lands with wilderness characteristics. (2)"

Gunnison County requests the corridor be so shifted.

J. Skiff Milkvetch

The Section 368 Energy Corridor Regional Reviews – Region 2, dated May, 2018, notes regarding Skiff Milkvetch:

"Agency Input: in the Gunnison FO RMP, the South Beaver Creek ACEC was designated to protect the Skiff Milkvetch. The species occurs as small, scattered colonies throughout the ACEC and surrounding areas, which is the only place in the world this plant is known to occur. Colonies are typically on southeast to southwest exposures, although surveys from the past several years have found them on flats near existing colonies."

The Review further notes:

"The corridor width is 1,000 ft in Gunnison FO because of the presence of Skiff Milkvetch. The RMP states that ROW development is allowed throughout the ACEC provided surface disturbance does not impair or degrade colonies of the Skiff Milkvetch. Appropriate mitigation would be required on all ROWs involving surface disturbing activities. The Gunnison FO typically conducts inventories for this plant in proposed project areas and relocates new disturbances to areas where there is no Skiff Milkvetch. Inventory would be done as part of the ROW application process. (1)"

In the same manner that the corridor should be shifted to minimize intersections with lands with wilderness characteristics, it should be shifted – now – to avoid Skiff Milkvetch.

K. South Beaver Creek ACEC

The Section 368 Corridor Regional Review – Region 2, dated May 2018, notes the following regarding the South Beaver Creek ACEC, ID # 87-277:

"The Agencies must use a consistent approach that makes clear commitments to addressing intersections with ACECs and other special designations and provides details on opportunities to do so through corridor revisions." That Review continues: "The Gunnison RMP specifically allows ROWs through the South Beaver Creek ACEC 'provided surface disturbance does not impair or degrade colonies of Skiff Milkvetch' and that on-the-ground inventories are done and appropriate mitigations are applied. ROWs will be authorized on a case-by-case basis when exclusion and avoidance criteria are satisfied and protective stipulations are in place. Further analysis is not a consideration for corridor-level planning."

Gunnison County strongly disagrees that the Gunnison RMP was the appropriate analytic document – or that Gunnison RMP was the appropriate regulatory mechanism – to preapprove a

corridor up to a mile wide crossing the entire width of Gunnison County, including the South Beaver Creek ACEC. This inappropriate use of the Gunnison RMP to avoid the necessary analysis and mechanisms is logically – and legally – unsupportable.

L. Western Yellow-billed Cuckoo (ESA-listed: threatened)

The Section 368 Energy Corridor Regional Reviews – Region 2, dated May, 2018, notes regarding Western Yellow-billed Cuckoo:

"Agency Input: Western Yellow-billed Cuckoo identified by BLM CO as an issue for this corridor. Comment on abstract: unspecified number of miles through Western Yellow-billed Cuckoo proposed critical habitat."

The Review further notes:

"The corridor location within Western Yellow-billed Cuckoo proposed critical habitat is not easily resolved or avoided by corridor-level planning because alternate routes may still require siting through the proposed critical habitat. Further analysis to determine the presence of the Western Yellow-billed Cuckoo and its proposed critical habitat within the area would be required prior to authorizing development in the corridor."

Gunnison County proposes that now – not later – is the time to perform this analysis.

III. CONSERVATION EASEMENTS

Regarding non-federal lands, as specified by Section 368, the federal energy corridors would be designated only on federal land. Project proponents that would use the corridors would need to identify the preferred project – specific route across and plan for gaining access to private lands. Project applicants would need to secure access on private and non-federal lands in

the same manner that they currently obtain access on those lands (i.e. negotiation, condemnation) independent of the federal corridor designations. The Section 368 Energy Corridor Regional Reviews – Region 2, dated May, 2018, notes regarding conservation easements:

"Comment on abstract: corridor crosses private lands encumbered by conservation easements or CPW-owned properties, which are managed for wildlife, wildlife related recreation, and other recreational uses. In many instances, corridor development would be incompatible with the purpose for which those properties are managed. Recommend avoiding CPW properties for corridor alignments, otherwise close pre-planning and coordination with CPW staff would be required. In instances where an easement prohibits corridor development and avoidance of the parcel is not possible, and the exercise of Eminent Domain may result, then the lost conservation values due to corridor development must be compensated for and replaced." The Review further notes: "BLM can only authorize land uses on public land. Any gaps between public land within a new proposal would have to be coordinated with those landowners/managers. Since the corridor is centered on the existing WAPA ROW/easement, additional uses may be compatible within that footprint, depending on how the conservation easements and the WAPA easements across non-BLM managed lands are written." A number of conservation easements on private lands in the Gunnison Basin are crossed by the corridor. These conservation easements require the owner of the real property to maintain existing conservation easement values and to not place (or allow to be placed) new structures that are not compatible with the conservation easement values. Elimination by the federal government of those easements because of the identification of the corridor or activity on the corridor might, of necessity, require condemnation and compensation.

The following is an illustrative – and perhaps incomplete – identification of those existing conservation easements within or touching the corridor:

ID	NAME	TRANSDATE	Acreage in energy corriodor	LEGAL
208720...	Four-Mile Gulch	12/7/1999	169.1	498583
208720...	Four-Mile Gulch	12/7/1999	232.0	498583
208720...	Peterson Ranches	1/6/1999	204.8	490030
208720...	Peterson Ranches	1/6/1999	88.0	490030
208720...	Phelps Ranch I Upper Meadow	9/29/1998	125.4	487412,564389
208720...	Lypps	6/30/2006	273.4	566576,569082
208720...	Dallas A. Collins	9/12/2007	125.3	578716

It must be noted that, with 134 other private parcels impacted by the potential corridor, there are likely implications to future conservation easements as well. The implications of the potential corridor to existing and future conservation easements – and the loss of conservation values – requires further analysis.

IV. SOILS AND NATURAL HAZARDS

There are numerous areas along the proposed corridor that are not realistically suitable for buried energy transmission facilities (e.g. extensive rock, topographic features).

In addition, the corridor may cross some or all of the soils and natural hazards in the list below.

Alluvial land
Alluvial land, wet
Big Blue loam, 0 to 1 percent slopes
Cryolls-Cryaquolls association, 0 to 15 percent slopes
Dewville loam, 5 to 15 percent slopes
Duffson-Corpening loams, 5 to 35 percent slopes
Duffson-Spring creek stony loams, 5 to 40 percent slopes
Evanston loam, 5 to 20 percent slopes
Gas Creek sandy loam, 0 to 1 percent slopes
Gold Creek silty clay loam, 0 to 5 percent slopes
Goosepeak gravelly loam, cool, 20 to 65 percent slopes
Herbman very gravelly sandy loam, 25 to 65 percent slopes
Herbman, moist-Kismuth complex, 25 to 65 percent slopes
Irim loam, 0 to 1 percent slopes
Kezar-Cathedral gravelly sandy loams, 5 to 35 percent slopes
Kubler loam, 5 to 35 percent slopes
Lucky-Cheadle gravelly sandy loams, 5 to 45 percent slopes
Moran-Telluride-Rock outcrop complex, 5 to 40 percent slopes, extremely stony
Ohman-Perfecto complex, 25 to 65 percent slopes
Parlin-Hopkins channery loams, 5 to 45 percent slopes
Parlin-Mergel gravelly loams. 5 to 45 percent slopes
Perfecto-Ohman-Legault complex, 25 to 65 percent slopes, very bouldery
Quander, cool-Bushpark-Rock outcrop complex, 15 to 45 percent slopes
Rock outcrop
Ruby gravelly sandy loam, 5 to 30 percent slopes
Shule and sapinero loams, 10 to 50 percent slopes
Stony rock land
Storm family very cobbly sandy clay loam, 10 to 65 percent slopes
Tellura very gravelly clay loam, dry, 15 to 65 percent slopes, very bouldery
Tellura, moist-Quander complex, 5 to 25 percent slopes
Uinta and tolvar soils, 10 to 50 percent slopes
Vanwirt-Storm complex, 5 to 40 percent slopes
Vulcan gravelly sandy loam, 10 to 35 percent slopes
Water
Youman-Leaps loams, 5 to 35 percent slopes
Youman-Passar loams, 5 to 30 percent slopes

Further analysis is required of the consequences of construction, installation, maintenance and emergency responses required in those soils and natural hazard areas in the corridor.

V. WIDTH OF CORRIDOR

It appears that the width of the corridor ranges from 1,000 feet (near Hartman Rocks to avoid consequences to Skiff Milkvetch) to 5,280 feet for the remainder of the route through the Gunnison Basin.

Gunnison County requests further analysis to determine the minimum necessary width required to accomplish the functions for which the corridor is intended.

VI. OTHER.

A. There are two proposed revisions for the 87-277 Corridor (Review, P. 25):

1. Consideration of shifting the corridor south between MP5 and MP43 (south is not good for GuSG) and narrowing or shifting the corridor between MP 103 and MP 115 to avoid lands with wilderness characteristics.

2. Consideration of shifting the corridor slightly to avoid overlap with roadless areas and to avoid overlap with the active geothermal lease. Gunnison County requests that, although no specific revision has been identified, there should be further consideration of alternate routes to avoid or minimize impacts on GuSG and the species' habitat. While Gunnison County commits to work with the Agency, the onus to initiate this process is on the Agency.

B. The "minimum specifications" for "corridor management" (Review, P. 31) lacks the detail needed to administer Section 368 energy corridors effectively in terms of corridor utilization and resource protection. Again, while Gunnison County commits to work with the agency, the onus to initiate this process is on the agency.

C. Interagency Operating Procedures ("IOP's") (Review, P. 32) emphasizes "wildlife migration corridors", though it does also mention "habitat" as a "potential" new IOP. This requires significant further consideration.

D. Regarding Greater sage-grouse habitat, the Review, Exhibit, P.23 suggests consideration of re-aligning a corridor to "avoid" Greater sage-grouse habitat. If such consideration is appropriate for a species not listed under the Endangered Species Act, it ought be mandatory for a species that is listed.

E. There is no discussion of private lands specific to corridor 87-277. The Review does list a "potential corridor deletion" for Corridor 130-274 in Colorado in part to "… minimize potential impacts on conservation easements on private land to protect GuSG…" Apparently, Corridor 130-274 is an "…isolate parcel that does not promote efficient use of the landscape or maximize utility." Further review must be provided regarding conservation easements in the Gunnison Basin.

Thank you for your consideration. Again, Gunnison County makes available to the Agency, its staff.

BOARD OF COUNTY COMMISSIONERS of GUNNISON COUNTY, COLORADO by:

David Baumgarten, County Attorney of Gunnison County Colorado
200 E. Virginia Ave.
Gunnison, Colorado 81230
970.641.5300
dbaumgarten@gunnisoncounty.org

Appendix Index

Appendix A	Gunnison County Comment Letter, 2/23/2018.
Appendix B	Habit Prioritization Tool; Gunnison Sage-grouse, 2018 Update.
Appendix C	Effects of electric power lines on the breeding ecology of greater sage-grouse.
Appendix D	Greater Sage-Grouse Habitat Function Relative to 230-kV Transmission Lines.

Gunnison County
COLORADO

Gunnison County Board of County Commissioners
Phone: (970) 641–0248 • Fax: (970) 641–3061
Email: bocc@gunnisoncounty.org • www.GunnisonCounty.org

February 23, 2018

U.S. Department of Energy
U.S. Department of Interior
U.S. Forest Service

Re: West-Wide Energy Corridors Regional Review; Section 368 Stakeholder Input

Dear Agencies:

The Board of County Commissioners of the County of Gunnison, Colorado ("Gunnison County Commissioners") submit the following "Section 368 Stakeholder Input" regarding Corridor 87-277, and in particular, the "*Western Portion of Corridor 87-277*". The Gunnison County Commissioners commit to participate in this Stakeholder Input Process and Resultant Processes, and reserve their right to make further comments and to participate fully in each available component of the processes of the U.S. Department of Energy, the U.S. Department of the Interior and the U.S. Forest Service regarding these matters.

The Gunnison County Commissioners have a unique perspective that informs their comments:

A. First, the Gunnison County Commissioners have the authority to protect and promote the public health, safety and welfare of the people of Gunnison County, and the authority to regulate land use planning and environmental quality and protection (including site selection and construction of major facilities of public utilities) in Gunnison County, Colorado. Pursuant to these authorities, the Gunnison County Commissioners have duly adopted policies and regulations including the review, approval, conditioning or denial of proposed activities and uses of land and natural resources that reasonably may be implicated by the *Western Portion of Corridor 87-277*. In particular, C.R.S. § 24-65.1-101 *et seq.*, the Areas and Activities of State Interest Act ("AAASIA" or "HB 1041"), authorizes Gunnison County to designate and then regulate certain activities or areas of state interest through a permitting process established by the County. These areas include "site selection and construction of major public utility facilities", which is defined as central office buildings of telephone utilities; transmission lines, power plants, and substations of electrical activities; and pipelines and storage areas of utilities providing natural gas or other petroleum derivatives." *See* C.R.S. §24-65.1-104(8). Gunnison County has designated these matters of state interest and instituted a permitting system, which would necessarily include any such public utility facilities in Corridor 87-277 passing through Gunnison County.

200 East Virginia Avenue • Gunnison, CO 81230

Appendix A

B. Second, the Gunnison County Commissioners consistently have provided personnel, facilities and finances to implement their authorities.

C. Third, the decisions of the U.S. Department of Energy, the U.S. Department of the Interior and the U.S. Forest Service regarding the *Western Portion of Corridor 87-277* will be consequential to the citizenship and the social, economic and environmental fabric and future of the Gunnison County community, in qualities and impacts that are unique to the Gunnison County community.

For your consideration, please find the following comments regarding the *Western Portion of Corridor 87-277:*

1. Figure 1b. Page 2: The area labeled as "Chaffee County" is actually Gunnison County.

2. Figure 2b. Page 5, "Source" column: The area labeled as the "Royal Gorge Field Office" is actually within the administrative boundary of the Gunnison Field Office of BLM.

3. Table, Page 10: Poncha Springs is north of Poncha Pass. La Veta Pass is on the southeast side of the San Luis Valley. We assume you are referring to Poncha Pass not La Veta Pass.

4. Table, Page 13, "Agency Review and Analysis" column: There are no Greater sage-grouse in the Gunnison Basin (here specifically MP 77 to MP86). We assume you are referring to Gunnison sage-grouse (GuSG) critical habitat. We also note that in the area noted (MP 77 to MP 86) the only direction a corridor shift would accomplish avoidance of GuSG critical habitat would be a northward shift.

5. Table, Page 14, "Agency Review and Analysis" column: We recognize that the entire corridor within the Gunnison Basin is located within U.S. Fish and Wildlife Service's designated GuSG critical habitat. We also note that the existing transmission line within this corridor has been identified as adversely impacting GuSG. In addition to the impacts of the towers and lines themselves, corridor maintenance practices/results have been identified as fragmenting GuSG habitat. Gunnison County recommends a review of all maintenance and repair practices to reduce impacts. We also believe that conformance with the Gunnison Basin Gunnison sage-grouse Conservation Agreement on Federal Lands is a mandatory part of all corridor practices in the Gunnison Basin.

6. Table, Page 14, "Agency Review and Analysis" column: We note that the USFS GMUG National Forest is in the process of a Forest Plan Revision which may impact this corridor. Also, the BLM GuSG Draft RMP amendment is still under consideration and once finalized, may also impact this corridor. The "exclusion" of Section 368 energy corridors from ROW exclusion areas is by no means a "done deal".

7. The corridor passes directly over the historic Aberdeen quarry (granite used in State Capitol building), which is a locally designated landmark. http://gunnisoncounty.org/785/Historic-Sites#Aberdeen

8. The corridor analysis document on page 20 states that the corridor does not cross the North Branch of the Old Spanish Trail (National designated historic trail), but on page 22 the analysis document states that the corridor does cross the Trail. We believe it does cross the Trail at least 2 times in Gunnison County but not on federal land.

9. The *Western Portion of Corridor 87-277* crosses significant water bodies including Tomichi Creek and Cochetopa Creek. Particular attention is required to avoid immediate, on-site consequences to these water bodies and their tributaries, as well as downstream impacts to the waters in the Curecanti National Recreation Area and Black Canyon of the Gunnison River.

10. The "Corridor Rationale" states that "(a)ny new pipelines would likely follow along U.S. Highway 50; there is one existing gas pipeline that roughly follows U.S. Highway 50 east of Gunnison." Adoption of this rationale ought not to be assumed to be an accomplished fact without considerable evaluation of the impacts to private properties, lands subject to conservation easements, water bodies, agricultural and cultural lands adjacent to Highway 50, the Gunnison County Landfill, a Federal Uranium Mill Tailings Radiation Control Act disposal and long-term stabilization site, and the Coldharbour Institute, a community supported nonprofit that facilitates education, incubation and demonstration of responsible personal, community and land practices, located near the intersection of Highway 50 and Highway 114, where a substantial federal wetland reserve is located.

We appreciate your consideration.

Thank you.

Respectfully submitted,

THE BOARD OF COUNTY COMMISSIONERS
OF THE COUNTY OF GUNNISON, COLORADO

By: David Baumgarten
David Baumgarten,
Gunnison County Attorney

Gunnison Sage-grouse Habitat Prioritization Tool

2018 Update

Documentation

Table of Contents

page

1. Habitat Potential……3
    1.1 Habitat……3
    1.2 Impacts…… 8
2. Validation ……10
3. Scoring Reference Matrix……11
4. Mapped Acreage ……13
5. Summary of Updates……13
6. Future Update Plan……15
7. 2018 Project Update Team……16
8. 2011 Project Team……16
9. References……17
10. Acronyms ……18
Appendix I ……19

The below listed information was incorporated into a spatial model to evaluate habitat within the Gunnison Basin for Gunnison sage-grouse. The spatial model in itself can only be used on a broad scale for planning and rough habitat assessment. Projects and development will still need to be evaluated with an onsite assessment on a project-by-project basis.

This updated version of the model sought to update data and spatial layers to ensure the best, most-current science and knowledge was used in the prioritization of Gunnison sage-grouse habitat within the Gunnison Basin.

Address why this model only covers occupied critical habitat and not all critical habitat. The Habitat Prioritization Tool only addresses Gunnison Sage-grouse occupied habitat. Unoccupied habitat within USFWS designated critical habitat was not addressed because of discrepancies in soil types, necessity of significant habitat modifications to make it actually usable by GuSG, and other issues. The importance of prioritizing habitat where the species actually exists was determined to be of paramount importance.

This model has been developed through collaborative efforts of the Gunnison Basin Sage-grouse Strategic Committee with specific guidance from Gunnison County, US Fish and Wildlife Service (USFWS), Bureau of Land Management (BLM), US Forest Service (USFS), Colorado Parks and Wildlife (CPW), National Park Service (NPS), Natural Resources Conservation Service (NRCS), Gunnison Conservation District and interested stakeholders. This model incorporates the most recent information providing a representation of potential on the ground habitat conditions in the Gunnison Basin. Data included is the best information available at the time. Future updates will be essential when new and better data is available.

1. HABITAT POTENTIAL

Gunnison sage-grouse habitat potential was evaluated within the CPW Occupied Habitat boundary for the Gunnison Basin population. This mapped layer is updated frequently and this tool currently uses data from 2015 with slight modification to include areas around Blue Mesa reservoir down to the high water line. All land within the outer boundary is evaluated. This layer is slightly different than the habitat polygon delineated in the Federal Register. Potential and vacant/unknown habitats are not included in scoring because of lack of habitat and geospatial data. Vacant/Unknown habitat is apparently high quality habitat without birds. Potential habitat would require a significant amount of time, energy and resources to create to a habitat of sufficient quality that could be colonized by grouse.

This tool evaluates the habitat potential as a sum of the weighted scores assigned to each habitat layers in combination with perceived impacts (uncontrollable threats.) This score is the foundation for assigning habitat statuses (Tier 1 and Tier 2). The goal of this valuation is to decease future habitat fragmentation and to increase the ability for conservation planning. Tier 1 habitat is defined as those habitats scoring 15 or higher. Tier 2 habitats are all other habitats (<15).

1.1 HABITAT

Lek: The official lek status and high male count are defined and reported from lekking data collected and published by CPW in their annual Gunnison Basin Lek Count Summary and Population Estimate. The Official Status of a lek is given as a cumulative status and designated as Active, Historic, Inactive, or Unknown. To be Officially Active, a lek only needs to be designated as Active in the current year. A lek is not considered Officially Inactive unless it has been seasonally Inactive for five consecutive years. Thus, a lek might not have any birds for a given season, but its official status may be Unknown because the lek had not been Inactive all of the past five years. Historical lek status is not given until a lek has been Inactive for 10 consecutive years. (Jackson and Seward, 2011)

- **Geospatial Data:** This layer is the CPW lek polygon layer and includes a 0.6 mile buffer from the outside edge of the lek polygon with spatial boundaries from the 2014 unofficial update as well as the local status from 2016. Buffering the lek polygons by 0.6 miles matches up with the disturbance guidelines in the Rangewide Conservation Plan. This 0.6 mile buffer serves as a measure of protection to ensure that the entire lek polygon is captured within the buffer polygon and that potential direct or indirect impacts directly adjacent to a lek that could influence lekking behavior are evaluated.

- **Evaluation class breaks (weight) justification:** Leks are considered important habitat for the grouse. Habitat alteration on or near a lek has the potential to have a great impact to the population. There is a need to conserve all leks, regardless of the number of birds displaying on the lek. (Aldridge, 2011b; Phillips, 2011; Jackson and Seward, 2011.)
  - Active (15) *Active leks are those of greatest value to the grouse population. Birds are displaying regularly on an annual basis.*
  - Unknown (10) *These leks could have and Official Status of unknown for many reasons, including missing count data. Leks can fall into this category in a one year time frame.*
  - Inactive (8) *These leks should not be completely discounted. There is potential for the grouse to comeback and begin using these areas on a regular basis if numbers increase or surrounding habitat improves. It takes 5 years for a lek to move into this category.*
  - Historic (1) *The majority of these leks are close to high build-out densities and will probably never be able to recover to active status regularly. The lek would have been inactive for 10 years or greater.*

- **Data for support:**
  - 2015 Gunnison Basin Gunnison sage-grouse Lek Count Summary and Population Estimate Final Report (Jackson and Seward, 2015).
  - 2011 Gunnison Basin Gunnison Sage-grouse Lek Count Summary and Population Estimate Final Report (Jackson and Seward, 2011).
  - 2011. Seward, Nate. Lek Status Definitions.
  - 2011b. Aldridge, Cam. Public meeting information, December 1, 2011. Meeting to validate the priority tool model called by the Technical Subcommittee for the Gunnison Basin Strategic Committee for the Gunnison Sage-grouse.
  - 2011. Phillips, Mike. Public meeting information, December 1, 2011. Meeting to validate the priority tool model called by the Technical Subcommittee for the Gunnison Basin Strategic Committee for the Gunnison Sage-grouse.
  - *Endangered and Threatened Wildlife and Plants: Critical Habitat for Gunnison Sage-Grouse; Final Rule*, 79 Fed. Reg. 69312 (November 20, 2014)

- **Area for improvement:**
  - The Local CPW Office GuSG Annual Report definitions do not align with the RCP or current Statewide definitions for Official Lek Status as defined by Colorado Parks and Wildlife. Local CPW staff has maintained consistency in local definitions and is working to align them with the RCP and Statewide definitions.

Brood Rearing Habitat: Brood rearing habitat is defined in the Rangewide Conservation Plan (RCP). It includes mesic areas (swales, meadows, sagebrush near irrigation ditches and irrigated meadows) with lush vegetation.

- **Geospatial Data:** This layer was updated extensively in the Version 2 model. A 10m DEM slope assessment was completed to find all drainages and draws. This layer was then combined with the NHD Stream Layer and ditch layers to capture more brood rearing habitat. Using a cost analysis which incorporated slope, the group was then able to create a varied width representing the actual floodplain and thus the brood habitat. The model also incorporated the wet meadow/sagebrush interface and all Aw (alluvial) soils. Areas within lakes and irrigated areas outside the 50m of ditches were removed from the Brood layer. Lastly areas outside of nesting/summer/fall/winter habitat but within the occupied habitat boundary were removed from this layer. The modifications to this layer tried to improve upon the general 50m buffer provided for in the Gunnison Basin Local Plan by incorporating varying relief and differences in width in these floodplain areas. Some areas may be wider than 50m while other are less.

- **Evaluation class breaks (weight) justification:**
  - Present (13)

- **Data for support:**
  - The Nature Conservancy: Gunnison Basin Mesic area project prioritization model, 2017
  - Gunnison Sage-grouse Rangewide Conservation Plan
  - Gunnison Basin- Colorado. 1997. Local species management plan.
  - USFWS Federal Register Critical Habitat
  - CPW streams layer

- **Area for improvement:**
  - Removal of any brood rearing habitat from heavily treed areas, and open water.
  - There is a need to add other features including springs and seeps that are not captured in the current data layers.

Nesting/Summer/Fall/Winter Habitat: These habitats are defined in the RCP and in the Federal Register for Critical Habitat and includes sagebrush dominated areas.

- **Geospatial Data:** This data layer was compiled from NRCS soils data and includes all sagebrush dominated range sites (mountain loam, subalpine loam, mountain outwash, dry mountain loam, dry exposure and deep clay loam) and stony rock areas. *See Appendix X for soils included from each Soil Survey.* Brood and irrigated layers were removed from this layer.
- **Evaluation class breaks (weight) justification:** As we looked at the map the group decided to differentiate nesting habitats based on proximity to brood rearing habitat-- nesting habitat closer to the brood rearing habitat would receive a higher score. Sage grouse hens have to be able to move their broods from the nests to brood rearing habitat by walking. All nesting habitat is of value, but nesting habitat closer to brood rearing habitat has potential to be of higher value. All nesting habitat within 4 miles of a lek is accounted for in the model (Connelly et al 2000, Aldridge 2011b).
  - Present <750 ft from brood rearing and winter habitat (15)
  - Present >750 ft from brood rearing and winter habitat (10)

- **Data for support:**
  - Gunnison Sage-grouse Rangewide Conservation Plan; Gunnison Basin- Colorado. 1997. Local species management plan.
  - NRCS Soil Surveys—See Appendix X
  - 2011b. Aldridge, Cam. Public meeting information, December 1, 2011. Meeting to validate the priority tool model called by the Technical Subcommittee for the Gunnison Basin Strategic Committee for the Gunnison Sage-grouse.
  - Connelly et. al 2000

- 2011. Phillips, Mike. Public meeting information, December 1, 2011. Meeting to validate the priority tool model called by the Technical Subcommittee for the Gunnison Basin Strategic Committee for the Gunnison Sage-grouse.

- **Area for improvement:**
- Updated NRCS soils mapping and ecological site mapping.

- **Critical Winter Habitat:** Gunnison Sage-grouse Rangewide Conservation Plan; Gunnison Basin- Colorado. 1997. Local species management plan. This layer was not included in the HPT because defining data was not available.

- **Area for improvement::**
- There is a need to define these areas spatially, but the group does not have the tools/data necessary at this point.
-

Land Near Active Leks: Land near active leks is considered a higher priority for preservation. Leks are often in close proximity to quality nesting habitat. (Connelly et al. 2000; Aldridge et al. 2011) The Local Gunnison Sage-grouse Conservation Plan notes that these areas are priority areas used by nesting hens (1997).

- **Geospatial Data:** A two mile buffer was placed around the outer edge of the 2017 CPW lek polygon layer. Both the area within the 2 mile buffer and the lek itself were included in this layer. Irrigated areas were removed from this layer. The two mile buffer is from the Gunnison Sage-grouse Rangewide Conservation Plan (1997).

- **Evaluation class breaks (weight) justification:**
- Areas within active leks and < 2 miles from the edge of the active leks (5)

- **Data for support:**
- Connelly, J.W., M.A. Schroeder, A.R. Sands and C.E. Braun. 2000. Guidelines to manage sage grouse populations and their habitat. Wildlife Society Bulletin 28:967-985.
- Aldridge et al. 2011
- Gunnison Sage-grouse Rangewide Conservation Plan; Gunnison Basin- Colorado. 1997. Local species management plan.

Irrigated Lands: Irrigated areas greater than 50m from the sagebrush interface and outside CPW lek polygons are not considered as suitable grouse habitat.

- **Geospatial Data:** This is a spatial layer of irrigated meadows where the inside of the polygon greater than 50m from the sagebrush was scored to reduce the value of the habitat as indicated in the RCP and Federal Register. If this area happened to coincide with a lek polygon, the value was not removed (the higher score was kept). Irrigated areas within brood habitat were removed from this layer.

- **Evaluation class break (weight) justification**:
- Present (1)

- **Data for support:**
- Gunnison Sage-grouse Rangewide Conservation Plan; Gunnison Basin- Colorado. 1997. Local species management plan.

- *Endangered and Threatened Wildlife and Plants: Threatened Status for Gunnison Sage-Grouse; Final Rule*, 79 Fed. Reg. 69192 (November 20, 2014)
- 2011. Phillips, Mike. Public meeting information, December 1, 2011. Meeting to validate the priority tool model called by the Technical Subcommittee for the Gunnison Basin Strategic Committee for the Gunnison Sage-grouse.

Tree Canopies: Trees are not typically present in grouse habitat, not only do they reduce desired vegetation by the grouse, they also increase the risk of predation. This is not a specific layer in the HPT. It is somewhat defined by the forested soils layer.

1.2 Impacts

Subdivisions: Areas divided by subdivision and development have greater impacts on grouse habitat.

- **Geospatial Data:** Gunnison and Saguache County's parcel layers, as well as their 9-1-1 house point layers, have been combined to determine development potential/impact. Development was defined as home, barn, or any improvement valued at more than $30,000 on a parcel. At each house point, there was a 300 foot radius buffer added to the known structure. House points that were within 1000 ft of another two house points were then buffered by 1000 ft due to the increased impact on the grouse. (Cochran, 2011) The 300 ft buffered housing points buffer was clipped and removed from the 1000 ft buffer so that points did not receive a negative score for both the buffers. Parcel and house point data is from 2017 updates for both counties.

- **Evaluation class break (weight) justification:**
  - Areas within 300ft of a house point (-5) *Areas adjacent to houses are not suited for grouse habitation.*
  - Areas where a 3 house points are within 1000 ft (-20) *Areas where more house points are located closer together (subdivisions) will have an even greater negative impact on the grouse habitat.*

- **Data for support:**
  - Cochran, Jim. 2011. Personal communication.
  - Phillips, Mike. 2011. Personal communication.

Roads and Trails: All roads and improved trails were evaluated for their impact to the habitat from fragmentation and predator corridors. ***Use and recreation impacts from disturbance are not considered in this layer. This is a habitat impact evaluation of the roads themselves.*** Improved roads are considered all roads bigger than all season, 2-wheel drive roads. Improved roads are defined as passenger car roads, highways, and improved county roads. Double track roads are considered unimproved roads and include: admin routes, jeep trails, primitive roads, high clearance roads, private roads, and ATV routes. Single track routes are considered trails (mechanized and motorized are included). Closed routes are routes that are permanently closed (not seasonally) that have not been reclaimed.

- **Geospatial Data:** Road data from the county, CPW, BLM, NPS and USFS were used to create this layer. Data included is from 2017 and the 2010 USFS/ BLM Travel Management Plan

- **Evaluation class break (weight) justification:**
  - <150 ft from the centerline of an improved road (-4) *These roads are defined as passenger car roads, highways, and county roads.*
  - <50 ft from centerline of a double track(-3) *These roads are defined as roads with vegetation growing between the tracks and include admin routes, jeep trails, primitive roads, private roads (driveways), unmaintained roads, and ATV routes.*
  - <25 ft from that center line of a single track *(-2) These are defined as smaller disturbances that include trails, including both mechanized and motorized uses.*
  - <25 ft from that center line of a closed route *(0) These are defined as routes that are permanently closed (not seasonally) that have not been reclaimed.*

- **Data for support:**
  - Aldridge et al. 2010- Aldridge does not agree with the 150ft buffer. He feels that improved roads can impact nesting habitat up to 8km away. Double track roads can have an impact to over 6 km away. He feels that there is not a non-linear response as you move away from the road and that a regression model needs to be used to depict this.

- *2010 Gunnison Basin USFS and BLM Federal Travel Management Plan*

- **Area for improvement:**
- Winter use trails and roads should be incorporated when information is available
- Reclaimed roads and trails should be incorporated

Power Lines: Power lines pose a potential risk for habitat degradation due to predation and fragmentation. There is a significant distinction between WAPA lines and the GCEA lines. WAPA lines do have large structures, high lines, and improved roads associated with them. GCEA lines are smaller primary and secondary lines that usually do not have roads associated with them.

- **Geospatial Data:** There is a data layer available with large, above ground, WAPA transmission lines mapped.

- **Evaluation class break (weight) justification:**
- 0 to 820 ft. (0.25km) from an above-ground, transmission power line (WAPA) (-3) *These lines typically have a maintained road and taller structures associated with them.*
- 820 ft. to 1,640 ft. (0.25 to 0.5 km) from an above-ground, transmission power line (WAPA) (-2) *These lines typically have a maintained road and taller structures associated with them.*
- 1,640 ft. to 4,920 ft. (0.5 to 1.5 km) from an above-ground, transmission power line (WAPA) (-1) *These lines typically have a maintained road and taller structures associated with them.*
- 4,920 ft. to 6,560 ft. (1.5 to 2km) from an above-ground, transmission power line (WAPA) (0) *These lines typically have a maintained road and taller structures associated with them.*
- 150 ft. to 450 ft. from a GCEA above-ground, distribution power line (-1) *Are typically smaller in structure and have no maintained road that accompanies them.*
- <150 ft. from a GCEA above-ground, distribution power line (-2) *Are typically smaller in structure and have no maintained road that accompanies them.*

- **Data for support:**
- 2011. Phillips, Mike. Public meeting information, December 1, 2011. Meeting to validate the priority tool model called by the Technical Subcommittee for the Gunnison Basin Strategic Committee for the Gunnison Sage-grouse. Mike feels that an impact from power lines is for direct mortality (2 birds within the scope of his study).
- 2011b. Aldridge, Cam. Public meeting information, December 1, 2011. Meeting to validate the priority tool model called by the Technical Subcommittee for the Gunnison Basin Strategic Committee for the Gunnison Sage-grouse.
- Messmer, T. et al. 2017 Greater sage-grouse lek persistence and breeding distributions relative to electric power transmission and distribution lines

- **Area for improvement:**

- Exponential decay out to about 2.5km is more probably the direct influence of the power lines. This would reflect the impact of predation on the grouse from perching predators. (Aldridge 2011b.)

Unsuitable Habitat: There are areas within the Gunnison Basin that may have been included within CPW's occupied habitat layer that need to be removed. This layer servers to call out specific, finite areas that should not be counted as grouse habitat.

- **Geospatial Data:** The spatial information comes from aerial imagery and county parcel data.

- **Evaluation class break (weight) justification:**
  - Landfill boundary (-30) *The Gunnison County landfill does not count as grouse habitat due to the level of disturbance, lack of appropriate vegetation and/ or subsidized predation.*
  - <500 ft of the landfill boundary (-30) *This area still provides large subsidies for predators and reduces the quality of habitat to the grouse due to increased levels of predation.*
  - UMTRA site (-30) *This site is the mitigated tailing location for uranium mining that has historically occurred in the valley. Currently, the area is capped with a very thick layer of course black rock that precludes growth of vegetation. The boundary of the rock can be seen using aerial imagery and it is not grouse habitat.*
  - Gunnison County Airport (-30)
  - Large areas of open water (-30)
  - Large, historic gravel pits (-30)

- **Data for support:**

- **Area for improvement:**

2. Validation

The 2012 HPT was validated using known grouse locations by CPW. The 2018 HPT has not been validated against known grouse locations.

Model Accuracy*		
	Version 1	*Version 2*
Tier 1	87.75	
Tier 2	12.25	
Total	100.00	

**Number presented are the % of known bird locations accounted for within the tool.*

Scoring Reference Matrix

Habitat Potential	Evaluation Class	Weight
Lek (0.6 mile buffer from edge of lek polygon)	active	15
	unknown	10
	inactive	8
	historic	1
Brood Rearing Habitat within 50m of water (riparian, irrigation ditches, mt meadows, swales) and sagebrush	present	13
Nesting/Summer/ Fall/ Winter Habitat (sagebrush dominated ecological sites and stony rock lands)	< 750ft from brood rearing habitat	15
	> 750ft from brood rearing habitat	10
Land Near Active Leks (areas within 2 miles of an active lek and the lek itself)	lek and land <2 miles from active lek boundary	5
Land Near Active Leks (areas within 2 miles of an active lek and the lek itself)	lek and land <2 miles from active lek boundary	5
Irrigated Lands (irrigated land greater than 50m from sagebrush not discounting any leks in these areas)	present	1

Impacts *(This accounts for impacts on the habitat that will not likely be changed.)*	Evaluation Class	Weight
Subdivisions (areas with development at certain densities)	within 300' of development (house)	-5
Subdivisions (areas with development at certain densities)	areas with 3 housing points within 1000'	-20
Subdivisions (areas with development at certain densities) **Roads and Trails** (this accounts for the fragmentation impacts of the road/trail structure	<150ft from the centerline of improved roads	-4

and NOT the impacts associated with the recreational use) **Roads and Trails** (this accounts for the fragmentation impacts of the road/trail structure and NOT the impacts associated with the recreational use)	<50ft from the centerline of a double track roads	-3
Powerlines	<25ft from the centerline of a single track roads	-2
	<25ft from the centerline of a closed routes	-1
	0 – 820 ft from above ground transmission line (-3)	-3
	820ft – 1,640ft from above ground transmission line (-2) 1,640 – 4920 ft from above ground transmission line (-1_ 4,920 – 6,560 ft from above ground transmission line (0) 150- 450ft from above ground distribution line (-1) <150ft from above ground distribution line (-2)	-5
Unsuitable Habitat	Landfill boundary (-30)	-30
	< 500ft of the landfill boundary (-30)	-30
	UMTRA site (-30)	-30
	Gunnison County Airport (-30)	-30
	Open water (-30)	-30
	Large, historic gravel pits (-30)	-30

4. Mapped Acreage

Mapped Acreage			
		Version 1 (2012)	*Version 2 (2018)*
Lek	Active Unknown Inactive Historic		
	Brood Rearing Habitat		
	Nesting/Summer/ Fall Habitat		
	Winter Habitat		Included with Nesting/Fall
	Critical Winter Habitat	Not Evaluated	
	Land Near Active Leks		
	Irrigated Lands		
Subdivisions	< 300' of a development 3 housing points within 1000' <70 acres and developed		
Roads and Trails	<150' from improved road <50' from double-track <25' from single-track <25' from closed route		
Power Lines	<450' from GCEA line <450' from WAPA line		

6. Summary of Updates

In order to maintain the usefulness and improve the accuracy of this tool, occasional updates will be needed. It is proposed that this tool be reviewed and adjusted according to new science and spatial information. Reviews should coincide with CPW's species review for the Gunnison sage-grouse or at the request of the Gunnison sage-grouse Strategic Committee.

The major changes to the HPT are:

- Reduced the **buffer to proximity of Brood Rearing** (BR) habitat to the Nesting/ Summer/ Fall (NSF) habitat and added proximity to Winter habitat. This was to capture the idea that NSF and Winter habitat in closer proximity to brood rearing/ mesic areas has higher value.

- Drastically updated the **brood rearing habitat** to capture the floodplain versus a buffered line (increased brood rearing substantially)—based on the TNC mesic area project prioritization model created by The Nature Conservancy in their Climate Resiliency Project. This update also captured small depression areas in ephemeral drainages that might not have been captured in the first tool.
- Added missing **soil layers** (like Taylor Park Soil Survey)
- Removed the **development threat to areas greater than 70 acres**. This tended to reduce the core of high quality habitat for political reasons that is not appropriate for a habitat assessment.

Updates that were not incorporated, but may provide useful in future updates:

- **Tree stands** are not consistently removed from the habitat model. Is there a better way to capture sites that have the potential to produce trees? If so, those areas should be removed.
- **Noxious weeds** and invasive species information would be very valuable to add to the tool, but due to inconsistencies in mapping across private and public lands, it is hard to incorporate into this model. Adding this layer would also tend to indicate a permanent loss or degradation of habitat that may not actually reflect new treatment and restoration technologies.
- Consider using a view shed analysis to review implications of **powerlines** on habitat. Currently there is a gradient, but topography is not weighing in to the mapping. To complete this analysis, we would need more information like tower and wire heights.

Major Questions/ Concerns:

- Have we adequately captured grouse habitat (at nearly 60% of the basin)? Can we ground truth this again like we did in the previous model with the CPW data. (Version 1 captured >80% of the bird locations.)
- Winter habitat was combined with the nesting/summer/fall habitat. Differentiation between the two habitat types was difficult and inaccurate. A new Critical Winter Habitat layer is needed in future year updates.
    - Official lek status was updated to 2016 data provided by CPW. The lek boundary layer remains the 2012 layer.
    - The occupied habitat layer collected by CPW will be updated from the 2005 data to the 2015 data.
    - All address points (indicating development and housing) will be updated to the current available data (2017).
    - Road data is current as of 2010 for BLM, USFS, County, Municipal, State and US.
    - Unofficial Taylor Park Soil Survey data was incorporated into the model.
    - Updated power line data to include GCEA local distribution lines.
    - To simplify the geospatial layers included in the model, the 2018 model will only include scored habitat and impact layers. All other layer data will be kept for future years project analysis.
    - Small sliver polygons less than 1 acre will be blended into an adjacent polygon in which it shares the largest border. Due to the model's spatial inaccuracies, the removal of these small polygons will more closely reflect the data's accuracy.
    - More information is needed to substantiate the ranking values assigned.
    - Comparative analysis of model to known grouse locations as provided by CPW and NPS needs to be done to fully understand the model's ability to capture grouse habitat suitability. Initial reviews of the original tool with on the ground assessment and preliminary data from CPW have shown good ability to capture habitat values.
    - A future update strategy needs to be created.
    - Area around Blue Mesa that was initial outside of CPW's occupied habitat layer but above the Bureau of Reclamation's high water line for the reservoir was added back in.
    - When compared to several other models that have been created specifically for the Gunnison sage-grouse, the HPT is the only one that focuses on habitat potential based upon soils and not bird tracking locations. Both Mindy Rice's (CPW) and Cam Aldridge's models (USGS) focus on resource selection which may not truly depict habitat potential, quality and distribution.

6. HPT Future Update Plan

Annual: (These updates do not require approval by the Strategic Committee unless a majority of the Committee requests review/approval of one or more of these updates. These updates will only occur if new data is available.)

House points

Lek status (including new leks identified by CPW)

Roads and trails

New roads/trails

Changed status of roads/trails (upgrades/downgrades)

Decommissioned roads/trails

Every 5 years: (These updates require recommendation by the Technical Subcommittee and approval by the full Strategic Committee. At minimum a review of the specific data/layers noted below is required by the Technical Subcommittee to determine if updates in any of these categories are necessary/appropriate.)

Lek polygons

Occupied habitat polygon

Consider any new science that may be applicable to the HPT

Continue work to refine the brood rearing habitat layer

Continue work to refine/improve the treed layer within the HPT

Changes to soil layer if needed

Reporting: The Chair of the Technical Subcommittee and/or the Gunnison County GIS Program Manager shall report to the Strategic Committee at its June meeting annually on any updates made to the HPT.

7. 2018 Project Update Team

Matt Vasquez- US Forest Service**,** *chair*
Russ Japuntich- Bureau of Land Management
Kathy Brodhead- Bureau of Land Management
Theresa Childers- National Park Service
Jim Cochran- Gunnison County
Mike Pelletier- Gunnison County
Nathan Seward- Colorado Parks and Wildlife
Brooke Vasquez- Gunnison Conservation District
Gay Austin- Bureau of Land Management
Tara DeValois- Bureau of Land Management
Liz With- Natural Resources Conservation Service
John Scott- Scott Resources Management
Brooke Vasquez- Gunnison Conservation District
Mark Brennan- USFWS
Pat Magee- Western State Colorado University
Suzie Parker- USFS
Aleshia Fremgen- Interested community member

8. 2011 Project Team

Matt Vasquez- US Forest Service
Russ Japuntich- Bureau of Land Management
Tony Apa- Colorado Parks and Wildlife
Mike Phillips- Colorado Parks and Wildlife
Theresa Childers- National Park Service
Jim Cochran- Gunnison County
Mike Pelletier- Gunnison County
Nathan Seward- Colorado Parks and Wildlife
Gay Austin- Bureau of Land Management
Tara DeValois- Bureau of Land Management
Liz With- Natural Resources Conservation Service
John Scott- Natural Resources Conservation Service
Amanda- Bureau of Land Management
Ken Stalhnecker- National Park Service
John Toolen- Bureau of Land Management
Charlie Sharp- US Fish and Wildlife Service
Susan Linear- US Fish and Wildlife Service

8. References

Colorado Division of Wildlife. *2011 Gunnison Basin Gunnison Sage-Grouse Lek Count Summary and Population Estimate Final Report*. Colorado Division of Wildlife, Gunnison basin, Colorado, USA.

Colorado Division of Wildlife. *2010 Gunnison Basin Gunnison Sage-Grouse Lek Count Summary and Population Estimate Final Report*. Colorado Division of Wildlife, Gunnison basin, Colorado, USA.

Colorado Division of Wildlife. *2009 Gunnison Basin Gunnison Sage-Grouse Lek Count Summary and Population Estimate Final Report*. Colorado Division of Wildlife, Gunnison basin, Colorado, USA.

Gunnison Sage-grouse Rangewide Steering Committee. 2005. Gunnison sage-grouse rangewide conservation plan. Colorado Division of Wildlife, Denver, Colorado, USA.

Web Soil Survey - Home. USDA Natural Resources Conservation Service. Web. 15 Nov. 2011. <http://websoilsurvey.nrcs.usda.gov/app/>.

Aldridge, Cameron L., D. Joanne Saher, Theresa M. Childers, Kenneth E. Stahlnecker, and Zachary H. Bowen. "Crucial Nesting Habitat for Gunnison Sage-Grouse: A Spatially Explicit Hierarchical Approach." *Journal of Wildlife Management*.

Rice M. etal. The importance of seasonal resource selection when managing a threatened species: targeting conservation actions within critical habitat designations for the Gunnison sage-grouse. 2017. CSIRO Publishing

9. Acronyms

BLM- Bureau of Land Management
CPW- Colorado Parks and Wildlife
CDOW- Colorado Division of Wildlife
GCEA- Gunnison County Electric Association
NPS- National Park Service
NRCS- Natural Resources Conservation Service
RCP- Gunnison Sage-grouse Rangewide Conservation Plan
USFS- US Forest Service
USFWS- US Fish and Wildlife Service
WAPA- Western Area Power Association

Appendix I: NRCS Soil Survey data

Nesting/Summer/Fall

Soil survey CO660: [MUSYM] in ("127", "138", "142")] and in NE aspects (331 to 149 degrees) in ("107", "131", "139", "153", "165", "172", "191")

Soil survey CO661: [MUSYM] in ("PeA") and in NE aspects (331 to 149 degrees) in ("BaE", "BaF", "EyF", "GoE", "JuF", "LiF", "LmF", "LuE", "LuF", "MhF", "Rl", "SmF", "SoF", "St", "SuF")

Soil survey CO662: [MUSYM] in ("BsB", "CuB", "DeB", "EvB", "EvD", "GeB", "IrB") and in NE aspects (331 to 149 degrees) in ("Ad", "BoE", "CeE", "CoE", "CrE", "DeC", "DoE", "DrE", "DsE", "EvD", "GeE", "JeE", "KcE", "KuE", "KvE", "LeE", "LhF", "MoE", "MrE", "PhF", "PmF", "PwE", "RcE", "Ro", "Rs", "RuE", "SuE", "St", "YgE", "YlE", "YpE")

Soil Survey: CO663 [MUSYM] in ("108") and in NE aspects (331 to 149 degrees) in ("105", "109", "110", "111", "119", "121", "122", "130", "131", "132", "133", "141", "142")

Winter Habitat (just the SW aspects of 150 to 330 degrees for all following soils)

Soil survey CO660: [MUSYM] in ("107", "131", "139", "153", "165", "172", "191")

Soil survey CO661: [MUSYM] in ("BaE", "BaF", "EyF", "GoE", "JuF", "LiF", "LmF", "LuE", "LuF", "MhF", "Rl", "SmF", "SoF", "St", "SuF")

Soil survey CO662: [MUSYM] in ("Ad", "BoE", "CeE", "CoE", "CrE", "DeC", "DoE", "DrE", "DsE", "EvD", "GeE", "JeE", "KcE", "KuE", "KvE", "LeE", "LhF", "MoE", "MrE", "PhF", "PmF", "PwE", "RcE", "Ro", "Rs", "RuE", "SuE", "St", "YgE", "YlE", "YpE")

Soil survey CO663: [MUSYM] in ("105", "109", "110", "111", "119", "121", "122", "130", "131", "132", "133", "141", "142")

~~Nesting/ Summer/ Fall Habitat~~

~~Soil Survey~~	~~Soil~~	-
	~~107~~	
	~~127~~	
	~~138~~	
	~~139~~	
	~~142~~	
	~~165~~	
	~~172~~	
~~CO660~~	~~191~~	
~~Grand Mesa-West Elk~~	~~153~~	~~*only NE aspects~~
	~~BaE~~	
	~~BaF~~	
~~CO661~~	~~EyF~~	

	~~GoE~~	
	~~JuF~~	~~*only S aspects~~
	~~LiF~~	
	~~LuE~~	
	~~LuF~~	
	~~MhF~~	
~~Taylor Park~~	~~SmF~~	~~*only elevations below 9,500 ft~~
	~~BeD~~	
	~~CeC~~	
	~~CoE~~	
	~~CuE~~	
	~~DeB~~	
	~~EvD~~	
	~~GeE~~	
	~~JeE~~	
	~~KvE~~	
	~~LeE~~	
	~~MoE~~	
	~~MrE~~	
	~~PwE~~	
	~~RcE~~	
	~~SuE~~	
	~~YgE~~	
	~~YlE~~	
	~~YpE~~	
	~~CrE~~	~~*only NE aspects~~
	~~DrE~~	~~*only NE aspects~~
	~~DsE~~	~~*only NE aspects~~
	~~KcE~~	~~*only NE aspects~~
	~~LhF~~	~~*only NE aspects~~
	~~PhF~~	~~*only NE aspects~~
~~CO662~~	~~PmF~~	~~*only NE aspects~~
~~Gunnison~~	~~MrE~~	~~*only NE aspects~~
	~~105~~	
	~~108~~	
	~~110~~	
	~~111~~	
	~~119~~	
	~~121~~	
	~~122~~	
	~~131~~	
~~CO663~~	~~132~~	

	~~133~~ ~~141~~ ~~142~~	
~~Cochetopa~~	~~110~~	~~*only NE aspects~~

~~Brood Rearing Habitat~~

~~Soil Survey~~	~~Soil~~	~~-~~
~~CO660 Grand Mesa-West Elk~~	~~127~~ ~~162~~	~~*50m in if adjacent to sagebrush~~
~~CO661 Taylor Park~~	~~Ad~~ ~~DnF~~ ~~PeA~~ ~~PnA~~ ~~PnE~~ ~~TnA~~	~~* only if irrigated~~ ~~-~~
~~CO662 Gunnison~~	~~Ad~~ ~~Ao~~ ~~Aw~~	~~-~~
~~CO663 Cochetopa~~	~~106~~ ~~108~~ ~~109~~	~~*only NE aspects~~

~~Wintering Habitat~~

~~Soil Survey~~	~~Soil~~	~~-~~
~~CO660 Grand Mesa-West Elk~~	~~153~~ ~~-~~	~~-~~
~~CO661 Taylor Park~~	~~none~~ ~~-~~	~~-~~

	~~CrE~~	~~*only SE to NW aspects~~
	~~DrE~~	~~*only SE to NW aspects~~
	~~DsE~~	~~*only SE to NW aspects~~
	~~KcE~~	~~*only SE to NW aspects~~
	~~LhF~~	~~*only SE to NW aspects~~
	~~PhF~~	~~*only SE to NW aspects~~
~~CO662~~	~~PmF~~	~~*only SE to NW aspects~~
~~Gunnison~~	~~MrE~~	~~*only SE to NW aspects~~
~~CO663~~	~~110~~	
~~Cochetopa~~	~~130~~	~~-~~

PLOS ONE |

RESEARCH ARTICLE

The effects of electric power lines on the breeding ecology of greater sage-grouse

Michel T. Kohl[1☯]*, Terry A. Messmer[1☯], Benjamin A. Crabb[2☯], Michael R. Guttery[1], David K. Dahlgren[1], Randy T. Larsen[3,4], Shandra N. Frey[1], Sherry Liguori[5], Rick J. Baxter[4]

1 Jack H. Berryman Institute, Department of Wildland Resources, Utah State University, Logan, Utah, United States of America, **2** Remote Sensing/GIS Laboratory, Quinney College of Natural Resources, Utah State University, Logan, Utah, United State of America, **3** Department of Plant and Wildlife Sciences, Brigham Young University, Provo, Utah, United States of America, **4** The Monte L. Bean Life Sciences Museum, Brigham Young University, Provo, Utah, United States of America, **5** Rocky Mountain Power/Pacific Power, Salt Lake City, Utah, United States of America

☯ These authors contributed equally to this work.
* michel.kohl@usu.edu

Check for updates

OPEN ACCESS

Citation: Kohl MT, Messmer TA, Crabb BA, Guttery MR, Dahlgren DK, Larsen RT, et al. (2019) The effects of electric power lines on the breeding ecology of greater sage-grouse. PLoS ONE 14(1): e0209968. https://doi.org/10.1371/journal.pone.0209968

Editor: Tim A. Mousseau, University of South Carolina, UNITED STATES

Received: February 23, 2018

Accepted: December 14, 2018

Published: January 30, 2019

Copyright: © 2019 Kohl et al. This is an open access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Data Availability Statement: Data are available through Utah State University (USU) who meet the criteria for access to confidential data. Data held by USU are restricted for ethical and legal reasons as many of the locations were collected by permission of private landowners who allowed researchers access to private lands for the purpose of the research, on condition exact locations would not be disclosed. The power line and lek data were provided under a confidentiality agreements by the Utah Division of Wildlife Resources (UDWR) and Rocky Mountain Power (RMP). Given the

Abstract

Anthropogenic infrastructure can negatively affect wildlife through direct mortality and/or displacement behaviors. Some tetranoids (grouse spp.) species are particularly vulnerable to tall anthropogenic structures because they evolved in ecosystems void of vertical structures. In western North America, electric power transmission and distribution lines (power lines) occur in sagebrush (*Artemisia* spp.) landscapes within the range of the greater sage-grouse (*Centrocercus urophasianus*; sage-grouse). The U.S. Fish and Wildlife Service recommended using buffer zones near leks to mitigate the potential impacts of power lines on sage-grouse. However, recommended buffer distances are inconsistent across state and federal agencies because data are lacking. To address this, we evaluated the effects of power lines on sage-grouse breeding ecology within Utah, portions of southeastern Idaho, and southwestern Wyoming from 1998–2013. Overall, power lines negatively affected lek trends up to a distance of 2.7 and 2.8 km, respectively. Power lines died not affect lek persistence. Female sage-grouse avoided transmission lines during the nesting and brooding seasons at distances up to 1.1 and 0.8 km, respectively. Nest and brood success were negatively affected by transmission lines up to distances of 2.6 and 1.1 km, respectively. Distribution lines did not appear to affect sage-grouse habitat selection or reproductive fitness. Our analyses demonstrated the value of sagebrush cover in mitigating potential power line impacts. Managers can minimize the effects of new transmission power lines by placing them in existing anthropogenic corridors and/or incorporating buffers at least 2.8 km from active leks. Given the uncertainty we observed in our analyses regarding sage-grouse response to distribution lines coupled with their role in providing electric power service directly to individual consumers, we recommend that buffers for these power lines be considered on a case-by-case basis. Micrositing to avoid important habitats and habitat reclamation may reduce the potential impacts of new power line construction.

conservation status of the species and pending litigation, the Utah Division of Wildlife Resources has asked us not to release sage-grouse lek or location data. RMP has also asked us not to provide the shapefiles for the power lines we used as part of our analyses. We provide a redacted dataset that includes all covariate and response data but excludes spatial information pertaining to lek and sage-grouse locations (i.e., GPS coordinates). This would permit interested parties in rerunning our analyses and reaching the same conclusions drawn in the manuscript. If, however, researchers were interested in obtaining the raw spatial data, these can be obtained through a Government Records Access and Management Act (GRAMA) request through the UDWR. The UDWR will establish the conditions of use. Researchers wishing to replicate the study can request all of these datasets from UDWR, RMP, and USU. Data inquiries can be made through Jason Robinson, Upland Game program Coordinator, UDWR, (jasonrobinson@utah.gov), and Scott Edmisten, Environmental Analyst, RMP, (scott.edmisten@pacificorp.com). Sage-grouse spatial location requests can be made through Terry Messmer, Director of Utah Community-based Conservation Program Database, USU, (terry.messmer@usu.edu).

Funding: This work was supported by Utah Public Lands Policy Coordinating Office, Jack H. Berryman Institute, Quinney Professorship for Wildlife Conflict Management, U.S. Bureau of Land Management, Utah Division of Wildlife Resources, and Utah State University Extension. SH was employed by Rocky Mountain Power/Pacific Power, 1407 West North Temple, Salt Lake City, Utah, United States of America. The funder provided support in the form of salaries for this author [SH], but did not have any additional role in the study design, data collection and analysis, or decision to publish. The specific roles of these authors are articulated in the 'author contributions' section.

Competing interests: SH was employed by Rocky Mountain Power/Pacific Power, 1407 West North Temple, Salt Lake City, Utah, United States of America. This does not alter the authors' adherence to PLOS ONE policies on sharing data and materials.

Introduction

Over the past century, human population growth has facilitated land use changes at a global scale [1]. The infrastructure (e.g., roads, electrical lines) required to support this human population growth can negatively impact wildlife [2]. Anthropogenic structures constructed in previously unfragmented landscapes [3], can have direct and indirect effects on local wildlife populations [4–6]. For example, tall anthropogenic structures such as power lines and wind turbines can cause direct mortality due to wildlife collisions [5, 7]. Anthropogenic development may also indirectly affect wildlife populations by causing changes in animal behavior (e.g., displacement [3]), increased predation risk [8], or by creating impediments to seasonal migration [9, 10]. The magnitude and consequences of these behavioral changes are often difficult to measure due to the absence of immediate population level effects [11, 12]. As such, identifying and quantifying both the direct and indirect effects of anthropogenic structures on wildlife as well as effective measures to minimize negative impacts are essential for conserving affected wildlife populations [3, 12].

The greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) is a sagebrush (*Artemisia* spp.) obligate species that requires large, intact sagebrush systems [13]. Populations have declined nearly 50% in portions of their historic range [14]. Some of the observed declines have been attributed to the construction, operation, and maintenance of anthropogenic infrastructure such as tall structures and associated linear features (i.e., energy developments, roads and power lines) [15]. Some tetranoids, including sage-grouse, may be particularly vulnerable to tall anthropogenic structures because they evolved in landscapes void of such structures [3].

The potential incompatibility between tetranoids and anthropogenic structures led the U.S. Fish and Wildlife Service (USFWS) to identify the placement, operation, and maintenance of tall structures and associated linear features (i.e., roads and power lines) related to energy development and transmission in sagebrush habitats as a conservation threat for sage-grouse in their 2010 decision to designate the species as a candidate for protection under the Endangered Species Act of 1973 [16]. They concluded the placement of electric power lines in seasonal sage-grouse breeding habitats could impact local populations through increased predation of adults, juveniles, and nests or abandonment of suitable habitats.

The USFWS conclusion was based on research suggesting that oil and gas development can negatively influence sage-grouse lek counts, activity, survival, and habitat selection [17–21]. However, despite these and other studies (see UWIN [22]), it has been difficult to separate the combined influence of anthropogenic structures (e.g., well sites, roads) and their associated human activities from the presence of tall linear structures such as power lines [11, 23]. Furthermore, using studies of various types of energy development (i.e., oil/gas, wind) may not be comparable to power lines because of differing project footprints (polygons vs. linear) and amounts of human activity [11, 23]. For example, workers may be routinely present throughout oil fields or wind developments, yet power lines may only be visited infrequently for inspections or repairs. Power line inspection cycles vary depending on the line voltage, agency requirements, and location, but may occur as often as twice/year or as infrequent as once over five to ten years. Because power lines often occur on landscapes with other human activity, it is difficult to distinguish between potential impacts of the tall structures versus impacts related to other human activity, such as disturbance or habitat loss. In addition, isolating the effects of tall structures from other development activities on sage-grouse populations is particularly problematic if an a-priori status assessment was not completed before the structures were placed [22]. However, in the absence of experimental data, retrospective analysis of the potential effects of anthropogenic activities and their related structures on sage-grouse breeding

distributions may provide new insights to prevent, minimize, or mitigate conservation threats [11].

Given that, our current knowledge regarding the influence of power lines on sage-grouse is limited and equivocal. Historically, researchers relied on untested causal mechanisms to infer the negative effects of power lines on sage-grouse [23]. For example, Knick et al. [24] used reported foraging distances of golden eagles (*Aquila chrysaetos*) [25, 26] and common ravens (*Corvus corax*) [8, 27] to estimate that electric power transmission lines had a negative impact on 50% of all sagebrush within the range of sage-grouse [11]. More recently, intense field studies have documented a reduction in sage-grouse habitat use [28–30] and vital rates [30, 31] in areas adjacent to power lines. Together, this has led to suggestions that power lines have been a potential factor in the extirpation of sage-grouse from historical ranges [32]. It is still unclear, however, under what conditions power lines negatively affect sage-grouse. For example, sage-grouse may not avoid power lines in years of low raven abundance [30]. There may also be site-specific conditions that counteract the negative influence of power lines on sage-grouse. This was demonstrated by Westover et al. [33] who observed positive selection for transmission lines during the brooding period in Utah. These temporally dependent and site-specific conditions may explain why Johnson et al. [34] did not detect a consistent relationship between distance to power lines and leks trends across the specie's range.

This conflicting information has created a dilemma for wildlife and land managers who are attempting to develop best management practices (BMP) for power lines in sagebrush habitats. The USFWS and Avian Power Line Interaction Committee (APLIC) have recommended seasonal and spatial buffers as BMPs for power lines placed near leks in sage-grouse breeding habitats to minimize the potential for negative impacts [35, 36]. However, UWIN [20], Messmer et al. [11], and Manier et al. [37] concluded the BMP buffer zones vary widely (e.g., 0.3 to 8.0 km) because of challenges associated with interpreting the area influenced by power lines. In addition, differences between transmission and distribution lines, which serve different purposes and therefore can occur in different landscapes, and are constructed at differing heights, have not been previously assessed. Together, this lack of information, combined with the potential site-specific variation in sage-grouse response detailed above demonstrates the need for a landscape-scale evaluation of power line effects on sage-grouse.

Given this knowledge gap, the overarching purpose for our study was to provide an empirical evaluation of the effects of transmission and distribution power lines on sage-grouse breeding ecology and to identify appropriate buffer distances. Specifically, our objectives were to identify the relative effects of both transmission and distribution power lines on sage-grouse leks, seasonal habitat-use, and reproductive success. To achieve this, we analyzed Utah sage-grouse lek persistence rates, male lek counts, and radio-marked female sage-grouse breeding site selection, nest and brood success recorded from 1998–2013 in Utah, portions of southeastern Idaho, and southwestern Wyoming. These study populations represented the majority of sage-grouse populations in the study area including representation from all 13 Sage-Grouse Management Areas in Utah ($> 30{,}164$ km^2). To our knowledge, this is the first landscape-level comparison for an entire jurisdictional entity (i.e., a US sate) examining the relationship between power line classification and known sage-grouse nest and brood locations. For comparison, other large-scale field studies that have evaluated the influence of power line on sage-grouse were ~ 3,400 km^2 [28, 31] and 7,000 km^2 [30]. Within this context, we hypothesized that transmission lines would have a larger effect on sage-grouse breeding ecology than distribution lines due to their increased structure height, which may provide increased perching and nesting habitat for avian predators, and larger right-of-way (ROW) corridors [38]. Similarly, distribution lines may not affect sage-grouse to the same extent as transmission lines because they are more homogenously distributed across the landscape, thus mitigating

avoidance behaviors, and because they often occur in previously disturbed areas. This information will assist state and federal conservation planners to refine conservation BMP buffer zone recommendations for new power line construction to avoid and minimize the potential effects on sage-grouse and their breeding habitats.

Materials and methods

Study area

Our study area encompassed known sage-grouse breeding habitats and distributions in Utah, portions of southeastern Idaho, and southwestern Wyoming [39]. These habitats exhibited more natural and anthropogenic fragmentation when compared to the Wyoming Basin [40, 41]. Sage-grouse populations in the northern part of our study area inhabit sagebrush-steppe, while populations in central and southern Utah primarily use sagebrush semi-desert [42]. Both are shrub-dominated sagebrush systems contrasted with an increased herbaceous component in higher latitude sagebrush-steppe systems compared to lower latitude sagebrush semi-desert. Big sagebrush (*A*. *tridentata*) varieties typically dominate most landscapes with Wyoming (*A*. *t*. *wyomingensis*), basin (*A*. *t*. *tridentata*), and mountain (*A*. *t*. *vaseyana*) big sagebrush at lower, mid, and high elevations, respectively. Shallow soils support low (*A*. *arbuscula*) and black (*A*. *nova*) sagebrush communities throughout the study area.

Sage-grouse data

The Utah Division of Wildlife Resources (UDWR) provided the 1998–2013 sage-grouse lek location and count data we used to conduct our lek persistence and lek trend analysis for the portion of the study area located in Utah (UDWR, unpublished data). We accessed the sage-grouse nest and brood location data used in our study from a geo-referenced database maintained by Utah State University (USU, unpublished data). This database contained > 17,000 sage-grouse Universal Transverse Mercator (UTM) locations recorded between 1998 and 2013 during radio-telemetry studies completed by researchers at USU and Brigham Young University (BYU) to describe sage-grouse breeding ecology [39]. This included 15 unique study areas that varied in study length (range = 2–15 years) dependent on management and conservation needs. To complete these studies, sage-grouse were captured, radio-marked with very high frequency (VHF) radio-collars, released on-site, and routinely monitored to assess vital rates and habitat-use using standard protocols [39, 43] described below. The study protocols were approved by the USU or BYU Institutional Animal Use and Care Committee (USU [2322, 2411, 2419, 2560, 1451, 2189, 942, 942R, 1194, 1404, 1332]; BYU [100302, 110301, 050301, 080402]). The UDWR approved Certificates of Registration permitting sage-grouse captures, radio-marking, and monitoring.

Sage-grouse monitoring

We monitored radio-marked hens every few days until they began to localize in an area. Upon localization, we would located the hens approximately daily to verify nest initiation, which was determined when a female was found in the same location on two consecutive visits during the breeding season. Nesting was verified by visually locating the nesting females by walking concentric circles. Actively nesting females were observed 3–5 times per week until the nest hatched or failed. A successful nest hatch was determined when egg halves were found intact in or near the nest bowl, and/or the inner membrane of the eggs was separated from the shell [44]. A failed nest was determined when no eggs or egg halves were found at the nest site, if egg halves were not intact, or if only egg fragments remained at or near the nest site [45]. We

attempted to verify nest fate by locating the marked hen and recording brooding type behavior or visually identifying chicks as soon as the nest had been vacated. A global positioning system (GPS) location was recorded at each nest after fate was determined and the female was no longer present.

After a successful hatch, we attempted to locate broods two to three times per week until the brood reached 42 days of age or until the brood failed. We tracked brooding females using radio-telemetry, and walked concentric circles around the female location until brooding behavior or chicks were observed. Upon brood confirmation, we recorded a GPS location where the female was observed. A failed brood was determined if the female flushed with one or more adult females and no chicks were seen on two consecutive location attempts.

Landscape variables

Distance to power lines. We acquired geo-referenced linear electric power distribution and transmission line (power line) locations directly from the electric utility companies PacifiCorp, Garkane Energy, Idaho Power, and Raft River Rural Electric Cooperative. These data were provided through confidentiality agreements specifically for this study. Each line in the power line database contained attributes indicating its status as a distribution line (<46 kV) or as a transmission line (> = 46 kV); in total the data represent 16,493 km of transmission lines and 20,061 km of distribution lines throughout Utah, southern Idaho, and southwestern Wyoming.

Transmission lines, which deliver electric power from the source of generation to substations, are supported by taller structures (height: 18–40 m). These lines included linear structures that were located at lower elevations and often bisected sage-grouse habitat. In contrast, distribution lines are supported by shorter structures (height: ~ 10 m) that deliver electric power to customers (e.g., homes, businesses). Distribution lines were interspersed throughout sage-grouse habitat [22]. All power lines evaluated were in service prior to 1998.

We restricted our analysis to power lines located in occupied sage-grouse habitat [39] and excluded all lines that were not within 10 km of a sage-grouse lek, nest or brood location (Fig 1). We selected this buffer distance because it accommodated the average maximum movement distances documented for sage-grouse broods from nest sites in Utah (8.45 km) [39] and the upper recommended conservation buffer zones reported in the literature for tall structures and linear features (8.0 km) [37]. Moreover, assessing data, and as such, buffers beyond 10 km is unlikely to contribute to sage-grouse conservation because most sage-grouse habitat falls within 8 km of a lek [37]. Consequently, only 10% of transmission lines and 7% of distribution lines within the study area were within 10 km of these sage-grouse use habitats. This resulted in a reduced dataset of 1,698 km and 1,496 km of electric power transmission and distribution lines, respectively (Fig 1), and a sample of 425 nests and 2,514 unique brood locations obtained from 239 broods. We then constructed distance from transmission and distribution power lines using the spatstat library [46] in R (Version 3.3.3; [47]).

Roads. Because power lines can often parallel roads, we determined the percentage of the power lines adjacent to roads using road location data obtained from the U.S. Census Bureau [48]. Most of the electric power distribution (69% and 95%) and transmission (54% and 87%) lines in our study area were located within 100 m and 500 m of a road, respectively. When we considered distribution lines within 10km of a sage-grouse location, 69% were within 100 m of a road and 95% were within 0.5 km of a road. When we considered transmission lines within 10 km of a sage-grouse location, 54% were within 100 m of a road and 87% were within 0.5 km of a road. Because over 90% of the power lines analyzed were within 0.5 km of a road and roads frequently bisected power lines, we did not have a robust sample size to isolate differences between power lines with and without roads.

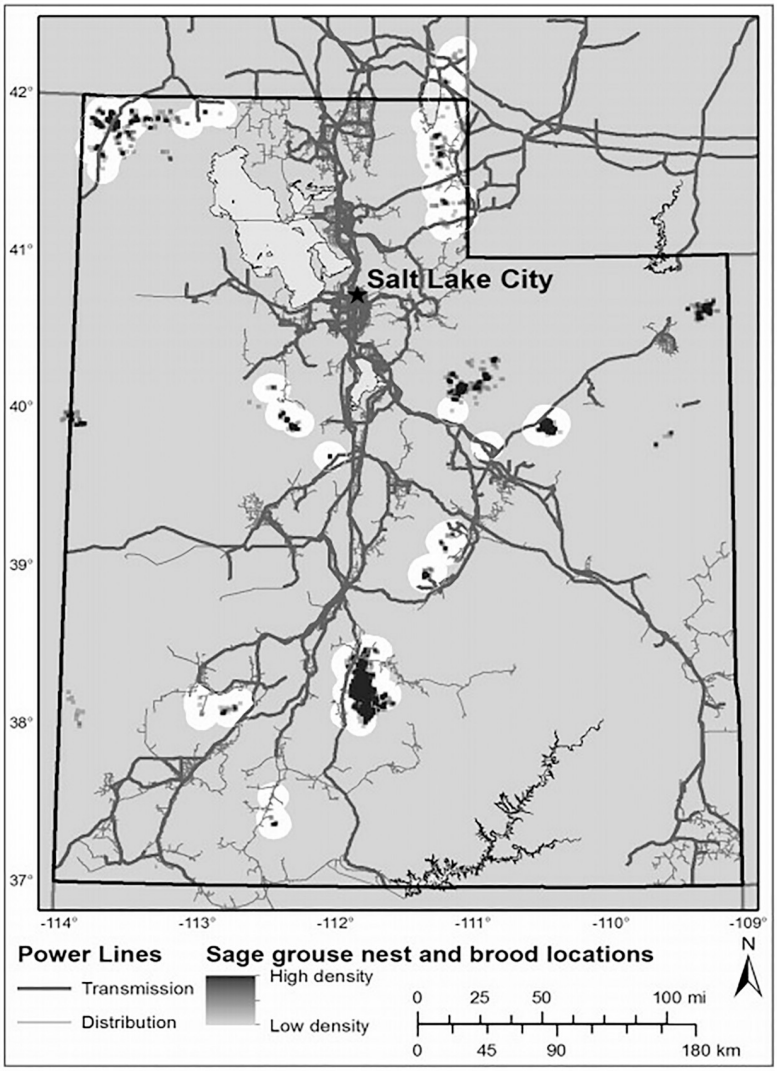


Fig 1. Electric transmission and distribution power lines relative to greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) nest and brood locations in Utah, portions of southeastern Idaho, and southwestern Wyoming, USA, 1998–2013. Highlighted areas indicate sage-grouse locations within 10 km of the power lines studied.

https://doi.org/10.1371/journal.pone.0209968.g001

Percent sagebrush cover. To assess the percent of sagebrush cover, we quantified the proportion of 30-m resolution pixels classified as any type of sagebrush within 1 km of a given pixel using the moving window analysis in ArcGIS 10.3. The 'Sagebrush' category represents the combination of nine shrubland cover types identified by LANDFIRE 1.2.0 System Group physiognomies [40] and considered suitable sage-grouse habitat [40]. These communities included; 1) Colorado Plateau, 2) Mixed Low Sagebrush Shrubland, 3) Wyoming Basins Dwarf Sagebrush Shrubland and Steppe, 4) Great Basin Xeric Mixed Sagebrush Shrubland, 5) Inter-Mountain Basins Big Sagebrush Shrubland, 6) Columbia Plateau Low Sagebrush Steppe, 7) Inter-Mountain Basins Big Sagebrush Steppe, 8) Inter-Mountain Basins Montane Sagebrush Steppe, 9) Inter-Mountain Basins Semi-Desert Shrub-Steppe, and 10) *A. tridentata* ssp. *vaseyana* Shrubland Alliance.

Elevation. Because broods have been shown to move up in elevation as the season progresses ([39]), we included a measure of elevation in our analyses. This data (30 x 30 m) was obtained from the National Elevation Dataset administered by the U.S. Geological Survey (https://www.usgs.gov/core-science-systems/ngp/3dep).

Data analysis

We tested for the influence of power lines on lek trends, lek persistence, nest and brood site selection, and nest and brood success. For each analysis, we developed a linear model that tested the relationship between distance to power lines and the response metric of interest (e.g., lek trend). We then compared this model to a null model to establish whether a power line effect existed. We next added measures of sagebrush cover, elevation, and distance to roads as covariates of interest to assess whether these covariates improved model fit. Lastly, we tested for an interactive effect between distance to power lines and our measure of sagebrush cover because previous work has identified this as a potential driver of sage-grouse habitat selection and vital rates [30]. Due to model complexity, we did not assess other interactions. In total this produced 13 model sets (Table 1).

Next we tested for a threshold effect of distance to power lines on the response metric of interests (e.g., lek trend). Within this context, we hypothesized that if distance from a power line affected sage-grouse, the effects would be magnified for sage-grouse that were located closer to power lines [11, 24, 37]. Thus, to explicitly evaluate the distance at which sage-grouse response to power lines changed, we tested for a response threshold by comparing the aforementioned model combinations (Table 1) to models with a threshold effect specified by two piecewise linear splines. Piecewise splines consist of a continuous covariate (e.g., distance to power line) defined over specified segments (e.g., $>$ and $<$ 2.0 km) and a response variable (e.g., lek trend) that is a continuous function of the covariate over all segments but with different slopes in each of the segments. To determine the presence and placement of thresholds, we performed a grid search of candidate models that included the sequential placement of a threshold every 0.1 km from 0.1–9.9 km. To minimize outlier effects that may bias threshold locations, we limited the threshold location such that it fell within the 5% and 95% quantiles of data for each analysis. This resulted in between 85 and 92 grid search candidate models depending on the analysis.

We tested for the additive (percent sagebrush cover, elevation, and distance to roads) and interactive effects (power lines x percent sagebrush cover) on each response metric of interest as described above. This produced 12 additional model sets which we evaluated (Table 1). Due to convergence issues, we were not able to assess the importance of additional covariates (i.e., percent sagebrush cover, distance to roads, elevation) for lek persistence and lek trends. Across all model sets (n = 24; Table 1), we selected the model with the lowest Akaike Information Criterion corrected for small sample sizes (AICc; [49]) score as our best fitting model. However, if a threshold model demonstrated equal support (ΔAICc $\leq$ 2.0) as being the best-fit model to either a null or linear model, we also highlighted this information in our results because this directly addressed our primary interest in identifying any response thresholds relative to power lines.

If a threshold model was identified as the best-fitting model, we then identified uncertainty (i.e., 95% confidence intervals) around the placement of each threshold. For general linear models (GLM), we used the 'confint.segemented' command within the segmented library in R. This approach was used for the lek trend and lek persistence analyses. Because the segmented library did not accommodate the use of generalized linear mixed models (GLMM), we identified uncertainty around a threshold GLMM as any threshold model that fell within ΔAICc of

Table 1. Model combinations used to evaluate the influence of power lines on sage-grouse (*Centrocercus urophasianus*) habitat selection and vital rates.

Model Sets		Lek Trend	Lek Persistence	Nest Selection	Brood Selection	Nest Success	Brood Success
Null Model							
	Null	✓	✓	✓	✓	✓	✓
Linear Models							
	DistTL	✓	✓	✓	✓	✓	✓
	DistTL + Sage			✓	✓	✓	✓
	DistTL + Elev			✓	✓	✓	✓
	DistTL + Rd			✓	✓	✓	✓
	DistTL + Sage + Elev			✓	✓	✓	✓
	DistTL + Sage + Rd			✓	✓	✓	✓
	DistTL + Elev + Rd			✓	✓	✓	✓
	DistTL + Sage + Elev + Rd			✓	✓	✓	✓
	DistTL * Sage			✓	✓	✓	✓
	DistTL * Sage + Elev			✓	✓	✓	✓
	DistTL * Sage + Rd			✓	✓	✓	✓
	DistTL * Sage + Elev + Rd			✓	✓	✓	✓
Nonlinear Models							
	DistT1 + DistT2	✓	✓	✓	✓	✓	✓
	DistT1 + DistT2 + Sage			✓	✓	✓	✓
	DistT1 + DistT2 + Elev			✓	✓	✓	✓
	DistT1 + DistT2 + Rd			✓	✓	✓	✓
	DistT1 + DistT2 + Sage + Elev			✓	✓	✓	✓
	DistT1 + DistT2 + Sage + Rd			✓	✓	✓	✓
	DistT1 + DistT2 + Elev + Rd			✓	✓	✓	✓
	DistT1 + DistT2 + Sage + Elev + Rd			✓	✓	✓	✓
	DistT1 * Sage + DistT2 * Sage			✓	✓	✓	✓
	DistT1 * Sage + DistT2 * Sage + Elev			✓	✓	✓	✓
	DistT1 * Sage + DistT2 * Sage + Rd			✓	✓	✓	✓
	DistT1 * Sage + DistT2 * Sage + Elev + Rd			✓	✓	✓	✓

* Sage represents our percent sagebrush cover covariate, Elev represents an elevation covariate, and Rd represents a distance to any road covariate.
Check marks identify whether a model set was evaluated for a given response metric.

https://doi.org/10.1371/journal.pone.0209968.t001

2.0 of the best-fit threshold model [50]. This uncertainty approach was applied to the nest selection, brood selection, nest success, brood success analyses.

Although piecewise linear splines are useful for identifying thresholds, the segmenting of data leads to reduced sample sizes for a given spline. This contributes to a lack of statistical significance due to the reliance of p-values on sample size [51]. As such, we ignored arbitrary significance thresholds (e.g., p-value ≤ 0.05) in our interpretation of power line effects [52, 53], and rather, focused our interpretation on the marginal response of sage-grouse to power lines (i.e., slope of the relationship). As such, we do not provide measures of significance (i.e., p-values) in our model outputs, but rather present only information on confidence intervals for each model coefficient.

Preponderance of evidence approach. Many of our analyses consisted of small sample sizes, which when combined with likely population differences in habitat selection and vital rates across study sites, likely contributed to increased model uncertainty regarding the influence of power lines on our response variables of interest. Thus, we evaluated each response

metric individually within the results section, and then used a proponderance of evidence approach [54] to assess whether our landscape scale analyses was suggestive of a power line effect. More specifically, we evaluated the relationship between distance to power lines and our response metric for each analyses using the best-fit model. Then, in our weight of evidence approach, we examined additional models sets that had equal support as the best-fit model ($\leq$ ΔAICc of 2.0) to assess whether a threshold effect may exist. For example, if a linear model was the best-fit model (ΔAICc of 0.0) but a piecewise spline model was within ΔAICc of 2.0, we interpreted the result as having potential support for a threshold effect, and then examined whether or not that potential support existed across analyses. This interpretation was based on the marginal response coefficients for the spline prior and after the threshold for the best-fitting nonlinear model. If a model coefficient was positive prior to the threshold, we interpreted that as support for a negative power line effect at distances close to the power line.

Lek trends

We employed a 2-stage analytic approach to assess the impact of distance to power lines on sage-grouse lek trend. In the first stage we estimated the overall count trend for each lek. In the second stage we treated the estimated trends as our response variable and modeled them as a function of distance to the nearest power line using both a continuous linear effect as well as piece-wise linear trends to determine if the magnitude or direction of the effect changed at some distance.

Statewide, 379 leks were monitored in $\geq$ 1 year between 1998 and 2013. However, to obtain reliable lek trend estimates we only analyzed data from leks that were monitored in $\geq$ 12 years, thereby reducing the total number of leks retained for analysis to 172 leks. The temporal trend for each lek was estimated using a Negative Binomial generalized additive model (GAM) to model the annual maximum number of males counted for lek i in year t as a linear function of year while accounting for population cycles [50] by fitting a smoothed effect of the total number of males counted statewide in each year. To be comparable through time, the annual total number of males was calculated using only those leks that were monitored in all 16 years of the study period. A negative binomial distribution was used because many leks had an excess number of zero males counted, thereby violating the mean-variance relationship of the Poisson distribution. Despite having reduced the dataset to only include those leks that were monitored in $\geq$ 12 of the 16 years, the trend analysis for some leks produced warning messages suggesting that the models did not converge and parameter estimates were not reliable. Concomitantly, we further reduced the resulting vector of estimated lek trend estimates by retaining only those estimates that were within 1 standard deviation of the average trend estimate. This resulted in a sample size of 125 lek trend estimates being carried forward to the second stage of our analysis.

To examine the role of power lines on lek trends, we constructed a General Linear Model with a Gaussian distribution as implemented in the base R (Version 3.3.3; [47]). To evaluate the potential for a response threshold, we used the aforementioned grid search approach to compare the linear and nonlinear model fits. The small number of leks for which we had trend estimates and were within 10 km of either transmission or distribution lines (n = 70) required that we analyze lek trends as function of distance to combined power line types. Distance to power lines (km) was included as the sole explanatory variable because the small number of leks precluded the evaluation of other habitat variables (e.g., percent sagebrush cover, roads) due to convergence issues.

Lek persistence

We defined persistence as leks where at least 2 strutting males were observed in 2 years of each of the 5-year periods 1996–2000 and 2009–2013 [55, 56]. To examine the role of power lines

on lek persistence, we constructed a GLM with a binomial distribution (persist vs. not persist) and logit-link function as implemented in the base R package. We employed the grid search of potential response thresholds similar to the lek trend analysis to compare the linear and non-linear model fits. Due to the small number of leks within 10 km of either transmission or distribution lines (n = 56), we analyzed lek persistence as the function of distance to combined power line types. Distance to power lines (km) was included as the sole explanatory variable because the small number of leks precluded the evaluation of other habitat variables (e.g., percent sagebrush cover, roads) due to convergence issues.

Nest and brood site selection

We used a resource selection function (RSF) approach within a use-available study design [57] evaluated at the population level [58] to determine the relative influence of distance to power lines and sagebrush cover on sage-grouse nest or brood-site selection. We included sagebrush cover because it has previously been reported as a factor that influences sage-grouse distributions [24, 59].

We used our database of known sage-grouse nest and brood locations and randomized potential locations with our study area to conduct the RSF. For the nest RSF, we generated 15 potential sage-grouse use locations as random points for every nest location. Our placement of potential sage-grouse locations was constrained to sagebrush vegetation types mapped by the inter-agency LANDFIRE project. Given that, random nest points were constrained such that they were located within 10 km of either a transmission or distribution line, and within the convex hull drawn around nest locations for each study population [39]. This established a distribution of availability that corresponded to any nesting habitat within a given study area that was also located within 10k of a power line. Using this information, we constructed our RSF using a generalized linear mixed model (GLMM) with a binomial distribution (presence vs. random) and a logit-link function implemented in the lme4 package of R. We included distance to either transmission or distribution lines as either a linear or piecewise spline covariate. Power line types were analyzed separately (i.e., two separate RSF models) to accurately measure whether a threshold response occurred to either or both power line types. Because nest site selection is also a function of percent sagebrush [13], we also tested for the additive and interactive effects of percent sagebrush cover. Lastly, we included additive effects of elevation and distance to roads as covariates to both linear and piecewise spline models (Table 1). Study area was included as a random factor.

We repeated this process for our brood site RSF, except that an additional constraint was placed on random locations. Random brood locations were constrained such that they were located: 1) within 10 km of either a transmission or distribution, 2) within the convex hull drawn around brood locations for each study population, and 3) within 10 km of each individual brood location. This established a distribution of availability that was individual specific such that random locations were in close proximity to a given brood while also meeting the prior constraints. Using this information, we constructed our RSF using a GLMM with a binomial distribution (presence vs. random) and a logit-link function implemented in the lme4 package of R. We included distance to either transmission or distribution lines as either a linear or piecewise spline covariate as described above. Although it has been suggested sage-grouse may move up in elevation as the brooding season progresses [59], we did not evaluate this in our models because it appeared to occur only in specific sites within our study area (S1 Appendix). Furthermore, the inclusion of elevation and Julian date in our models led to convergence issues, which necessitated that we focus on the effects of power lines on brood site selection. We included our measure of percent sagebrush cover as either additive or interactive

effects. Lastly, we included additive effects of elevation and distance to roads to both linear and piecewise spline models (Table 1). Brood ID and study area were included as nested random effects. We built both nest and brood models using standardized coefficients (x_i - $\bar{x}$/s) to facilitate direct comparison within models.

Nest and brood success

We used our nest database to construct nest models using a GLMM with a binomial distribution (success vs. failure) and a logit-link function implemented in the lme4 package of R. We included distance to either transmission or distribution lines as either a linear or piecewise spline covariate. We included our measure of percent sagebrush cover as an additive and interactive effect in the models. Lastly, we included additive effects of elevation and distance to roads to both linear and piecewise spline models (Table 1). Study area was included as a random effect in the nest analysis.

We used our brood-site database to construct nest models using a GLMM with a binomial distribution (success vs. failure) and a logit-link function implemented in the lme4 package of R. To provide a cumulative response value for this analysis, we identified the median distance to transmission and distribution lines for each brood using their associated telemetry locations. We only retained individuals in the analysis where the median value of each individual was $\leq$ 10 km from either a transmission or distribution line. We included distance to either transmission or distribution lines as either a linear or piecewise spline covariate. We included our measure of percent sagebrush cover as an additive and interactive effect in the models. Lastly, we included additive effects of elevation and distance to roads to both linear and piecewise spline models (Table 1). Brood ID and study area were included as nested random effects. We built both nest and brood models using standardized coefficients (x_i - $\bar{x}$/s) to facilitate direct comparison within models.

Results

Lek trend

Of the 125 leks we estimated temporal trends for, 70 leks were within 10 km of power lines (including both transmission and distribution). For these leks, a model that contained a linear effect of power lines on lek trend (ΔAICc = 0.42) was a worse fit to the data than the null model (ΔAICc = 0.00). However, support for the null model was substantially weaker (ΔAICc = 4.53) than the best-fit threshold model.

Thus, our data suggests that lek trends increased for leks located farther from a power line (β = 0.26, 95% CI = -0.05, 0.56) up until a distance of 1.2 (95% Threshold CI = 0.1, 2.3) km (Fig 2). After this threshold, lek trends decreased but the slope of the relationship was diminished in comparison to the pre-threshold relationship (β = -0.02, 95% CI = -0.05, -0.00).

Lek persistence

We identified 186 leks within 10 km of transmission and distribution lines, of which 56 were considered to be persistent [55, 56]. For these leks, a model containing a linear effect of power lines on lek persistence (ΔAICc = 2.08) was a worse fit to the data than the null model. A model containing a threshold effect of distance to power lines on lek persistence did not improve model fit (ΔAICc = 2.15) suggesting that power lines did not influence lek persistence in our study (S2 Appendix).

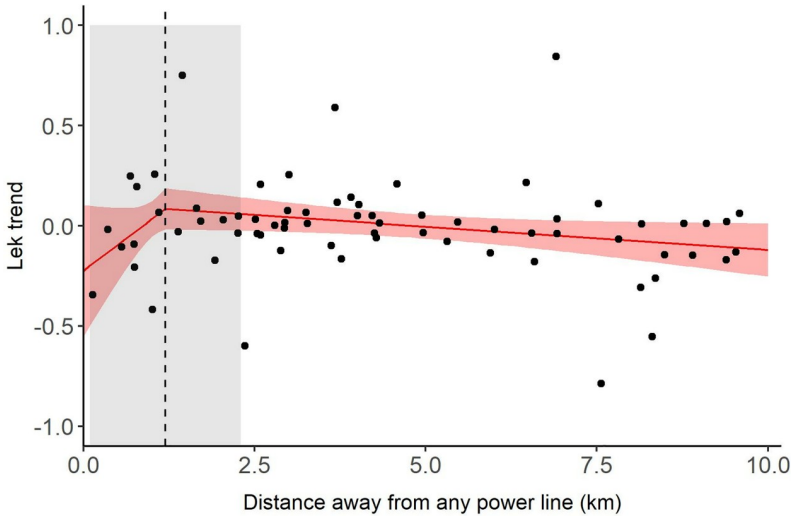


Fig 2. Effect of power lines on greater sage-grouse (*Centrocercus urophasianus*) lek trends and persistence in Utah, USA, 1998–2013. Lines represent the fitted values from the best-fit model of the effect of power lines on lek trends (S2 Appendix). The vertical dashed line identifies the response threshold at which sage-grouse response (i.e., lek trend) changed. Shaded areas highlight uncertainty (95% CI) around the location of the response threshold.

https://doi.org/10.1371/journal.pone.0209968.g002

Nest and brood site selection

Nests. Of 429 nests, 365 were within 10 km of a transmission line and 222 were within 10 km of a distribution line. Individual sage-grouse nests were recorded as close as 103 m and 239 m from electric power transmission and distribution lines, respectively. For these nests, a model that contained a linear effect of distance to transmission lines on the relative probability of nest-site selection was a better fit to the data than the null model (ΔAICc = 1.52). A model that contained an interaction between distance to transmission lines and percent sagebrush cover further improved model fit over the univariate linear distance to power line model (ΔAICc = 175.33). However, support for this best-fit linear model was substantially weaker (ΔAICc = 7.67) than the best fit threshold model that included an interaction between distance to transmission lines and percent sagebrush cover. Thus, our data suggests that the relative probability of nest-site selection increased as sage-grouse moved farther from transmission lines up until a distance of 1.1 (range = 1.1–1.3; S3 Appendix) km (Fig 3A). After this threshold, the relative probability of nest-site selection declined in areas of high sagebrush cover but remained relatively constant in areas of low sagebrush cover. In accordance, a linear (univariate) analysis suggested that sage-grouse selected nest sites farther from transmission lines (β = 0.10, 95% CI = -0.00, 0.21).

For nests within 10 km of a distribution line, a model that contained a linear effect of distribution lines on the relative probability of nest-site selection was a better fit to the data than the null model (ΔAICc = 0.26). A full model that included a linear effect of distance to distribution line further improved model fit over the univariate linear distance to distribution line model (ΔAICc = 63.11). The best-fit threshold model did not improve model fit (ΔAICc = 0.32) over the best-fit linear model. For our best-fit model, the relative probability of nest site selection increased as distance from distribution lines increased (β = 0.12, 95% CI = -0.08, 0.33; S3 Appendix).

Broods. We recorded 3,335 brood locations during the study, of which 2,986 were within 10 km of a transmission line and 1,610 were within 10 km of a distribution line. For these broods, a model that contained a linear effect of transmission lines on brood-site selection was

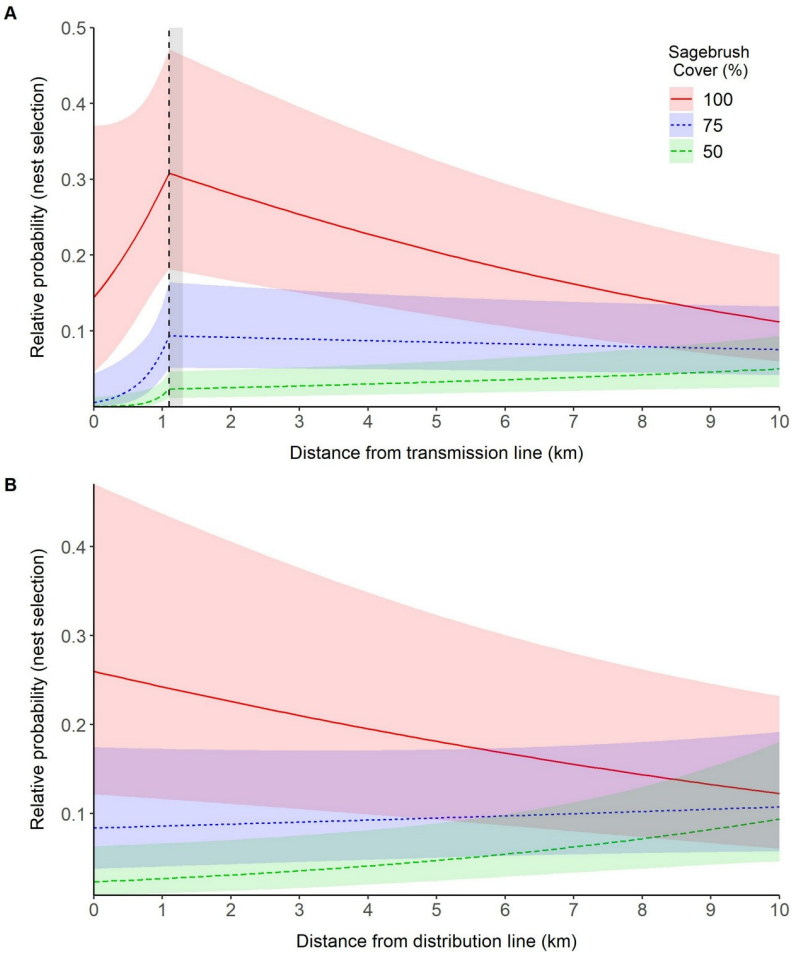


Fig 3. Effect of power lines on the relative probability of nest site selection of greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) throughout Utah, portions of southeastern Idaho, and southwestern Wyoming, USA, 1998–2013. Lines are population-averaged fitted values from the best-fit GLMM (S3 Appendix) describing the effects of transmission lines (A) and distribution lines (B) on sage-grouse nest site selection. The vertical dashed line identifies the response threshold at which sage grouse response changes. The shaded areas highlight uncertainty (ΔAICc < 2) around the location of the response threshold.

https://doi.org/10.1371/journal.pone.0209968.g003

a better fit to the data then the null model (ΔAICc = 176.50). The full model that included a threshold effect of distance to transmission line further improved model fit over the linear distance to transmission line model (ΔAICc = 1584.34). However, support for the best-fit linear model was substantially weaker (ΔAICc = 154.13) than the best fit threshold model which included an interaction between distance to transmission lines and percent sagebrush cover. Thus, our data suggest that the relative probability of brood use increased for leks located farther from a transmission line up until a distance of 1.2 (range = 1.2–1.4; S4 Appendix) km (Fig 4). After this threshold, the relative probability of brood-site selection declined in areas of high sagebrush cover but remained relatively constant in areas of low sagebrush cover.

For brood sites within 10 km of a distribution line, a model containing a linear effect of distribution lines on the relative probability of nest-site selection was a better fit to the data than the null model (ΔAICc = 193.5). The full model that contained a linear effect of distance to distribution lines further improved model fit over the linear distance to distribution line model (ΔAICc = 638.65). However, support for the best-fit linear model was substantially weaker

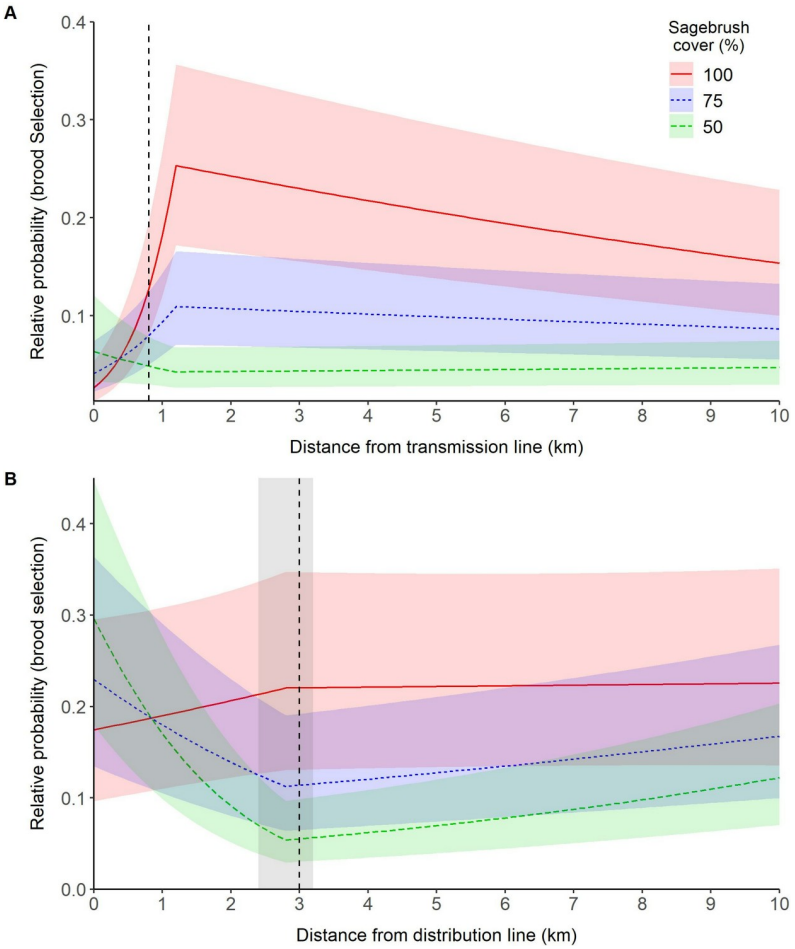


Fig 4. Effect of power lines on the relative probability of greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) brood site selection in Utah, portions of southeastern Idaho, and southwestern Wyoming, USA, 1998–2013. Lines are population-averaged fitted values from the best-fit GLMM (S4 Appendix) describing the effects of transmission lines (A) and distribution lines (B) on sage-grouse brood site selection. The vertical dashed line identifies the response threshold at which sage grouse response changes. The shaded areas highlight uncertainty (ΔAICc < 2) around the location of the response threshold (no uncertainty was recorded for distance from transmission lines).

https://doi.org/10.1371/journal.pone.0209968.g004

(ΔAICc = 126.15) than the best fit threshold model which included all covariates and interactions (S4 Appendix). Thus, our data suggests the relative probability of brood use may be positively influenced by distribution lines except in cases of high sagebrush cover until a distance of 3.0 (range = 2.4–3.2; S4 Appendix) km (Fig 4). After this threshold, the relative probability of brood-site selection remained relatively constant.

Nest and brood success

Nests. We recorded 422 nests during the study, of which 83% (n = 352) were within 10 km of a transmission line and 50% (n = 212) were within 10 km of a distribution line. For these nests, a model that contained a linear effect of transmission lines on nest success was a better fit to the data than the null model (ΔAICc = 2.95). A model that include the linear effect of distance to transmission lines and distance to roads improved model fit over the univariate linear distance to transmission model (ΔAICc = 1.00). The best-fit threshold model did not improve model fit (ΔAICc = 0.94) over the best-fit linear model. For our best-fit model, the

relative probability of nest success increased as distance from transmission lines increased (β = 0.27, 95% CI = 0.05, 0.48; S3 Appendix; Fig 5).

For nests within 10 km of a distribution line, a model containing a linear effect of distribution lines on nest success did not improve model fit (ΔAICc = 1.77) over the null model. However, support for the null model was weaker (ΔAICc = 1.00) than the best-fit threshold model which included an additive effect of percent sagebrush cover. Thus, our data suggested that the probability of nest success declined as you moved farther from a distribution line (β = -0.27, 95% CI = -0.64, 0.08; Fig 5) up until a distance of 8.9 (range = 6.2–9.2; S5 Appendix) km, after which, nest success increased (β = 3.45, 95% CI = -1.03, 8.40). It is likely that the decrease in nest success beyond the threshold was driven by our sample size (n = 35 / 222) beyond 8.9 km. Of those 35 nests, 77% (n = 27) were located in two study areas which had a combined 66% nest success suggesting that these areas influenced our model results beyond 8.9 km.

Broods. We recorded 434 broods during the study, of which 89% (n = 386) were within 10 km of a transmission line and 47% (n = 206) were within 10 km of a distribution line.

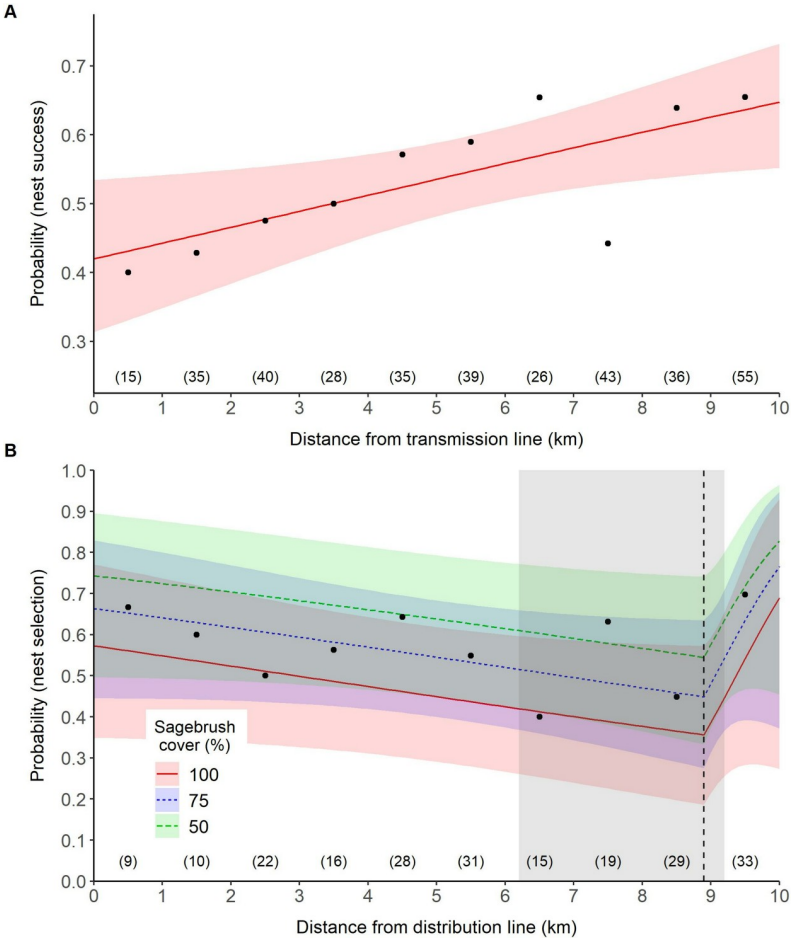


Fig 5. Effect of power lines on the greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) in Utah, portions of southeastern Idaho, and southwestern Wyoming, USA, 1998–2013. Lines are population-averaged fitted values from the best-fit GLMM (S5 Appendix) describing the effects of transmission lines (A) and distribution lines (B) on sage-grouse nest success. The vertical dashed line identifies the response threshold at which sage-grouse response changes. The shaded areas highlight uncertainty (ΔAICc < 2) around the location of the response threshold. Circles represent a binning of data points that informed the model; sample sizes within each 1 km bin are identified in parentheses. For example, 15 nests were recorded between 0–1 km from a transmission line, of which 40% (n = 6) persisted.

https://doi.org/10.1371/journal.pone.0209968.g005

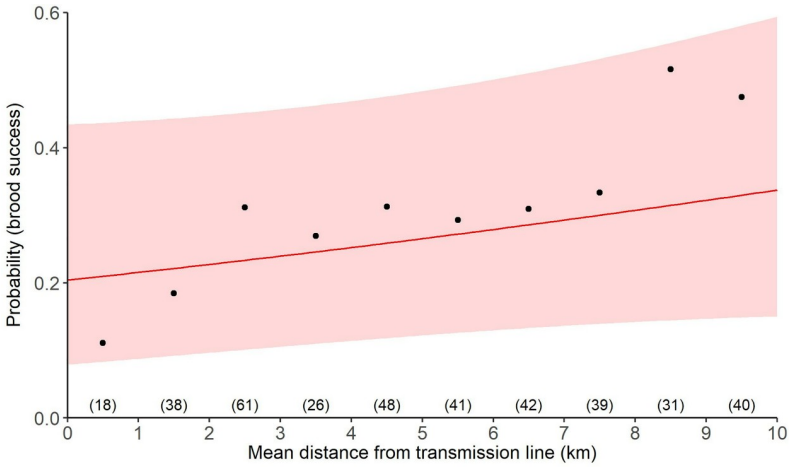


Fig 6. Effect of power lines on the greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) in Utah, portions of southeastern Idaho, and southwestern Wyoming, USA, 1998–2013. Lines are population-averaged fitted values from the best-fit GLMM (S6 Appendix) describing the effects of transmission lines on sage-grouse brood success. Circles represent a binning of data points that informed the model; sample sizes within each 1 km bin are identified in parentheses. For example, 18 nests were recorded between 0–1 km from a transmission line, of which 11% (n = 2) persisted.

https://doi.org/10.1371/journal.pone.0209968.g006

Brood locations were documented as close as 205 m and 24 m from transmission and distribution power lines, respectively. Because our data set contained multiple locations for each brood that were recorded regularly throughout the season, we were also able to determine if some broods may have traveled under power lines. We recorded eight radio-marked female sage-grouse with broods (4%) crossing under transmission lines 27 times. Eleven brooding females (8%) crossed under distribution lines 86 times. For broods that crossed distribution lines, the median number of crossings per brood was three (range 2–33). Fifteen broods (6%) crossed under both transmission and distribution lines.

For these broods, a model that contained a linear effect of transmission lines on brood success was a better fit to the data than the null model (ΔAICc = 1.13). A model that included a linear effect of transmission line and elevation farther improved model fit over the univariate linear distance to transmission line model (ΔAICc = 0.70). The best-fit threshold model did not improve model fit (ΔAICc = 0.52) over the best-fit linear model. For our best-fit model, the relative probability of brood success increased as distance from transmission lines increased (β = 0.19, 95% CI = -0.09, 0.47; S3 Appendix; Fig 6).

For broods within 10 km of a distribution line, a model that contained a linear effect of distribution on brood success was a worse fit than the null model (ΔAICc = 1.72). A model that contained a threshold effect of distance to distribution lines on brood success did not improve model fit (ΔAICc = 1.83) beyond the null model (S6 Appendix).

Preponderance of evidence

There was support (< ΔAICc of 2.0) for a nonlinear model being our best-fitting model for all analyses except lek persistence (Table 2). For lek trend, our best-fit model suggested that there was a negative effect of power lines up until a distance of 1.2 km. We report similar results for nest-site selection (1.1 km), nest success (2.4 km), and brood success (1.3 km) relative to transmission lines (positive coefficient for D1 in Table 2). We observed the opposite pattern (higher selection for distances close to transmission lines) for brood-site selection, however, these

main coefficient effects were influenced by a percent sagebrush cover interaction which suggested a negative effect of transmission lines (Fig 4).

In comparison, our data suggested that sage-grouse may be negatively affected by distribution lines during the nesting period (positive coefficient for D1 in Table 2) but positively selecting for areas near distribution lines during the brood period (positive coefficient for D1 in Table 2). It is also important to note that our main effect coefficients for nest-site selection were influence by a percent sagebrush cover interaction that suggests that distribution lines may have a positive effect of nest-site selection (Fig 3B). As such, our overall weight of evidence approach suggests there was a negative effect of transmission lines up until a threshold of 2.4 km and there was general lack of support for a distribution line effect.

Discussion

Our results suggested that different types of power lines can have varying effects on sage-grouse demographics, and percent sagebrush cover may influence these effects. For example, lek trends were negatively affected by power lines up until a distance of 1.2 (95% CI = 0.1–2.3) km. When we were able to separate sage-grouse responses according to power line type, transmission lines appeared to have greater impacts to sage-grouse than distribution lines. Thus, our analyses yielded a data-driven 2.3-km BMP buffer zone around leks for the construction of new transmission power lines in occupied sage-grouse habitats. However, sage-grouse nest and brood locations where still documented within this BMP buffer zone. Because distribution lines had less of an impact on sage-grouse demographics than transmission lines, we recommend site specific planning as appropriate for distribution lines, which may include buffers, micrositing, habitat reclamation, other BMPs, or a combination of these practices.

Table 2. Preponderance of evidence Table. Delta AIC scores corrected for small sample sizes for the best-fit null, linear, and nonlinear model for each analyses.

Analyses		Null Model ΔAICc	Best Linear Model ΔAICc	Best Nonlinear Model ΔAICc	Threshold (km)	Best Nonlinear Model Dist1	Best Nonlinear Model Dist2
Lek analyses							
	Lek trend	0.47	0.88	0.00	1.2	0.26	-0.02
	Lek persistence	0.00					
Transmission line analyses							
	Nest selection (transmission line)			0.00	1.1	9.73	0.10
	Brood selection (transmission line)			0.00	1.2	-0.01	0.00
	Nest success (transmission line)		0.00	0.94	2.4	1.09	0.18
	Brood success (transmission line)	1.83	0.00	0.52	1.3	4.60	0.14
Distribution line analyses							
	Nest selection (distribution line)		0.00	0.32	9.5	0.19	-6.74
	Brood selection (distribution line)			0.00	3.0	-1.41	0.26
	Nest success (transmission line)		0.00	0.94	2.4	1.09	0.18
	Brood success (distribution line)	0.00	1.72	1.83	6.7	-0.38	0.88

Best-fit models were only displayed if they were within < ΔAICc of 2.0. For the best-fit nonlinear model, we identified the threshold and the main effect marginal coefficient before (D1) and after (D2) the threshold. Across all analyses, our data suggests a negative effect of transmission lines up to 2.4 km and no effect of distribution lines.

https://doi.org/10.1371/journal.pone.0209968.t002

Based on our analysis, sage-grouse avoided nesting within 1.1 km of transmission lines and nest success was most negatively affected at distances up until 2.4 km (Table 2). We did not detect an effect of distance to distribution lines on sage-grouse nest-site selection. Similarly, brooding female sage-grouse tended to avoid the immediate proximity of transmission lines up to a distance of 1.2 km, whereas they did not avoid distribution lines. Similar to our site-selection analyses, transmission lines had a negative effect on sage-grouse nest success up to a distance of 2.4 km, whereas, sage-grouse nests located closer to distribution lines were more successful. Transmission lines also had a negative effect on brood success up to a distance of 1.3 km, whereas distribution lines had no effect.

These preponderance of evidence suggests that sage-grouse may be more impacted by transmission lines than to distribution lines. It remains unclear, however, whether this was driven by habitat characteristics. In our study area, transmission lines were located at lower elevations on the landscape and farther from developed areas. In contrast, distribution lines were located in areas with greater anthropogenic development and habitat fragmentation than transmission lines, as they directly provide electrical power to homes, communities, businesses, and industry [60]. Thus, habitat availability alone may help explain increased avoidance of transmission lines but not distribution lines (i.e., sage-grouse could not avoid distribution lines without encountering other anthropogenic structures, whereas sage-grouse could have ranged in larger areas surrounding transmission lines in otherwise intact habitat). This is likely in our study areas because sage-grouse seasonal movements in Utah reflect habitat availability [39]. It may also be possible that the interspersed, and thus, more homogenous spatial arrangement of distribution lines on the landscape may have facilitated habituation by sage-grouse [34].

The high density and proximity of secondary roads adjacent to power lines may also explain sage-grouse avoidance of power lines [11, 22, 32]. In our study area, we observed both selection for (brood-site selection-distribution; S4 Appendix, nest-success: transmission; S5 Appendix) and avoidance of roads (brood-site selection-transmission; S4 Appendix). This inconclusive effect of roads may be in part due to the correlation of power lines and roads. In areas where transmission lines and distribution lines had been constructed, 54% and 69% of sage-grouse locations, respectively, were within 100 m of a road (S7 Appendix). These roads have established linear corridors that may exceed 300 m or more and may include unimproved power line access roads, county roads, and/or state/interstate highways [11]. Thus, sagebrush habitats located < 1 km of the power lines may have been degraded by historic road and power line construction that contributed to sage-grouse habitat loss and therefore site avoidance. Similar to other studies, [23], we were unable to separate these effects (anthropogenic development from and tall structures) due to small sample size. Moreover, Johnson et al. [34] and Wisdom et al. [32] cautioned that retrospective studies may be biased in that many of the factors affecting sage-grouse ecology were in place prior to their studies [11]. Despite this, our study does represent the first comprehensive examination of the direct and indirect effects of power lines on sage-grouse at a landscape scale. This is important because published research on the effects of these structures on the reproductive fitness of any grouse species is lacking [3].

Alternatively, it has been hypothesized that the avoidance of transmission lines is due to direct predation facilitated by increased predator visibility and increased raptor and corvid nesting substrates [11, 28, 30, 31]. Scientific evidence is still lacking as to whether sage-grouse instinctively avoid power lines specifically to avoid predators [11, 37], but given that transmission lines were 8–30 meters taller than distribution lines in our study area, this may be a potential mechanism to explain sage-grouse avoidance. It is also important to note that Lammers and Collopy [61] and Prather and Messmer [62] both documented high use of electric power distribution lines as perch sites for raptors and corvids in or near our study areas which suggest

that predation risk may be higher closer to power lines. Our results that demonstrated increased avoidance of transmission lines and lower survival in areas near them corroborates this. However, our study did document sage-grouse movements beneath power lines suggesting predation may not be as influential as sometimes stated. As such, this debate remains unresolved because of the difficulty in connecting predation risks to various combinations or types of power lines and avian predator species [11, 23, 37].

Although we were unable to identify the mechanism responsible for sage-grouse avoidance of power lines, we were able to provide the first landscape-scale empirical evaluation of the effects of power lines on sage-grouse during the breeding season. Our evaluation supports the broad-scale analysis by Wisdom et al. [32] and Gibson, Blomberg (30) that distance to transmission lines had a potential negative influence on lek persistence. However, our analyses extended beyond Wisdom et al. [26] in that we identified a BMP buffer zone of 2.3 km from active leks for power lines that could avoid and minimize the potential effects of new power line construction on sage-grouse ecology.

For comparison, a 3.0 km minimum BMP buffer zone has been previously recommended to mitigate the effects of tall structures on seasonal sage-grouse habitat [13, 63–65]. This BMP buffer zone was recommended because available range wide nesting data suggested most sage-grouse nest within 3.2 km of known leks [66]. In our study areas, nest success increased as females selected nesting sites farther from transmission lines. This effect was greatest up to a distance of 2.4 km. However, long-term sage-grouse nest location data collected in Utah and other states suggested that some female sage-grouse may nest up to 5.0 km or more from known leks [39, 67]. This may explain why nesting success increased, but at a slower rate, beyond the 2.4 km threshold (Table 2).

The BLM National Technical Team (NTT) reviewed data regarding distances from nest locations to the nearest leks where female sage-grouse were captured [68]. Based on these data, the BMP buffer zone would need to exceed a 6.0 km radius around leks to protect most of the nesting female sage-grouse. However, the NTT acknowledged a 6.0 km buffer would not be practical because of oil and gas leasing requirements and that within priority habitats existing lek-based BMP buffers may overlap precluding development [68]. As such, our results lend support to Connelly et al. [13], the Wyoming Sage-grouse Executive Order [69], and APLIC [36] recommendations of placing new electric transmission lines within existing corridors. If this is unfeasible, we suggest a 2.3 km buffer for the construction of transmission lines be applied around active leks to avoid and minimize impacts to nesting habitat in Utah. It is unclear from our data whether an active lek buffer associated with distribution lines is required around nesting habitat, thus, we would recommend that new distribution lines be co-located with existing disturbance if possible.

Beck et al. [70] estimated that 29,821 km^2 (13.6%) of Utah provided sage-grouse habitat. Connelly et al. [71] and Knick et al. [24] suggested that electric power transmission lines could have an impact on 40–50% (11,928–14,911 km^2) of all sagebrush within designated sage-grouse management areas. However, we found that only 10% of transmission lines and 7% of distribution lines within our study areas were within 10 km of occupied sage-grouse habitat suggesting that power lines may be less influential to overall sage-grouse habitat than previously thought in Utah. Moreover, if we applied a 2.3 km buffer zone around all known electric power transmission (1,698 km) and distribution (1,496 km) lines, our analysis suggests that power lines may only have an ecological effect on 22.6% (6,817km^2) of available sage-grouse breeding habitat in our study areas.

Our results highlighted the importance of maintaining suitable sagebrush cover in areas where power lines occur on the landscape, as percent sagebrush cover increased grouse selection of sites for nesting and brooding increased despite the presence of power lines. In

our study areas, percent sagebrush cover improved as distance to transmission lines increased ($\beta = 3.28$, $p \leq 0.01$). This may explain why nest and brood success continued to increase as sage-grouse females moved farther from transmission lines. Our results validate the value of reclaiming sagebrush habitats in areas in close proximity to power lines.

Female sage-grouse demonstrated high selection preferences for sites within ~ 1.1 km of transmission lines during the nesting and brooding period, which suggests these sites provide additional benefits which we did not account for in our models. In such cases, management strategies that increased the availability of useable sagebrush habitat space (i.e., removal of conifer encroachment and vegetation management to encourage low growing species) in areas where power lines occur could enhance population stability [39, 72, 73] and potentially counteract the negative impacts of power lines. However, it is possible that habitat improvement strategies could lead to population sink dynamics if sage-grouse are attracted to power lines and subsequently experience negative population growth due to factors such as increased predation [30]. Thus, managers should evaluate this practice on a case-by-case basis.

Currently 87% of the sage-grouse range is grazed by livestock [24]. Dahlgren et al. [54, 73] reported increased sage-grouse production on working landscapes grazed by domestic livestock using rotational grazing practices. Utility ROW vegetation management practices may serve a similar function to livestock grazing, as both reduce tall growing species and encourage growth of grassland and shrub species. Sandford et al. [72] reported increased sage-grouse nest survival and brood success in sagebrush landscapes where conifer encroachment was reduced. Messmer [74] suggested implementation and evaluation of these landscape-level management practices should be considered as part of the integrated toolkit to mitigate the potential effects anthropogenic activities have on sage-grouse and their habitats.

Our study represents the first landscape-level comparison within a state's jurisdictional boundary that examined the relationship between power line classification and known sage-grouse nest and brood locations. Despite our comprehensive approach, we were still unable to resolve a number of concerns that may influence sage-grouse responses to power lines due in a large part to our limited samples sizes. Specifically, our sample size limited our ability to evaluate how structure height and design may differentially influence sage-grouse response beyond our general classifications (e.g., distribution vs transmission). Similarly, it is unclear whether structure design may play a role in sage-grouse response given the variation in available perching and nesting substrates that power lines provide to avian predators [11]. We were also unable to evaluate the extent to which placement of new power lines within anthropogenic corridors (e.g., power lines, transportation) reduces the overall negative influence of sage-grouse (e.g., [29]), and whether those benefits to sage-grouse are capped at some development threshold (e.g., 2 vs. 4 power lines in a corridor). Due to the propensity of roads in proximity to power lines throughout our study area, we were also unable to distinguish between potential independent impacts from roads versus power lines. Lastly, we documented increased use of elevation during the brood period, however we were unable to explicitly evaluate how seasonal movement behaviors may interact with sage-grouse response to power lines (distance to power lines x elevation interaction), as birds may move away from power lines in response to other unrelated habitat factors. Given these limitations, we encourage future research that addresses these challenges. The increasing use of GPS technology in wildlife studies, including sage-grouse, and the larger sample sizes they provide, may provide new opportunities to evaluate these unanswered questions.

Conclusions

Our research is the first to quantify appropriate BMP buffer distances based on known sage-grouse seasonal habitat-use data for the construction of new electric power transmission and distribution lines in sage-grouse habitats. Our research also demonstrated that interactions between percent sagebrush cover and type of power line affect sage-grouse responses. Based on our results, we recommend a hierarchical approach for avoiding and minimizing the potential impacts of power lines on sage-grouse. New transmission power lines should be placed in existing utility or transportation corridors where feasible. If co-location is not feasible, lek buffers of 2.3 km for new transmission lines should be used to mitigate the potential impacts to sage-grouse. It is questionable from our results, however, that this buffer would also apply to distribution lines given the uncertainty we observed regarding sage-grouse response to distribution lines in our habitat selection and reproductive success analyses. In addition, other regulatory or resource conflicts (i.e., electric utilities are required by law to provide service to requesting customers and to minimize impacts to other resources–such as wetlands, cultural or paleontological resources, etc.) can result in new construction within a sage-grouse buffer in some circumstances. Thus, we recommend managers continue to incorporate habitat protection and reclamation as conservation strategies for new power line construction, and population monitoring (i.e., lek counts) as feedback mechanisms to evaluate the effectiveness of these strategies. The use of applicable BMPs, such as the sage-grouse BMPs for electric utilities developed by APLIC, should be considered and implemented on a project-by-project basis. It is important that wildlife resource agencies, land management agencies, electric utilities, and private landowners work together to address site-specific aspects of new power line locations and sage-grouse habitats. More broadly, the methodological process employed here can be used widely to evaluate the influence of anthropogenic structures on grouse species globally. With this information, land managers will be better suited to minimize impacts from ongoing human infrastructure construction on wildlife.

Supporting information

S1 Appendix.
(DOCX)

S2 Appendix.
(DOCX)

S3 Appendix.
(DOCX)

S4 Appendix.
(DOCX)

S5 Appendix.
(DOCX)

S6 Appendix.
(DOCX)

S7 Appendix.
(DOCX)

Acknowledgments

We thank J. Flory, R. Chi, J. Reinhart, C. D. Caudill, E. Thacker, S. Graham, N. Gruber-Hadden, O. Duvuvuei, S. Dettenmaier, H. McPherron, J. Robinson, B. Flack, A. Cook, B. Wing, C. Cardinal, L. Smith, C. Burnett, C. Perkins, B. Christiansen, K. Bunnell, R. Peck, J. Hennefer, D. Bambrough, J. Kaze, and J. Baxter. For leading field-based collection of the sage-grouse location data used in our analysis. We acknowledge D. Ramsey's USU Remote Sensing and GIS Laboratory in the Department of Wildland Resources for completing spatial analysis. We thank all the biological technicians that worked within study areas throughout the many field seasons. We acknowledge the private landowners who provided the access to enter their properties for data collection and for their participation within the local working groups that supported the research projects. The data used to complete our research were provided by the Utah Division of Wildlife Resources, USU, BYU, Rocky Mountain Power/PacifiCorp, Garkane Energy, and Raft River Rural Electric Cooperative, and Idaho Power.

Author Contributions

Conceptualization: Michel T. Kohl, Terry A. Messmer, David K. Dahlgren, Sherry Liguori.

Data curation: Benjamin A. Crabb, David K. Dahlgren, Randy T. Larsen, Shandra N. Frey, Sherry Liguori, Rick J. Baxter.

Formal analysis: Michel T. Kohl, Benjamin A. Crabb, Randy T. Larsen.

Funding acquisition: Terry A. Messmer.

Methodology: Michel T. Kohl, Benjamin A. Crabb, Michael R. Guttery, Randy T. Larsen.

Project administration: Shandra N. Frey.

Resources: Terry A. Messmer.

Software: Benjamin A. Crabb.

Supervision: David K. Dahlgren, Rick J. Baxter.

Writing – original draft: Michel T. Kohl, Terry A. Messmer, Sherry Liguori.

Writing – review & editing: Michel T. Kohl, Terry A. Messmer, Benjamin A. Crabb, Michael R. Guttery, David K. Dahlgren, Randy T. Larsen, Shandra N. Frey, Sherry Liguori, Rick J. Baxter.

References

1. Goldenwijk KK, Beusen A, van Drecht G, de Vos M. The HYDE 3.1 spatially explicit database of human induced global land-use change over the past 12,000 years. Global Ecol Biogeogr. 2010; 20: 73–86.
2. Benítez-López A, Alkemade R, Verweij PA. The impacts of roads and other infrastructure on mammal and bird populations: a meta-analysis. Biol Conserv. 2010; 143: 1307–1316.
3. Hovick TJ, Elmore RD, Dahlgren DK, Fuhlendorf SD, Engle DM. Review: evidence of negative effects of anthropogenic structures on wildlife: a review of grouse survival and behaviour. J Appl Ecol. 2014; 51: 1680–1689.
4. Hansen AJ, Knight RL, Marzluff JM, Powell S, Brown K, Gude PH, et al. Effects of exurban development on biodiversity: patterns, mechanisms, and research needs. Ecol Appl. 2010; 15; 1893–1905.
5. Kuvlesky WP Jr, Brennan LA, Morrison ML, Boydston KK, Ballard BM, Bryant FC. Wind energy development and wildlife conservation: challenges and opportunities. J Wildlife Manage. 2007; 71: 2487–2498.
6. Leu M, Hanser SE, Knick ST. The human footprint in the west: a large-scale analysis of anthropogenic impacts. Ecol Appl. 2008; 18: 1119–1139. PMID: 18686576

7. Bevanger K. Biological and conservation aspects of bird mortality caused by electricity power lines: a review. Biol Conserv. 1998; 86: 67–76.
8. Bui TD, Marzluff JM, Bedrosian B. Common raven activity in relation to land use in western Wyoming: implications for greater sage-grouse reproductive success. Condor 2010; 112: 65–78.
9. Wilcove DS, Wikelski M. Going, going, gone: is animal migration disappearing. Plos Biol. 2010. 6(7): e188. https://doi.org/10.1371/journal.pbio.0060188
10. Smith JA, Dwyer JF. Avian interactions with renewable energy infrastructure: an update. Condor. 2016; 118: 411–423.
11. Messmer TA, Hasenyager R, Burruss J, Liguori S. Stakeholder contemporary knowledge needs regarding the potential effects of tall structures on sage-grouse. Human Wildlife Interactions. 2013; 7: 273–298.
12. Mabey S, Paul E. Critical literature review: impact of wind energy and related human activities on grassland and shrub-steppe birds. National Wind Coordinating Collaborative. 2007; Available from: https://nationalwind.org/wp-content/uploads/2013/05/Critical-Lit-Review-Oct-2007.pdf
13. Connelly JW, Schroeder MA, Sands AR, Braun CE. Guidelines to manage sage-grouse populations and their habitat. Wildlife Soc Bull. 2000; 28: 967–985.
14. Connelly JW, Braun CE. Long-term changes in sage-grouse *Centrocercus urophasianus* populations in western North America. Wildlife Biol. 1997; 3/4: 123–128
15. U.S. Fish and Wildlife Service (USFWS). Greater Sage-grouse (*Centrocercus urophasianus*) Conservation Objectives: Final Report. U.S. Fish and Wildlife Service, Denver, CO. February 2013.
16. U.S. Fish and Wildlife Service (USFWS). Notice of 12-Month Petition Findings for Petitions to List Greater Sage-grouse as Threatened or Endangered. 2010; Available from (http://www.regulations.gov and www.fws.gov).
17. Walker BL, Naugle DE, Doherty KE. Greater sage-grouse population response to energy development and habitat loss. J Wildlife Manage. 2007; 71: 2644–2654.
18. Holloran MJ, Kaiser RC, Hubert WA. Yearling greater sage-grouse response to energy development in Wyoming. J Wildlife Manage. 2010; 74: 65–72.
19. Harju SM, Dzialak MR, Taylor RC, Hayden-Wing LD, Winstead JB. Thresholds and time lags in effects of energy development on greater sage-grouse populations. J Wildlife Manage. 2010; 74: 437–448.
20. Lyon AG, Anderson SH. Potential gas development impacts on sage grouse nest initiation and movement. Wildlife Soc Bull. 2003; 31: 486–491.
21. Doherty KE, Naugle DE, Walker BL, Graham JM. Greater sage-grouse winter habitat selection and energy development. Journal of Wildlife Management. 2008; 72: 187–195.
22. Utah Wildlife in Need Foundation (UWIN). Contemporary knowledge and research needs regarding the potential effects of tall Structures on sage-grouse (*Centrocercus urophasianus* and *C. mimimus*). 2010; Available from https://utahcbcp.org/ou-files/TallStructuresReportSeptember202010.pdf.
23. Walters K, Kosciuch K, Jones J. Can the effect of tall structures on birds be isolated from other aspects of development? Wildlife Soc Bull. 2014; 38: 250–256.
24. Knick ST, Hanser SE, Miller RF, Pyke DA, Wisdom MJ, Finn SP, et al. Ecological influence and pathways of land use in sagebrush. Chapter 13 in Studies in Avian Biology. No. 38. Berkeley: University of California Press; 2011.
25. Marzluff JM, Knick ST, Vekasy MS, Schueck LS, Zarriello TJ. Spatial use and habitat selection of golden eagles in southwestern Idaho. Auk. 1997; 114: 673–687.
26. McIntyre CL. Patterns in nesting area occupancy and reproductive success of golden eagles (*Aquila chrysaetos*) in Denali National Park and Preserve, Alaska, 1988–99. J Raptor Res. 2002; 36: 50–54
27. Boarman WI, Heinrich B. Common raven (*Corvus corax*). In: Poole A, Gill F, editors. The Birds of North America, No. 476. Philadelphia: The Birds of North America, Inc.; 1999. Pp. 1–31.
28. Dinkins JB, Conover MR, Kirol CP, Beck JL, Frey SN. Greater sage-grouse (*Centrocercus urophasianus*) select habitat based on avian predators, landscape composition, and anthropogenic features. Condor; 2014; 116: 629–642.
29. Hansen EP, Stewart AC, Frey SN. Influence of transmission line construction on winter sage-grouse habitat use in Southern Utah. Human Wildlife Interactions. 2016; 10: 169–187.
30. Gibson D, Blomberg EJ, Atamian MT, Espinosa SP, Sedinger JS. Effects of power lines on habitat use and demography of greater sage-grouse (*Centrocercus urophasianus*). Wild Monog. 2014; 92: 319–330
31. Dinkins JB, Conover MR, Kirol CP, Beck JL, Frey SN. Greater sage-grouse (*Centrocercus urophasianus*) hen survival: effects of raptors, anthropogenic and landscape features, and hen behavior. Can J Zoo. 2014; 92: 319–30.

32. Wisdom MJ, Meinke CW, Knick ST, Schroeder MA. Factors Associated with extirpation of sage-grouse. Chapter 19 in Studies in Avian Biology No. 38. Berkeley: University of California Press; 2011.

33. Westover M, Baxter J, Baxter R, Day C, Jensen R, Petersen S, et al. Assessing greater sage-grouse selection of brood-rearing habitat using remotely-sensed imagery: can readily available high-resolution imagery be used to identify brood-rearing habitat across a broad landscape? PloS one. 2016; 11: e0156290. https://doi.org/10.1371/journal.pone.0156290 PMID: 27218829

34. Johnson DJ, Holloran MJ, Connelly JW, Hanser SE, Amundson CL, Knick ST. Influences of environmental and anthropogenic features on greater sage-grouse populations, 1997–2007. Chapter 17 in Studies in Avian Biology No. 38. Berkeley: University of California Press; 2011.

35. U.S. Fish and Wildlife Service (USFWS). Interim guidelines to avoid and minimize wildlife impacts from wind turbines. 2003; Available from: (http//www.fws.gov/r9dhcbfa/windenergy.htm).

36. Avian Power Line Interaction Committee (APLIC). Best Management Practices for Electric Utilities in Sage-Grouse Habitat. Washington, DC: Edison Electric Institute and APLIC; 2015.

37. Manier DJ, Bowen ZH, Brooks ML, Casazza ML, Coates PS, Deibert PA, et al. Conservation buffer distance estimates for Greater Sage-grouse: a review. Geophysical J Intern. 2014; 200: 200–215.

38. Steenhof K, Kochert MN, Roppe JA. Nesting by raptors and common ravens on electrical transmission line towers. J Wildlife Manage. 1993; 57: 271–281.

39. Dahlgren DK, Messmer TA, Crabb BA, Larsen RT, Black TA, Frey SN, et al. Seasonal Movements of Greater Sage-Grouse Populations in Utah: Implications for Species Conservation. Wildlife Soc Bull. 2016a; 40: 288–299

40. Stiver, SJ, Apa AD, Bohne JR, Bunnell SD, Deibert PA, Gardner SC, et al. Greater Sage-grouse Comprehensive Conservation Strategy. 2006. Western Association of Fish and Wildlife Agencies. Unpublished Report. Cheyenne, Wyoming.

41. State of Utah. Final Conservation plan for greater sage-grouse in Utah. February 14, 2013.

42. West NE. Great Basin-Colorado Plateau sagebrush semi-desert. In West NE, editor. Temperate deserts and semi-deserts. Amsterdam: Elsevier; 1983. pp. 331–349.

43. Connelly JW, Reese KP, Schroeder MA. Monitoring of greater sage-grouse habitats and populations. Station Bulletin 80. Moscow: College of Natural Resources Experiment Station, University of Idaho; 2003.

44. Wallestad R, Pyrah D. Movement and nesting of sage grouse hens in central Montana. J Wildlife Manage. 38: 630–633.

45. Gregg MA, Crawford JA, Drut MS, DeLong AK. Vegetational cover and predation of sage grouse nests in Oregon. J Wildlife Manage. 1994; 58: 162–166.

46. Baddeley A, Rubak E, Turner R. Spatial Point Patterns: Methodology and Applications with R. London: Chapman and Hall/CRC Press; 2015.

47. R Core Development Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. 2014; Available from: http://www.R-project.org/.

48. US Census Bureau. TIGER Products. Washington DC, USA; Available from https://www.census.gov/geo/maps-data/data/tiger.html

49. Burnham KP, Anderson DR. Model selection and multi-model inference: a practical information-theoretic approach. 2nd ed. New York: Springer-Verlag; 2002.

50. MacNulty DR, Tallian A, Stahler DR, Smith DW. Influence of group size on the success of wolves hunting bison. PloS one. 2014; 9(11), e112884. https://doi.org/10.1371/journal.pone.0112884 PMID: 25389760

51. Arnold TW. Uninformative parameters and model selection using Akaike's Information Criterion. J Wildlife Manage. 2010; 74: 1175–1178.

52. Anderson DR, Burnham KP, Thompson WL. Null hypothesis testing: problems, prevalence, and an alternative. J Wildlife Manage. 2000; 64: 912–923.

53. Burnham KP, Anderson DR. P values are only an index to evidence: 20th–vs. 21st–century statistical evidence. Ecology 2014; 95: 627–630. PMID: 24804444

54. Dahlgren DK, Larsen RT, Danvir R, Wilson G, Thacker ET, Black TA, et al. Greater sage-grouse and range management: insights from a 25-year case study in Utah and Wyoming. Rangeland Ecol Manage. 2015; 68: 375–82.

55. Garton EO, Connelly JW, Horne JS, Hagen CA, Moser A, Schroeder MA. Greater sage-grouse population dynamics and probability of persistence. In Knick ST, Connelly JW, editors. Greater sage-grouse: ecology and conservation of a landscape species and its habitats. Studies in Avian Biology 38. Berkeley: University of California Press; 2011. pp. 293–381.

56. Utah Division of Wildlife Resources (UDWR). Utah Greater Sage-grouse Management Plan. Publication 09–17. Salt Lake City: State of Utah, Department of Natural Resources, Division of Wildlife Resources; 2009. 94 pps.

57. Manly BFJ, McDonald LL, Thomas DL, McDonald TL, Erickson WP. Resource selection by animals: statistical design and analysis for field studies. Boston: Kluwer Academic; 2002.

58. Johnson DH. The comparison of usage and availability measurements for evaluating resource preference. Ecology. 1980; 61: 65–71.

59. Connelly JW, Rinkes ET, Braun CE. Characteristics of greater sage-grouse habitats. In Knick ST, Connelly JW, editors. Greater sage-grouse: ecology and conservation of a landscape species and its habitats. Studies in Avian Biology 38. Berkeley: University of California Press; 2011. pp 69–83.

60. Knick ST, Hanser SE, Preston KL. Modeling ecological minimum requirements for distribution of greater sage-grouse leks: Implications for population connectivity across their western range, U.S.A. Ecol Evol. 2013; 3: 1539–1551. https://doi.org/10.1002/ece3.557 PMID: 23789066

61. Lammers WM, Collopy MW. Effectiveness of avian predator perch deterrents on electric transmission lines. J Wildlife Manage. 2007; 71: 2752–2758.

62. Prather PR, Messmer TA. Raptor and corvid response to power distribution line perch deterrents in Utah. J Wildlife Manage. 2010; 74: 796–800.

63. Schroeder MA, Robb LA. Fidelity of greater sage grouse *Centrocercus urophasianus* to breeding areas in a fragmented landscape. Wildlife Biol. 2003; 9: 291–299.

64. U.S. Bureau of Land Management (BLM). National Sage-Grouse Habitat Conservation Strategy. Washington, DC: U.S. Department of Interior; 2004.

65. Rowland MN. Effects of management practices on grassland birds: Greater Sage-grouse. Jamestown: Northern Prairie Wildlife Research Center; 2004. 47 pps.

66. Braun CE, Britt T, Wallestad RO. Guidelines for maintenance of sage grouse habitats. Wildlife Soc Bull. 1977; 5: 99–106.

67. Connelly JW, Hagen CA, Schroeder MA. Characteristics and dynamics of greater sage-grouse populations. In Knick ST, Connelly JW, editors. Greater sage-grouse: ecology and conservation of a landscape species and its habitats. Studies in Avian Biology 38. Berkeley: University of California Press; 2011. pp. 53–67.

68. U.S. Bureau of Land Management (BLM). A report on national greater sage-grouse conservation measures. Sage-grouse national technical team report. Washington, DC: U.S. Department of Interior; 2011. 74 pps.

69. Wyoming Executive Order (Wyoming EO). Greater Sage-grouse Core Area Protection Executive Order 2015–4. 2015. 45pp.

70. Beck JL, Mitchell DL, Maxfield BD. Changes in the distribution and status of sage-grouse in Utah. West N Amer Nat. 2003; 63: 203–214.

71. Connelly JW, Knick ST, Schroeder MA, Stiver SJ. Conservation assessment of greater sage-grouse and sagebrush habitats. Unpublished Report. Western Association of Fish and Wildlife Agencies; 2004.

72. Sandford CP, Kohl MT, Messmer TA, Cook A, Wing BR. Greater sage-grouse resource selection drives reproductive fitness under a conifer removal strategy. Rangeland Ecol Manag. 2017; 70: 59–67.

73. Dahlgren DK, Messmer TA, Koons DN. Achieving better estimates of greater sage-grouse chick survival in Utah. J Wildlife Manage. 2010; 74: 1286–1294.

74. Messmer, TA. Lessons learned from the greater sage-grouse: challenges and emerging opportunities for agriculture and rural communities. Policy Brief 6. National Agricultural and Rural Development Policy Center. 2013. Michigan State University, East Lansing, Michigan. USA. Available from: http://utahcbcp.org/files/uploads/publications/PolicyBrief_SageGrouse.pdfx

The Journal of Wildlife Management 1–14; 2019; DOI: 10.1002/jwmg.21749

Research Article

Greater Sage-Grouse Habitat Function Relative to 230-kV Transmission Lines

CHAD W. LEBEAU,[1] *Western EcoSystems Technology, Inc., 1610 Reynolds Street, Laramie, WY 82072, USA*
KURT T. SMITH, *Western EcoSystems Technology, Inc., 1610 Reynolds Street, Laramie, WY 82072, USA*
MATTHEW J. HOLLORAN, *Operational Conservation LLC, 2636 Cherry St., Fort Collins, CO 80521, USA*
JEFFREY L. BECK, *University of Wyoming, Department of Ecosystem Science and Management, Dept 3354, 1000 East University Avenue, Laramie, WY 82071, USA*
MANDY E. KAUFFMAN, *Western EcoSystems Technology, Inc., 1610 Reynolds Street, Laramie, WY 82072, USA*
GREGORY D. JOHNSON, *Western EcoSystems Technology, Inc., 1610 Reynolds Street, Laramie, WY 82072, USA*

ABSTRACT Greater sage-grouse (*Centrocercus urophasianus*) is a landscape-level species that requires large tracts of intact sagebrush (*Artemisia* spp.). Loss of functional habitat resulting from increased demand for energy generation, transmission, and distribution within greater sage-grouse habitats in the western United States has the potential to negatively affect this species. We monitored 346 radio-marked female greater sage-grouse from 2009 to 2014 to evaluate the potential effects of 27-m-tall, 230-kilovolt (kV) wood-pole, H-frame transmission lines on greater sage-grouse habitat selection and demography. We modeled the effect of the transmission lines in 2 different study areas simultaneously using consistent habitat data. Previous research in our study areas suggested that the effect of transmission lines was potentially confounded by other habitat features. We accounted for these potential confounding effects by estimating habitat suitability before estimating the effect of transmission lines. We combined habitat selection and demography results to estimate habitat function relative to transmission lines and inform management recommendations. Overall, we found evidence that transmission lines had a negative effect on greater sage-grouse habitat selection and survival within our study areas over 6 years, but the magnitude of this effect varied by habitat suitability and proximity to occupied leks. The effect of transmission lines on habitat function extended 1.0 km from a transmission line in habitats within 3.1 km of an occupied lek compared to 0.50 km from a transmission line in habitats beyond 3.1 km from occupied leks. Based on these results, we suggest future power line placement relative to sage-grouse nesting, brood-rearing, and summer habitats consider potential effects to sage-grouse habitat selection and demography. Effects can be minimized by incorporating design features that discourage avian predator perching and siting power lines in habitats with lower suitability and, in our study area, habitats beyond 3.1 km from occupied leks. © 2019 The Wildlife Society.

KEY WORDS *Centrocercus urophasianus*, energy development, fitness, power lines, survival, transmission.

Public demand for electricity has increased as a result of the expanding human population and industrial activities, resulting in >1.1 million km of high-voltage transmission lines in the United States (Giles and Brown 2015). The extent of power lines (transmission and distribution lines) is expected to increase with continued energy supply demands. Greater sage-grouse (*Centrocercus urophasianus*; i.e., sage-grouse), a species of conservation concern across the western United States (80 Federal Register 59857), is a landscape-level species that requires large tracts of intact sagebrush (*Artemisia* spp.) communities. The increase in demand for energy generation, transmission, and distribution within sage-grouse habitats has the potential to affect this species similar to other anthropogenic features (Naugle et al. 2011).

Power lines have the potential to directly and indirectly negatively affect sage-grouse populations. Direct mortality caused by colliding with power lines has been documented (Beck et al. 2006); however, indirect effects on population parameters are not well understood because of the lack of well-designed studies and various power line designs. Most power lines were established prior to large-scale sage-grouse studies, which makes it difficult to estimate the extent and magnitude of indirect effects of power lines on current populations (Johnson et al. 2011). In addition, a lack of newly established power lines limits our ability to implement well-designed studies to address potential indirect effects with pre-development data. Based on the few studies that exist, however, the extent and magnitude of effects appear to vary based on power line characteristics, amount

Received: 30 November 2017; Accepted: 15 July 2019

[1]*E-mail: cwlebeau@west-inc.com*

Appendix D

of available habitat, and the affected population parameter (Armentrout and Hall 2005, Schroeder 2010, Westover et al. 2016, Gibson et al. 2018, Kohl et al. 2019).

The variability among studies and power lines (e.g., voltage, size, configuration) makes it difficult to understand the potential effects of power lines on sage-grouse populations. This variability could be due to study design, study location, and other factors, such as landscape configuration and habitat characteristics that potentially confound inference (Walters et al. 2014, Westover et al. 2016, Kohl et al. 2019). For example, power lines are a linear feature often co-located with other linear anthropogenic features, such as roads, making it difficult to disentangle which feature is potentially affecting a sage-grouse population. In addition, interactive relationships between biotic, abiotic, and anthropogenic factors suggests that pulses in sage-grouse population growth, such as high recruitment in response to increased precipitation, may be mediated by habitats available to a population (Blomberg et al. 2012, Kohl et al. 2019). The extent and magnitude of these interactive effects may be difficult to assess because of potential confounding issues and inherent characteristics of the affected sage-grouse population.

There is some evidence that power lines negatively affect sage-grouse populations. For example, mean survival of adult sage-grouse increased as distance from leks to overhead lines (size or type of power line was not defined) increased within 20 km of overhead lines (Armentrout and Hall 2005). Nineteen of 20 leks in Washington, USA, within 7.5 km of multiple 500-kV transmission lines became vacant (Schroeder 2010). Landscape connectivity in Washington, in regard to gene flow and lek occupancy, was also affected by power lines (Shirk et al. 2015). In Nevada, USA, sage-grouse resource selection and demography were negatively associated with habitats ≤12.5 km from a 345-kV transmission line (Gibson et al. 2018). In addition, lek trends, nesting and brooding habitat selection, and nest and brood success were negatively correlated with power lines ≤2.8 km from power lines (Kohl et al. 2019). Whereas some researchers have documented negative relationships, others have not observed a relationship between power lines and different sage-grouse population parameters. For example, the same study in Nevada found only a weak effect of a 345-kV transmission line on adult female survival (Gibson et al. 2018). In Utah, USA, female sage-grouse with broods selected areas closer to transmission lines, but the authors acknowledged some potential confounding factors associated with this analysis (Westover et al. 2016). At the landscape scale, transmission lines did not affect lek persistence in a multi-state study (Kohl et al. 2019). There are several unique characteristics associated with each of these studies, including location, duration, seasonal timing, size of power line, and habitat characteristics, all of which have the ability to influence the interpretation of the generalized effects of transmission lines on sage-grouse populations.

We investigated potential effects of 230-kV wood pole, H-frame transmission lines on habitat selection and survival of a sage-grouse population during 3 biologically meaningful periods: nesting, brood-rearing, and summer. The objective of our study was to estimate the effects of 230-kV transmission lines on reproductive sage-grouse habitat selection and survival by accounting for local environmental conditions that could potentially confound the relationship with transmission lines in 2 different study areas. We predicted the presence of transmission lines would affect sage-grouse habitat function, but the extent and magnitude would vary based on habitat suitability.

STUDY AREA

Our study areas were located north of Interstate 80 and south of the Shirley Basin in Carbon County, Wyoming, USA, consistent with the description provided by LeBeau et al. (2017; latitude 41.91°, longitude −106.37°; Fig. 1). We separated our study area based on leks in 2 areas: the Seven Mile Hill (SMH) group consisted of 4 leks north of US Highway 30 and 287, and the Simpson Ridge (SR) group consisted of 6 leks south of US Highway 30 and 287. The average minimum distance between the SMH and SR leks was 11.7 km. We considered females from SMH area leks to occupy habitats within the SMH study area and females from the SR area leks to occupy habitats within the SR study area. We further defined each study area by calculating home ranges from the distribution of radio-marked females to define the outer boundary of each study area consistent with the description in LeBeau et al. (2017).

Multiple 230-kV wooden H-frame transmission lines occurred within each study area (Fig. 1). One transmission line bisected the SR study area east to west and 1 transmission line bisected the SMH study north to south. A portion of the transmission line at SMH was co-located with an existing county dirt road and located in the northern portion of the SMH. The transmission line that bisected the SMH study area also occurred within a small portion of the western SR study area. There were 30 km of transmission lines within SR and 31 km within SMH. The transmission lines within both study areas have existed on these landscapes for >10 years. The distance from capture lek to the nearest transmission line ranged from 3.0 km to 6.0 km at SMH and from 1.0 km to 6.4 km at SR.

METHODS

Field Methods

The main sampling units for our study were 10 occupied sage-grouse leks. From these leks, we captured female sage-grouse and monitored marked individuals through time. Leks targeted for captures were located throughout the study areas. Our field methods followed those described by LeBeau et al. (2017) where we captured 346 ($n = 160$ in SMH, 186 in SR) female sage-grouse at night roosts near leks by spotlighting and use of hoop nets (Giesen et al. 1982, Wakkinen et al. 1992) during the 2009 through 2013 breeding seasons. We classified individuals as yearling or adult (Eng 1955) and fitted each captured sage-grouse with a 22-g necklace-mounted very high frequency (VHF) radio transmitter with a battery life of 666 days (Advanced Telemetry Systems, model A4000, Isanti, MN, USA).

Appendix D

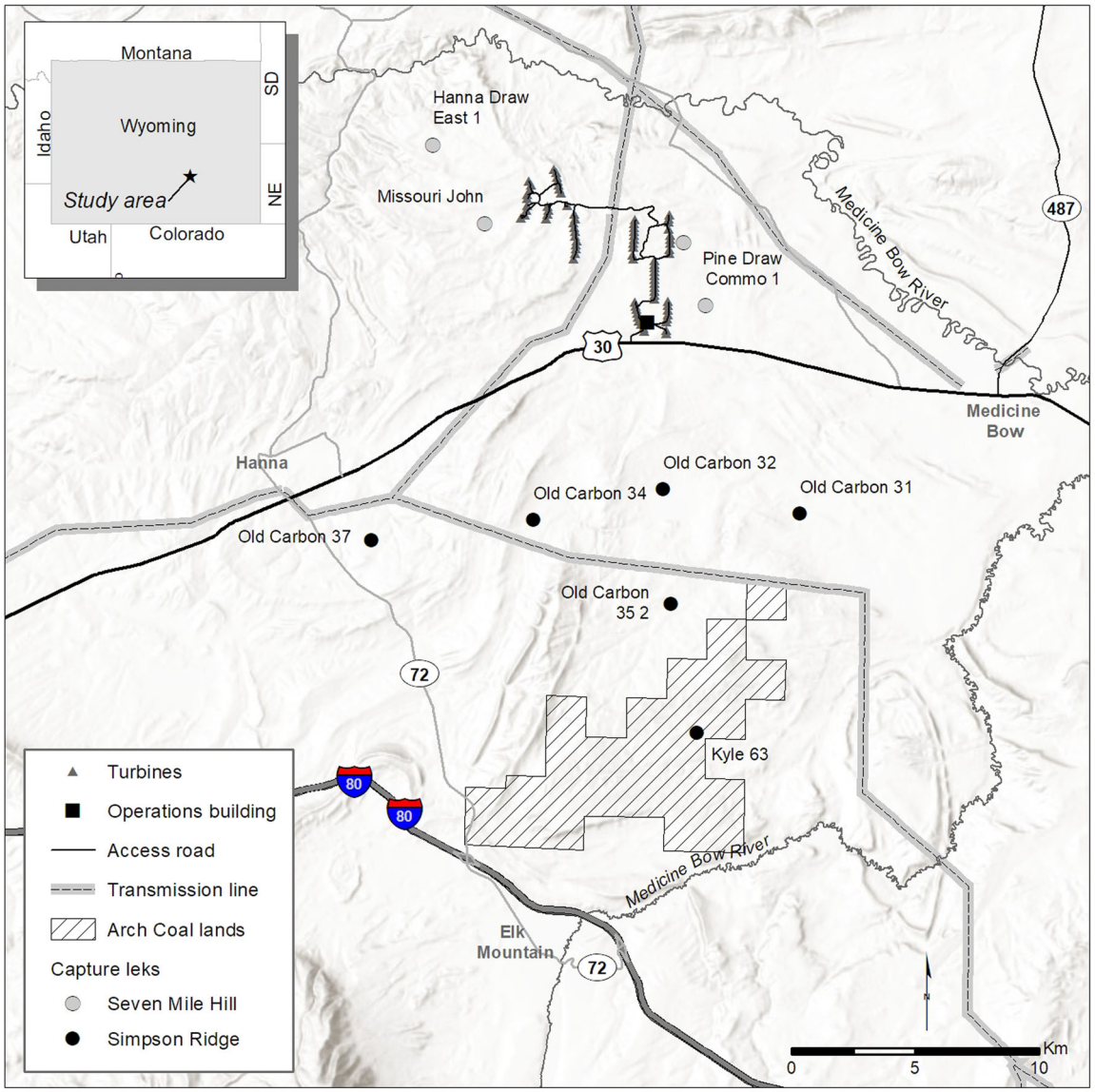


Figure 1. Location of transmission lines and occupied sage-grouse leks targeted for capture and monitoring female sage-grouse within the Seven Mile Hill and Simpson Ridge study area from 2009–2014 in Carbon County, Wyoming, USA.

Radio-transmitters were equipped with a mortality sensor that was trigged after 8 hours without movement. We obtained approval from the Wyoming Game and Fish Department (Chapter 33, permit 572) to capture, handle, and monitor female greater sage-grouse.

We attempted to locate each radio-marked female 3 times/week during the pre-nesting and nesting period (Apr through Jun); and at least once weekly for brooding and broodless females (i.e., females that were not currently nesting or raising young) from nest fate through 31 October (LeBeau et al. 2017). We monitored marked sage-grouse from the ground using hand-held receivers and antennas. We determined sage-grouse locations by triangulation or homing until marked individuals were visibly observed.

Once a nest location was established, we conducted incubation monitoring on an alternate-day schedule to determine nest fate. For each nest attempt, we collected data on timing of incubation and nest success. We considered a nest that successfully hatched (i.e., eggs with detached membranes; Wallestad and Pyrah 1974) ≥1 egg to be a successful nesting attempt (Rotella et al. 2004). Nests that failed to hatch ≥1 egg were failed nesting attempts. We mapped all nest locations using a hand-held global positioning system (GPS). We monitored females that were unsuccessful in their first nesting attempt 3 times/week through 15 June to determine possible second nesting attempts.

Geographic Information System Covariates

We developed a suite of anthropogenic, vegetation, and environmental covariates to estimate habitat selection and survival (Table 1). We digitized transmission lines and roads using aerial satellite imagery and ArcMap 10 (Environmental System Research Institute [ESRI], Redlands, CA, USA) to calculate the minimum distance to each feature. We developed a binary viewshed covariate (visible = 1 and not

Appendix D

Table 1. Explanatory anthropogenic and environmental covariates used in modeling sage-grouse nest, brood, and summer habitat selection and survival at the Seven Mile Hill and Simpson Ridge study areas, Carbon County Wyoming, USA, 2009–2014. We calculated percent cover at multiple scales specific to each analysis.

Covariates	Variable description
Anthropogenic infrastructure	
Distance to major roads	Distance from sage-grouse location to nearest major road (WYO HWY 72, US HWY 287 and 30, and I-80; km)
Distance to transmission line	Distance from sage-grouse location to nearest overhead transmission line (km)
Visible transmission line (viewshed)	A point on the landscape where a transmission line was visible to sage-grouse
Distance to turbines	Distance from sage-grouse location to nearest turbine (km)
Proportion of disturbance	% of surface disturbed by the Seven Mile Hill Wind Energy Facility (e.g., turbine pads and access roads) for each spatial scale.
Vegetation	
Bare ground	% bare ground (1-m resolution)
Big sagebrush[a]	% big sagebrush (30-m resolution)
Herbaceous	% herbaceous cover (1-m resolution)
Litter[a]	% litter (30-m resolution)
Sagebrush[a]	% sagebrush (30-m resolution)
Shrub	% shrub cover (1-m resolution)
Shrub height[a]	Shrub height (0–253 cm; 30-m resolution)
Meadow	% meadow (1-m resolution)
Distance to meadow	Distance from sage-grouse location to nearest meadow (km)
Wyoming big sagebrush[a]	% Wyoming big sagebrush (30-m resolution)
Environmental	
Slope	Degrees 0–90 (10-m resolution)
Terrain ruggedness	Variability in slope and aspect (0–1; 1 = complete terrain variation; Sappington et al. 2007; 10-m resolution)
Distance to capture lek	Distance from sage-grouse location to respective lek of capture
Distance to nearest occupied lek	Distance from sage-grouse location to nearest occupied lek
Elevation	Altitude above sea level (m; 10-m resolution)
Compound topographic index	Water accumulation (large values = high water accumulation; 10-m resolution)
Topographic position index	Variability in average elevation within a neighborhood (−1–1; Positive values = ridges; negative values = valleys; 10-m resolution)

[a] Vegetation covariates obtained from Homer et al. (2012).

visible = 0) that determined where a transmission line was visible to sage-grouse from any point on the landscape. The viewshed predictor assumed visibility from ground level without accounting for height of surrounding vegetation. We constrained our models with height above ground for the transmission line at 27 m tall and modeled the extent at which a sage-grouse could see the transmission line (i.e., viewsheds as either 0.5, 1, 1.5, 2, 2.5, or 3 km). We calculated viewsheds in ArcMap 10.

Vegetation layers used in the analysis were remotely sensed vegetation products developed from 1-m resolution National Agricultural Imagery Program (NAIP) image mosaics acquired in 2009 and 2012 (U.S. Department of Agriculture 2009, 2012; LeBeau et al. 2017) and vegetation products developed by Homer et al. (2012). We considered 4 primary continuous field components including percent bare ground, percent herbaceous cover, percent shrub cover (LeBeau et al. 2017), and percent litter (Homer et al. 2012), and 4 secondary components including percent sagebrush (*Artemisia* spp.), percent big sagebrush (*A. tridentata* spp.), percent Wyoming big sagebrush (*A. t. wyomingensis*), and shrub height (Homer et al. 2009, 2012; Table 1). We considered landscape features such as elevation, slope, compound topographic index (CTI), topographic positon index (TPI), and terrain ruggedness, all of which we calculated from a 10-m National Elevation Dataset (DEM; U.S. Geological Survey 2015). We also included distance to nearest lek (km) and distance to lek of capture (km) as covariates.

General Analysis Methods

We found evidence for variable effects of transmission lines in previous landscape-scale habitat selection and demographic analyses in our study areas (LeBeau et al. 2017). For example, sage-grouse appeared to select habitats close to transmission lines in 1 study area and avoided these habitats in the other study area during various seasonal periods. In addition, we observed a negative effect on nest survival but no effect on female survival. Therefore, we assumed that variation in behavior and demography relative to transmission lines was potentially confounded by other environmental factors (e.g., elevation, distance to lek, TPI, or a combination). To account for potential confounding factors, we followed the approach of Avgar et al. (2017) to estimate the effect of transmission lines on selection and survival, after accounting for habitat conditions other than transmission lines in our study areas. Our general approach was to first predict habitat selection and survival during each time period for each study area using models previously developed that excluded transmission line covariates. We converted those predictions to a habitat suitability index (HSI; described below) and used HSI as independent predictor variables in further modeling (models used to create the HSI are available online in Supporting Information). The HSI, therefore, incorporated several habitat covariates that could be simultaneously influencing selection and survival. We then evaluated models with the main effects of HSI and transmission line predictors and models that included interactions of HSI with transmission line

Appendix D

covariates to evaluate potential effects of transmission lines on resource selection or survival. These final models then served as a proxy for habitat function.

Habitat Selection Analyses

We had a unique opportunity to model the effect of transmission lines in 2 different study areas simultaneously using consistent habitat data, allowing us to compare the potential relationship of transmission lines between groups of individuals with differing available habitats. We previously developed habitat selection models that estimated the relative probability of nest site, brood-rearing, and summer habitat selection within our study areas (LeBeau et al. 2017). These models followed the form of a discrete choice habitat selection models (Arthur et al. 1996, Manly et al. 2002, McDonald et al. 2006). We removed the transmission line covariates that were included in these models and re-estimated the models in our study areas to develop our base habitat selection models. Models used to create base habitat selection models are available online in Supporting Information. The coefficients from these discrete choice models yielded resource selection functions (RSFs), defined as any function that provides predictions that are proportional to the probability of use of habitat units (Manly et al. 1993, 2002). We employed a Type I study design where habitat selection and availability were estimated at the population level and over a 6-year time period (Thomas and Taylor 2006). We defined available habitat by calculating kernel home ranges for all sage-grouse locations observed from 2009–2014 within each time period for the SMH and SR study areas consistent with LeBeau et al. (2017). Yearly kernel home range sizes and extents varied slightly during the study, thus we combined locations and established available habitat from all data by study area.

We developed RSFs during 3 biologically meaningful periods: nesting, brood-rearing, and summer. We included all first and second nesting attempts from a given year in the nest site habitat selection analysis. We included all early and late brood locations (i.e., 30–35 days post-hatch) associated with each female grouse that successfully hatched ≥1 egg in the brood-rearing habitat selection analysis. We did not include subsequent locations from females that were not successful during either the early or late brood-rearing period in the brood-rearing analysis because our goal was to model selection patterns of brooding females. We included the locations of broodless females and all locations observed after the late brood-rearing period through 31 October of each year in the summer habitat selection analysis.

We generated grid cells with 90-m × 90-m spacing to identify available habitat units within each study area's available extent. We extracted covariates associated with each available habitat unit at varying scales that were included in the previously developed RSFs to include in each RSF model that did not include a transmission line effect (LeBeau et al. 2017). A choice set included all available habitat units associated with a specific nest, brood-rearing, and summer location, and the used nest, brood, or summer habitat unit. We then used these models to evaluate habitat function by considering the effect of transmission lines.

Survival Analysis

Similar to the habitat selection analysis, we created survival models by applying previously developed nest and female survival models that did not consider the effect of transmission lines within our study areas (LeBeau et al. 2017). We did not estimate brood survival relative to transmission lines because of the small number of failed broods ($n = 7$) within 2 km of transmission lines. We included random effects associated with all individuals captured at specific leks to the best approximating model to allow for random fluctuations in the baseline hazard for each individual because variation in survival could be related to the habitat associated with the lek at which a female bred (Connelly et al. 2000, Liebezeit et al. 2009). We assessed the utility of including random effects using an analysis of variance (ANOVA) and a Wald chi-square test (Therneau 2015). We excluded the random effects term from the best approximating survival model if the ANOVA test indicated no significant differences between the random effects model and the proportional hazards model with only fixed effects. We used the Andersen-Gill (A-G) formulation of the Cox model to estimate female survival because of its ability to use time-varying covariates as covariates changed throughout the survival period (Anderson and Gill 1982). There was some uncertainty in the exact time of failure as a result of our discrete monitoring methods; however, we assumed the data were continuous in our modeling and this assumption would not influence our results.

We assessed nest survival for a 28-day incubation period during the 2009 through 2014 nesting seasons (incubation period lasts 25–29 days; Schroeder et al. 1999). We combined nests observed within each study area into 1 sample to model survival relative to transmission lines because we found no differences in survival relative to study area (LeBeau et al. 2017). Nests from second attempts following failed nests for each individual might not be independent of first nests and were excluded from survival analyses. Furthermore, a range-wide assessment suggested that nest success of second nest attempts was higher than first nest attempts (Taylor et al. 2012), which could potentially bias our results. First nests that hatched in early July were considered re-nests and excluded from analyses because they were within the hatch date range of other re-nests and we assumed the first nesting attempt was likely missed by the observer. Failures occurred when a female's nest was predated. We assigned the nest's date of failure half way between the last 2 monitoring intervals. We considered nests that contained at ≥1 egg at the end of the 28-day incubation period to be successful and censored them (Nur et al. 2004).

We modeled female sage-grouse survival from time of capture or 1 April to 31 October during all study years. We monitored female sage-grouse ≥1 time/week during this period. We assumed that seasons were independent when there were multiple seasons of survival data for a single

female. We recorded mortality events when we confirmed mortality visually via telemetry. We assigned the date of mortality by the condition of the carcass and last monitoring interval when the individual was known to be alive. We combined individuals into 1 sample because there was no differences in the variability of survival between the study areas (LeBeau et al. 2017).

Habitat Function

We used coefficients from base habitat selection and survival models to estimate RSFs or survival probability functions (SPFs; Kirol et al. 2015), respectively. Models took the form: $w(x) = \exp(\beta_1 x_1 + \beta_2 x_2 + \cdots \beta_k x_k)$, where β_1, β_2, β_k were coefficients of x_1, x_2, … x_k covariates. We transformed each RSF and SPF to an HSI, $\text{HSI} = w(x)/[1 + w(x)]$, to scale relative predictions between zero and 1 to compare multiple RSFs and SPFs.

We fit a second set of models for each behavior and demographic rate by interacting predicted HSI values and 1 transmission line covariate (distance to or visual transmission; Table 1). If a transmission line was influencing habitat selection or survival, we expected a model containing a transmission line covariate to be the most parsimonious model when compared to the model that only included HSI. We considered the most parsimonious model to be the model with the lowest corrected Akaike's Information Criterion (AIC_c; Akaike 1974, Burnham and Anderson 2002). A significant interaction (alpha level = 0.10) between transmission line and HSI would suggest that the relationship between transmission line and selection or survival varied with HSI. We created marginal effects plots to visually inspect the relative probability of selection or survival associated with transmission line covariates.

We used k-fold cross-validations to evaluate the predictive ability of each RSF that informed habitat function (Boyce et al. 2002). We partitioned used habitat units and respective choice sets into 5 equal-sized groups, removed 1 group (testing data) and re-estimated coefficients in each RSF model with the remaining groups (testing data). We then used coefficients from testing data models to generate predictions with testing data. We binned predictions within each choice set into 20 equal size percentile classes. We compared the number of used habitat units from all choice sets in each prediction class to binned class ranks using a Spearman's rank correlation. We repeated this process for each group and averaged Spearman's rank correlation coefficients (r_s) to test model performance.

Once we developed and validated RSFs and SPFs, we evaluated the relative probability of selection and survival during the different study periods and study areas to assess potential effects of transmission lines on habitat function. We placed a 90-m × 90-m grid within the extent of combined home ranges within both study areas to create predictive surfaces. Individual pixels with lower relative probability of use or survival were suggested to have low habitat function relative to pixels with high relative probability of use or survival. There were 3 covariates used in base models with values that changed from 2009–2011 to 2012–2014; thus, we generated predictive surfaces for each period. We averaged all the RSF and SPF predictive surfaces separately to get an average prediction for habitat selection and survival. We then averaged the habitat selection and survival predictions to estimate habitat function scores.

We then determined the distance from transmission lines at which habitat function was lowest. We evaluated habitat function relative to transmission lines and occupied leks across varying levels of HSI. We placed the HSI predictions into 3 equal-area bins (i.e., low, medium, high) using percentiles to represent habitats with progressively higher HSI predictions. We estimated thresholds or change points for each HSI percentile relative to transmission lines with a recursive partitioning approach with the change point defined as the first node of a classification tree for each HSI category (Qian et al. 2003). We determined the threshold using the rpart package in R (Therneau et al. 2019, R Core Team 2016). This method estimates the point resulting in the largest deviance reduction in the average habitat function score (e.g., average prediction) from all predicted surfaces. We resampled the habitat function scores from all predicted surfaces with replacement 100 times to attain bootstrap confidence intervals for the threshold using the percentile method (Qian et al. 2003, Manly 2006). We judged the significance of threshold results with a chi-square test of significance having 1 degree of freedom. We rejected the null hypothesis of no change point if the threshold identified by recursive partitioning was better than a null model with no threshold. We plotted habitat function for low and high HSI relative to distance to transmission line to visually inspect the results. In addition, we determined the average distance of pixels within each percentile bin to occupied leks to inform management recommendations.

RESULTS

The most parsimonious models for nest site selection at SR and SMH included an interaction between HSI and visible transmission line with a 1.5-km sage-grouse viewshed and an interaction between HSI and a quadratic effect of distance to transmission line, respectively (Table 2). However, we detected a significant interaction only between the visible transmission line covariate with a 1.5-km viewshed and HSI at SR (Table 3). In habitats with lower HSI predictions at SR (e.g., <0.6), the relative probability of nest site selection in visible and non-visible habitats were similar (Table 3; Fig. 2). As HSI increased, however, the relative probability of nest site selection increased in habitats that were not visible to transmission lines, suggesting females avoided selecting nests sites that were visible to transmission lines in habitats with higher suitability (Fig. 2). Visual inspection of partial plots suggested that relative probability of nest site selection at SMH increased as distance to transmission line increased to approximately 3.5 km before decreasing in high HSI habitats, providing some evidence of avoidance in high HSI habitats when sage-grouse are close to the transmission line (Fig. 3A). The

Appendix D

Table 2. Top 10 sage-grouse habitat selection models at the Seven Mile Hill and Simpson Ridge study areas, Carbon County, Wyoming, USA, 2009–2014. Model fit statistics include number of parameters (K), corrected Akaike's Information Criterion (AIC_c), change in AIC_c (ΔAIC_c), and Akaike weights (w_i). We included the habitat suitability index (HSI) base model if it was not within the top 10 habitat selection models. The transmission covariate included the linear distance to the nearest transmission line and the viewshed covariate determined if the transmission line was visible to sage-grouse assuming various distances at which the sage-grouse could see the transmission line.

Model	K	AIC_c	ΔAIC_c	w_i
Simpson Ridge nest site selection				
HSI × viewshed (1.5 km)	4	3,331.49	0.00	1.00
HSI × viewshed (2.0 km)	4	3,335.91	4.42	0.11
HSI + transmission	3	3,337.82	6.33	0.04
HSI + viewshed (2.0 km)	3	3,337.82	6.34	0.04
HSI × viewshed (2.5 km)	4	3,338.16	6.67	0.04
HSI + viewshed (1.5 km)	3	3,338.49	7.00	0.03
HSI × transmission + HSI × transmission^2	6	3,339.03	7.54	0.02
HSI × transmission	4	3,339.38	7.89	0.02
HSI + transmission + transmission^2	4	3,339.74	8.26	0.02
HSI × viewshed (3.0 km)	4	3,340.07	8.58	0.01
HSI	2	3,343.68	12.20	0.00
Seven Mile Hill nest site selection				
HSI × transmission + HSI × transmission^2	6	2,716.14	0.00	0.61
HSI + transmission + transmission^2	4	2,717.06	0.02	0.39
HSI × viewshed (1.0 km)	4	2,751.58	35.45	0.00
HSI × viewshed (0.5 km)	4	2,757.17	41.03	0.00
HSI × viewshed (3.0 km)	4	2,759.62	43.48	0.00
HSI + viewshed (3.0 km)	3	2,761.45	45.32	0.00
HSI × viewshed (1.5 km)	4	2,761.91	45.78	0.00
HSI × viewshed (2.0 km)	4	2,762.48	46.35	0.00
HSI + viewshed (2.5 km)	3	2,762.58	46.44	0.00
HSI × viewshed (2.5 km)	4	2,763.65	47.51	0.00
HSI	2	2,772.94	56.80	0.00
Simpson Ridge brood-rearing habitat selection				
HSI + transmission + transmission^2	4	9,137.10	0.00	0.75
HSI × transmission + HSI × transmission^2	6	9,139.32	2.22	0.25
HSI × transmission	4	9,156.53	19.43	0.00
HSI + transmission	3	9,179.77	42.67	0.00
HSI + viewshed (0.5 km)	3	9,181.20	44.10	0.00
HSI × viewshed (0.5 km)	4	9,182.39	45.29	0.00
HSI + viewshed (2.0 km)	3	9,184.39	47.29	0.00
HSI + viewshed (1.5 km)	3	9,185.82	48.72	0.00
HSI × viewshed (2.0 km)	4	9,185.94	48.84	0.00
HSI	2	9,186.97	49.87	0.00
Seven Mile Hill brood-rearing habitat selection				
HSI + transmission + transmission^2	4	7,364.41	0.00	0.76
HSI × transmission + HSI × transmission^2	6	7,366.76	2.34	0.24
HSI × viewshed (1.0 km)	4	7,397.18	32.77	0.00
HSI × viewshed (0.5 km)	4	7,397.48	33.07	0.00
HSI × viewshed (2.0 km)	4	7,406.67	42.26	0.00
HSI + viewshed (1.0 km)	3	7,406.71	42.30	0.00
HSI + viewshed (0.5 km)	3	7,407.66	43.25	0.00
HSI + viewshed (2.0 km)	3	7,410.48	46.07	0.00
HSI × viewshed (1.5 km)	4	7,412.26	47.84	0.00
HSI + viewshed (1.5 km)	3	7,414.20	49.78	0.00
HSI	2	7,433.18	68.76	0.00
Simpson Ridge summer habitat selection				
HSI × transmission + HSI × transmission^2	6	35,327.38	0.00	0.92
HSI + transmission	3	35,333.31	5.93	0.04
HSI × transmission	4	35,335.31	7.75	0.02
HSI + transmission + transmission^2	4	35,335.31	7.93	0.02
HSI + viewshed (3.0 km)	3	35,352.15	24.77	0.00
HSI + viewshed (2.5 km)	3	35,354.02	26.64	0.00
HSI × viewshed (3.0 km)	4	35,354.15	26.77	0.00
HSI × viewshed (2.5 km)	4	35,355.80	28.42	0.00
HSI + viewshed (2.0 km)	3	35,360.72	33.34	0.00
HSI × viewshed (2.0 km)	4	35,362.54	35.16	0.00
HSI	2	35,385.90	58.52	0.00
Seven Mile Hill summer habitat selection				
HSI + transmission + transmission^2	4	31,543.65	0.00	0.45
HSI + viewshed (3.0 km)	3	31,544.70	1.05	0.26
HSI × viewshed (3.0 km)	4	31,545.55	1.90	0.17
HSI × transmission + HSI × transmission^2	6	31,546.32	2.67	0.12

Table 2. (*Continued*)

Model	K	AIC_c	ΔAIC_c	w_i
HSI × viewshed (2.5 km)	4	31,559.77	16.12	0.00
HSI + viewshed (2.5 km)	3	31,561.48	17.83	0.00
HSI + transmission	3	31,563.80	20.15	0.00
HSI × transmission	4	31,565.67	22.02	0.00
HSI × viewshed (2.0 km)	4	31,577.12	33.47	0.00
HSI + viewshed (2.0 km)	3	31,578.30	34.65	0.00
HSI	2	31,590.86	47.21	0.00

5-fold validation indicated that RSF models developed at SMH and SR had moderate overall predictability ($\bar{x}\ r_s = 0.66$ and $\bar{x}\ r_s = 0.56$, respectively).

The most parsimonious models for brood-rearing habitat selection at SR and SMH both included a quadratic effect of transmission line (Table 2). Top models did not contain interactions between transmission line covariates and HSI at both study areas, suggesting no clear relationship of brood-rearing habitat selection relative to transmission lines across differing HSI values (Table 3). The relative probability of brooding rearing selection increased as distance to transmission line increased up to 4 km and 2.5 km before decreasing at SMH and SR, respectively. The 5-fold validation indicated that RSF models had good overall predictability (SMH $\bar{x}\ r_s = 0.87$, SR $\bar{x}\ r_s = 0.88$)

Similar to brood-rearing, the most parsimonious models for summer habitat selection at SR and SMH included quadratic effects of transmission lines (Table 2). Only SR models, however, contained an interaction between the quadratic effect of transmission lines and HSI during summer (Table 3). The relative probability of summer habitat selection at SR increased as distance to transmission line increased in habitats with high HSI, suggesting females selected summer habitats farther from transmission lines in high HSI habitats and transmission lines did not affect selection patterns in lower HSI habitats (Fig. 3B). The 5-fold validation indicated that RSF models developed at SMH and SR had good overall predictability ($\bar{x}\ r_s = 0.98$ and $\bar{x}\ r_s = 0.92$, respectively).

We observed 187 failed nesting attempts. Mammalian and avian predators were the main source of nest failures. The median distance to transmission lines from all successful nests (2.89 km) was similar to all failed nesting attempts (3.33 km). We used 302 first nesting attempts in the Cox proportional hazard modeling. The most parsimonious model for nest survival included an interaction between HSI and visible transmission line covariate with a 1.0-km sage-grouse viewshed (Table 4). The addition of lek of capture included as a random intercept term in the top model was not different from the model that excluded the random intercept term ($P = 0.30$). The relative probability of nest survival increased in habitats visible to transmission lines with increasing HSI, suggesting the magnitude of the effect of transmission lines on nest survival was greatest in habitats with lower habitat suitability and lowest in habitats with high suitability (Table 5; Fig. 4). Habitat suitability does not appear to influence nest survival when sage-grouse are using habitats that are not visible to transmission lines (Fig. 4).

We monitored 340 females during the summer period from 2009–2014. We observed 189 mortalities of sage-grouse during the study period. There were 14 instances where the radio-transmitter possibly fell off the female and we censored those individuals at the time and location of their last known location prior to discovery. In addition, we removed 5 mortalities from the analysis that were potentially related to the stress of capture and handling because these mortalities were recorded within 10 days of capture (Kurzejeski et al. 1987). Most mortalities (56.1%) occurred during the first 10 weeks of summer (1 Apr through 10 Jun). It was difficult to accurately determine cause of female mortality; however, most mortalities were likely attributed to avian predators because females are more effective at evading mammalian predators (Conover et al. 2010).

We used 6,378 locations, 31 monitoring intervals, and 511 female-years (340 individuals monitored across multiple years) to model female summer survival relative to transmission lines over the study period. We included year as a stratum in the A-G model to allow different baseline hazards each year. The most parsimonious model for female survival included the main effects of HSI and visible transmission lines with a 0.5-km sage-grouse viewshed (Tables 4 and 5). The addition of lek of capture included as a random intercept term in the top model was not significantly different from the model that excluded the random intercept term ($P = 0.97$). Risk of mortality was 1.4 times higher in habitats that were visible to transmission lines assuming a 0.5-km sage-grouse viewshed (Table 5).

We found evidence to suggest that the presence of the transmission lines reduced habitat function and the magnitude of this effect varied based on habitat suitability. By incorporating predictions from these models, we determined that the reduction in habitat function due to the presence of transmission lines was greater in habitats with higher suitability compared to habitats with lower suitability (Fig. 5). Habitats with high suitability within 0.95 km (90% CI = 0.949 − 0.962 km) of a transmission line were associated with lower survival and lower relative probability of use when we combined the habitat selection and demography results to evaluate habitat function (Fig. 6). The magnitude of the effect of transmission lines on habitat function was lower in habitats with lower suitability within 0.50 km (90% CI = 0.495–0.780 km; Fig. 6). We rejected the hypothesis of

Appendix D

Table 3. Coefficients and 90% confidence intervals associated with covariates included in the most parsimonious model for nest, brood-rearing, and summer habitat selection by sage-grouse at the Simpson Ridge (SR) and Seven Mile Hill (SMH) study areas, Carbon County, Wyoming, USA, 2009–2014. The habitat suitability index (HSI) covariate was the relative probability of habitat selection without the influence of transmission line. The transmission covariate included the linear distance to the nearest transmission line and the viewshed covariate determined if the transmission line was visible to sage-grouse assuming various distances at which the sage-grouse could see the transmission line.

	Nest site selection		Brood-rearing habitat selection		Summer habitat selection	
Covariate	**SMH**	**SR**	**SMH**	**SR**	**SMH**	**SR**
HSI	4.41 (−0.46, 9.29)	5.71 (4.63, 6.79)	10.15 (9.01, 11.30)	6.02 (5.50, 6.54)	4.95 (4.69, 5.21)	4.83 (4.16, 5.49)
Transmission	−0.69 (−4.19, 2.80)		0.72 (0.55, 0.89)	−0.15 (−0.22, −0.08)	−0.24 (−0.31, −0.18)	−0.55 (−0.89, −0.21)
Transmission^2	−0.10 (−0.71, 0.51)		−0.09 (−0.11, −0.07)	0.03 (0.02, 0.03)	0.02 (0.01, 0.03)	0.10 (0.05, 0.15)
Viewshed (1.5 km)		2.31 (1.28, 3.35)				
HSI × transmission	2.35 (−1.38, 6.09)					0.89 (0.44, 1.34)
HSI × transmission^2	−0.11 (−0.76, 0.54)					−0.14 (−0.21, −0.08)
HSI × viewshed (1.5 km)		−2.98 (−4.60, −1.37)				

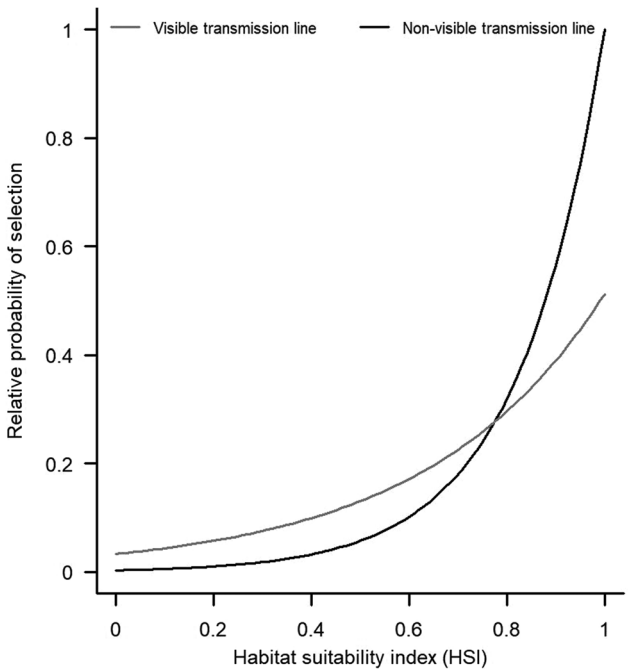


Figure 2. Probability of nest site selection relative to the visible transmission line covariate across levels of habitat suitability within sage-grouse home ranges at Simpson Ridge from 2009–2014 in Carbon County, Wyoming, USA.

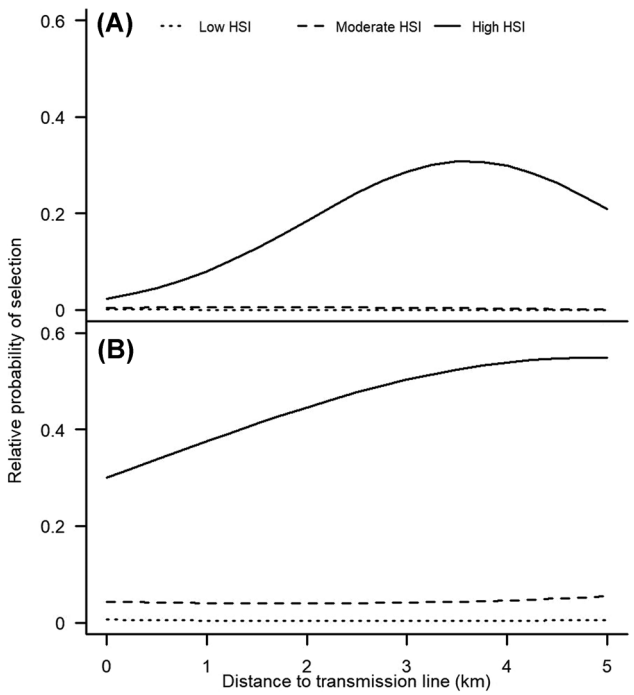


Figure 3. Probability of selection relative to the distance to transmission line covariate across low (0.1), moderate (0.5), and high (0.9) levels of habitat suitability index (HSI) within sage-grouse home ranges at Seven Mile Hill during the nesting period (A) and at Simpson Ridge during the summer (B) period from 2009–2014 in Carbon County, Wyoming, USA.

no change point because the threshold identified was better than the null model with no threshold ($P \leq 0.001$). In contrast, habitat function without the influence of transmission lines in habitats with high and low suitability did not experience a change point, providing further evidence that the presence of the transmission lines decreased habitat function (Fig. 5).

DISCUSSION

We examined habitat selection and survival to evaluate the effects of 230-kV transmission lines on female sage-grouse during the nesting, brood-rearing, and summer periods while accounting for potential confounding factors. Although the transmission lines we studied were the same voltage and configuration, the relative probability of habitat selection varied during different time periods and between study areas (LeBeau et al. 2017). Overall, transmission lines were negatively correlated with sage-grouse habitat selection and survival within our study areas over 6 years. By incorporating habitat conditions into 1 metric (i.e., HSI) and the variation in habitat suitability relative to

Appendix D

Table 4. Top 10 models for nest and female sage-grouse survival models at the Seven Mile Hill and Simpson Ridge study areas, Carbon County, Wyoming, USA, 2009–2014. Model fit statistics include number of parameters (K), corrected Akaike's Information Criterion (AIC_c), change in AIC_c (ΔAIC_c), and Akaike weights (w_i). The habitat suitability index (HSI) covariate was the relative probability of survival without the influence of transmission line. The transmission covariate included the linear distance to the nearest transmission line and the viewshed covariate determined if the transmission line was visible to sage-grouse assuming various distances at which the sage-grouse could see the transmission line.

Model	K	AIC_c	ΔAIC_c	w_i
Nest survival				
HSI × viewshed (1.0 km)	4	1,308.60	0.00	0.33
HSI × viewshed (1.5 km)	4	1,309.01	0.41	0.27
HSI + viewshed (1.5 km)	3	1,309.64	1.04	0.20
HSI + viewshed (0.5 km)	3	1,312.89	4.29	0.04
HSI + transmission + transmission^2	4	1,313.11	4.51	0.03
HSI + viewshed (1.0 km)	3	1,313.16	4.56	0.03
HSI × viewshed (0.5 km)	4	1,314.86	6.26	0.01
HSI + viewshed (2.0 km)	3	1,315.11	6.51	0.01
HSI + transmission	3	1,315.20	6.60	0.01
HSI × transmission + HSI × transmission^2	6	1,315.69	7.09	0.01
HSI	2	1,316.36	7.76	0.01
Female survival				
HSI + viewshed (0.5 km)	3	1,314.03	0.00	0.46
HSI × viewshed (0.5 km)	4	1,314.43	0.41	0.37
HSI + viewshed (1.0 km)	3	1,319.11	5.08	0.04
HSI + viewshed (3.0 km)	3	1,319.98	5.95	0.02
HSI × viewshed (1.0 km)	4	1,321.09	7.07	0.01
HSI	2	1,321.19	7.17	0.01
HSI + viewshed (1.5 km)	3	1,321.26	7.23	0.01
HSI + viewshed (2.5 km)	3	1,321.39	7.36	0.01
HSI × transmission	4	1,321.72	7.70	0.01
HSI × viewshed (3.0 km)	4	1,321.82	7.79	0.01

Table 5. Coefficients and 90% confidence intervals associated with covariates included in the most parsimonious nest and female survival models for sage-grouse at the Simpson Ridge and Seven Mile Hill study areas, Carbon County, Wyoming, USA, 2009–2014. The habitat suitability index (HSI) covariate was the relative probability of survival without the influence of transmission line. The viewshed covariate determined if the transmission line was visible to sage-grouse assuming various distances at which the sage-grouse could see the transmission line.

Covariate	Nest survival	Female survival
HSI	5.23 (3.11, 7.34)	4.80 (3.76, 5.83)
Viewshed (0.5 km)		0.89 (0.45, 1.33)
Viewshed (1.0 km)	5.31 (2.37, 8.26)	
HSI × viewshed (1.0 km)	−9.62 (−15.54, −3.70)	

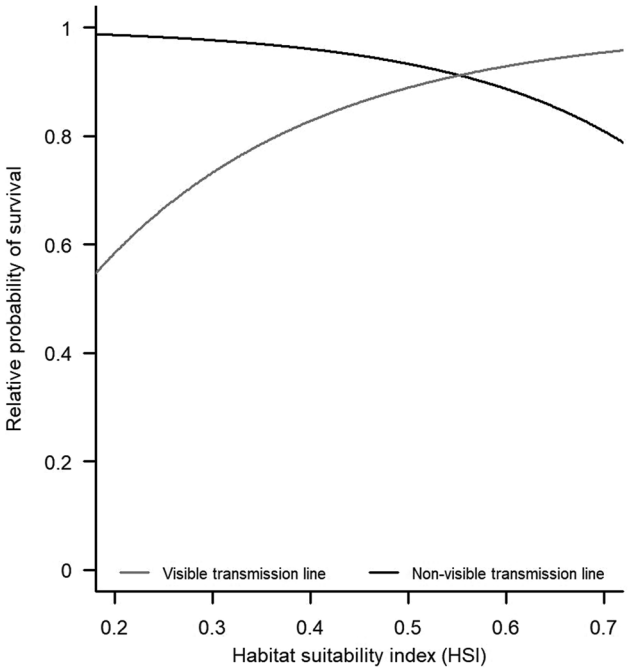


Figure 4. Relative probability of sage-grouse nest survival compared to the habitat suitability index (HSI) when transmission lines were either visible or not visible at the Seven Mile Hill and Simpson Ridge study areas from 2009–2014 in Carbon County, Wyoming, USA.

transmission lines, we obtained consistent results between SMH and SR. Our interpretation that sage-grouse avoided habitats close to transmission lines at SMH and selected habitats closer to transmission lines at SR in LeBeau et al. (2017) was likely confounded by the extent of available habitat and habitat features on the landscape and not the presence of the transmission lines. The few studies that have estimated the effects of transmission lines on sage-grouse habitat selection generally reported that habitat selection was not influenced by transmission lines, but the authors acknowledged some potential confounding issues (Wisinki 2007, Hansen et al. 2016, Westover et al. 2016). Kohl et al. (2019) did detect avoidance during the nesting and brooding season, but the magnitude of avoidance depended on the availability of sagebrush cover and possible correlation of power lines and roads. By incorporating habitat suitability in our analysis, we were able to estimate the effect of transmission lines in habitats with varying habitat suitability, addressing a potential issue confounding previous results. Further, because the base models used to estimate HSI included other anthropogenic stressors (e.g., wind turbines; Table 1), the potential confounding issues with these infrastructures were accounted for in our approach.

We found that habitat close to the transmission line may be of low suitability regardless of the presence of the transmission line (e.g., greater percentage of bare ground, close to major roads); therefore, low habitat function could be attributed to low suitability and not the presence of the transmission line. On the other hand, if habitat had high suitability and we observed an effect of transmission line, we attributed that effect to the transmission line and not the underlying habitat suitability. We consistently found the magnitude of the effect of transmission lines on habitat function to be greater in habitats with higher habitat suitability, suggesting transmission lines are negatively associated with habitat function. Nest survival was the only demographic rate we evaluated that was negatively associated with transmission lines in habitats with low suitability, suggesting that nest survival in high suitability habitats was less affected by the presence of transmission lines and possibly influenced more by habitat conditions, which was similar to Kohl et al. (2019). These transmission lines have existed on the landscape prior to our study; thus, sage-grouse

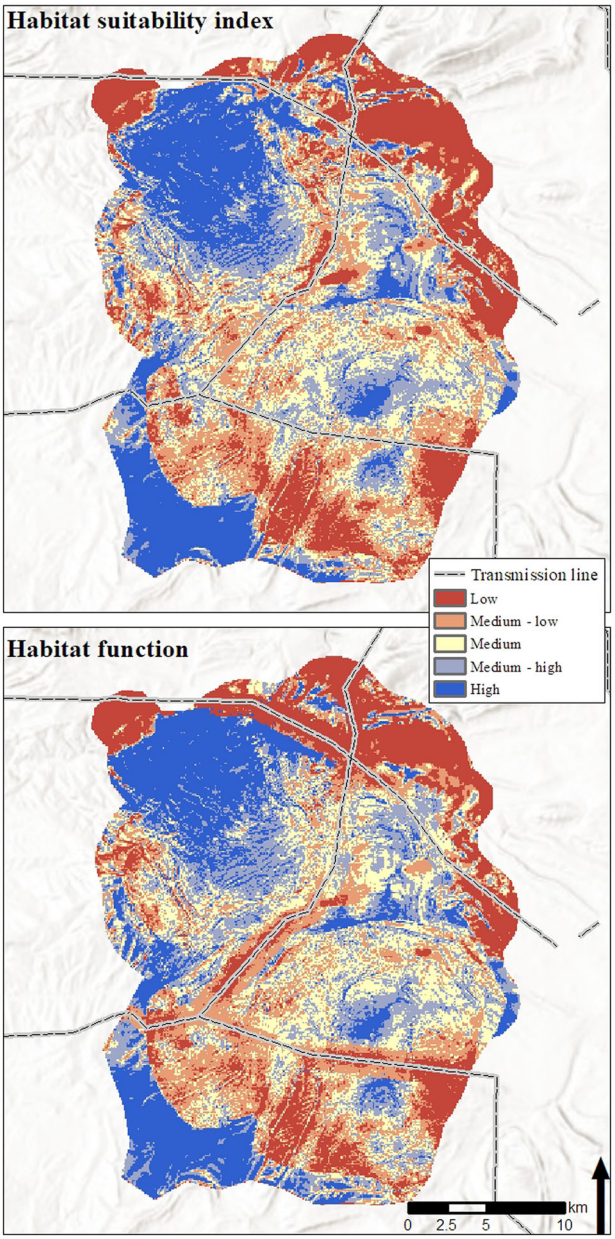


Figure 5. Predictive maps developed from resource selection and survival probability functions without the effect of transmission lines (habitat suitability index) and with the effect of transmission lines (habitat function) within sage-grouse home ranges during nesting, brood-rearing, and summer seasons combined at the Seven Mile Hill and Simpson Ridge study areas from 2009–2014 in Carbon County, Wyoming, USA.

were likely already selecting habitats relative to transmission lines, which could have influenced our estimates of habitat suitability. Nonetheless, we found clear differences in selection for transmission lines across different habitat suitability categories, suggesting we accurately captured habitat function relative to existing transmission lines.

Our results could have been strengthened with pre-construction data allowing for a before-after, control-impact (BACI) analytical approach or data from a control area in a control-impact study design (Green 1979). Many of the potential long-term effects of the transmission line may have already been realized on this sage-grouse population because it has existed on the landscape for >10 years (Johnson et al. 2011) resulting in our measuring the residual effects of the line. We benefited, however, from a long-term dataset that allowed us to detect small changes in population parameters relative to transmission lines.

Similar to other forms of anthropogenic disturbance, transmission lines may fragment the landscape, with the degree of fragmentation likely dependent on power line size (e.g., 69-kV vs. 500-kV), structure configuration (e.g., monopole vs. steel lattice), and placement on the landscape. Our results suggest that placing a 230-kV transmission line in lower suitability habitats that are not visible to sage-grouse may reduce the negative effects on habitat selection and survival. It is unknown, however, how both smaller power lines (distribution and transmission voltages) and larger transmission lines >230 kV may affect habitat selection and survival patterns, particularly given other variables, such as topography, habitat value, and predator-prey relationships within our study. We developed habitat suitability models using covariates that are important to sage-grouse populations and that were specific to this population. In general, on average, habitat suitability (e.g., 67–100% HSI) was highest within 3.14 km (90% CI = 3.14–3.16 km) of occupied leks, suggesting habitats close to leks have relatively higher suitability than those farther from leks. Kohl et al. (2019) recommended a buffer of 2.3–2.8 km from active leks to minimize the effects of new transmission lines on the population; this buffer was similar to the area we determined to have high suitability and the area where impacts are expected to be the greatest.

The mechanisms influencing habitat function relative to transmission lines are generally unknown; however, decreased habitat function could be related to the perceived threat of raptor perching (avoidance) or a higher density of predators (reduced survival; Gibson et al. 2018). Transmission lines may increase edge effects, which could increase predator efficiency (Batary and Baldi 2004). In addition, nests appeared to be more susceptible to failure in habitats visible to transmission lines with low habitat suitability, suggesting the presence of the transmission lines may have been facilitating increased predation rates in these sub-optimal habitats. Conversely, in habitats with high suitability, the presence of the transmission lines did not appear to influence nest survival potentially because the conditions in the underlying habitat were negating any advantage that transmission lines provided predators. A concurrent avian use study indicated that avian predator presence (raptors and corvids) in habitats with high suitability was greater closer to transmission lines, suggesting that higher avian predator density close to the transmission lines may have contributed to the reduction in habitat function we observed (C. W. LeBeau, Western EcoSystems Technology, Inc., unpublished data). Kohl et al. (2019) also documented high avian predator use of power lines in their study, which could have increased predation risk closer to power lines.

To our knowledge, only 3 previous studies have investigated sage-grouse nest and female survival relative to

Appendix D

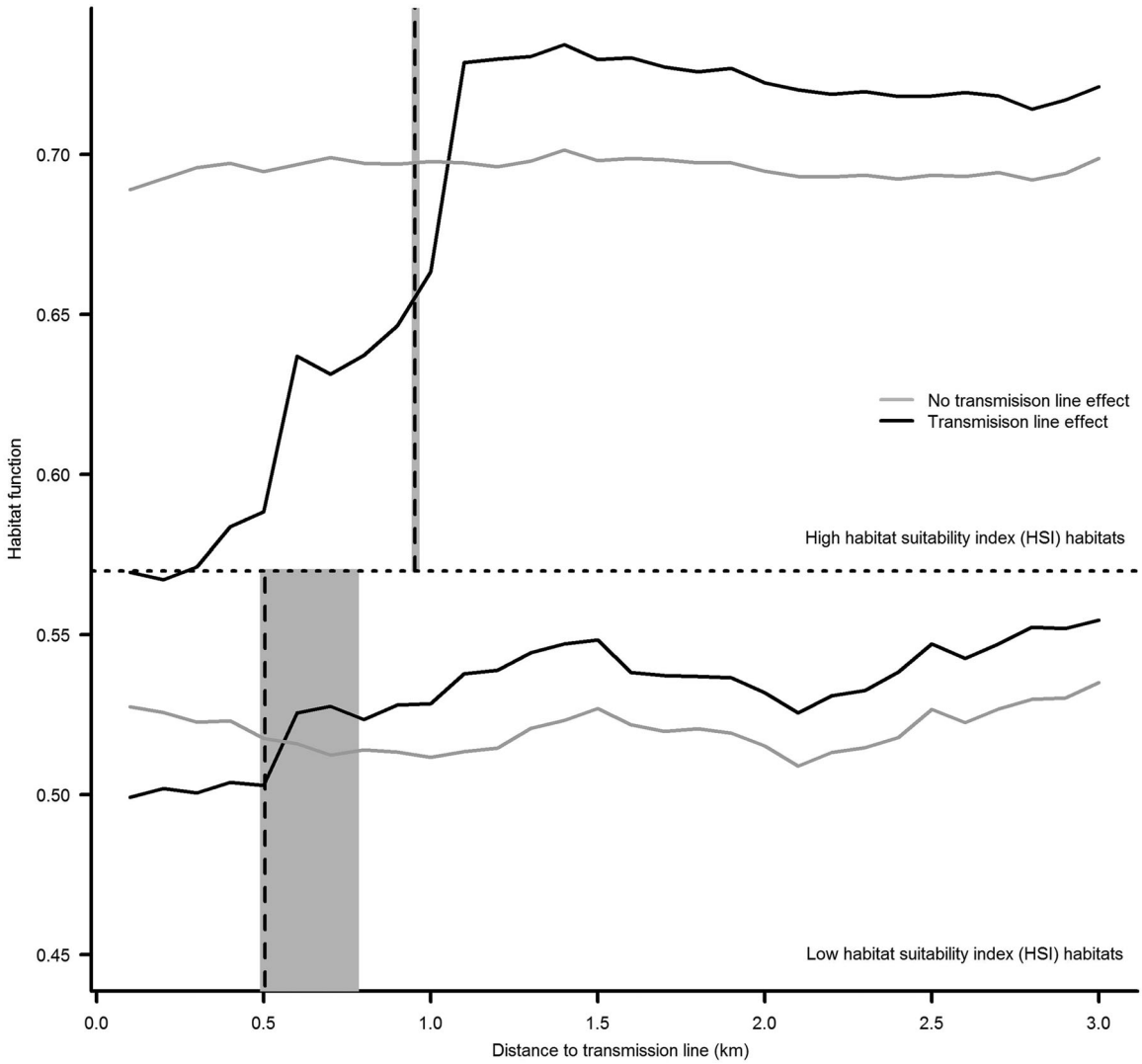


Figure 6. Sage-grouse habitat function within 3 km of transmission lines at the Seven Mile Hill and Simpson Ridge study areas from 2009–2014, Carbon County, Wyoming, USA within habitats that have a high (67–100%) and low (0–33%) habitat suitability index (HSI). Habitat function was the average relative probability of use and survival estimated during different time periods and different survival parameters. Habitats to the left the dotted line were associated with lower habitat function (e.g., low use and low survival) compared to habitats right of the dotted line when the effect of transmission lines were considered. The lower and upper 90% confidence interval bands are presented as the gray shaded areas.

transmission lines (Armentrout and Hall 2005, Gibson et al. 2018, Kohl et al. 2019). Like our study, these studies detected negative effects of the transmission lines on nest and female survival; however, the extent and magnitude of these effects varied between studies. This variation may relate to characteristics of each of these populations and to the characteristics of the power lines potentially affecting each population. In addition, differences could be related to the juxtaposition of transmission lines relative to other habitat features or predator density, which may have created confounding issues as we found in our study.

Our viewshed covariate assumed that the proximity of transmission lines has no effect on sage-grouse habitat selection and survival in habitats where transmission lines are not visible to sage-grouse. This was based on our hypothesis that if sage-grouse cannot see the transmission line then there are no mechanisms for avoidance and survival is not affected because they are less visible to avian predators perching on the transmission line. It also assumed that distances at which sage-grouse are influenced by visible transmission lines are restricted at 0.5, 1.0, 1.5, 2, 2.5, and 3 km. As we increased the sage-grouse viewshed, we essentially increased the potential magnitude of the effect of a transmission line on habitat selection and survival. By including 6 different viewsheds in our analysis, we were able to capture the extent to which a visible transmission line may be influencing sage-grouse and therefore we identified the spatial magnitude of the effect of transmission lines on habitat selection and survival. The viewshed covariates were comparable to linear distances to transmission lines; 86–93% of all habitats were in areas where transmission lines were visible. The models including viewsheds consistently outperformed HSI-only models and in many cases were similar to distance to transmission line models, suggesting that visibility of the transmission line to sage-grouse may be influencing habitat function.

The predicted surfaces allowed us to combine habitat selection and survival to determine the magnitude and extent of the transmission line effect. We assumed all time periods and survival parameters were equally important to the sustainability of this sage-grouse population, when in fact female survival may be more important to population viability than habitat use or nest survival (Taylor et al. 2012). Our goal, however, was to summarize the different effects of the transmission lines during different time periods into a single parameter that would be useful for management. We found evidence to suggest that habitats with high suitability (e.g., <3.1 km of an occupied lek) within 1.0 km of a transmission line were associated with lower survival and lower relative probability of habitat selection. Furthermore, habitats that were lower in habitat suitability (e.g., >3.1 km of an occupied lek) within 0.5 km of a transmission line were also associated with lower survival and relative probability of habitat selection.

MANAGEMENT IMPLICATIONS

The siting and design of the transmission lines in our study areas resulted in negative effects on the sage-grouse population. When designing future transmission lines, managers should avoid siting transmission lines in suitable sage-grouse habitat to ensure habitats remain intact. Recognizing this may not be possible based on our current energy demand, effects on sage-grouse populations may be minimized by siting transmission lines beyond 3.1 km from occupied leks. In addition, managers should consider monopole structure types with perch deterrents that reduce the potential for avian predator nesting and perching substrate. If effects associated with future 230-kV transmission lines cannot be avoided, the magnitude of reduction in habitat function can be quantified by summing up the size of the area within 0.5 km of transmission lines beyond 3.1 km of occupied leks and within 1.0 km of transmission lines within 3.1 km of occupied leks to determine the number of functional hectares of habitat lost due to the presence of the transmission line.

ACKNOWLEDGMENTS

We thank Hi-Allen Ranch, and PacifiCorp Energy for allowing us access to the study areas. We appreciate field assistance provided by J. Eddy, A. Hansen, P. Hansen, R. Hay, T. Higgins, M. Karsch, A. Kircher, J. Loos, A. Malone, J. Parson, T. Rintz, M. Salava, G. Shedd, B. Smith, and E. Vasquez. We thank J. Dahlke for providing project management support. We thank L. Neilson for reviewing this manuscript. We thank S. Howlin and T. McDonald for assisting in the analysis. We also thank the Associate Editor and 2 anonymous reviewers for helpful comments that improved our paper. We thank the Avian Power Line Interaction Committee, National Wind Coordinating Collaborative and Sage-Grouse Research Collaborative, American Wind Energy Association, Bates Hole-Shirley Basin Sage-grouse Local Working Group, EDP Renewables North America (formerly Horizon Wind Energy), Iberdrola Renewables, Margaret and Sam Kelly Ornithological Research Fund, PacifiCorp Energy, South-Central and Southwest Wyoming Sage-grouse Local Working Groups, United States Department of Energy, University of Wyoming Agricultural Experiment Station, University of Wyoming School of Energy Resources, and the Wyoming Reclamation and Restoration Center for providing funding support.

LITERATURE CITED

Akaike, H. 1974. A new look at the statistical model identification. IEEE Transactions on Automatic Control 19:716–723.

Anderson, P. K., and R. D. Gill. 1982. Cox's regression model for counting processes: a large sample study. Annals of Statistics 10:1100–1120.

Armentrout, D. J., and F. Hall. 2005. Conservation strategy for sage-grouse (*Centrocercus urophasianus*) and sagebrush ecosystems within the Buffalo-Skedaddle population management unit, Bureau of Land Management. Eagle Lake Field Office, Susanville, California, USA.

Arthur, S. M., B. F. J. Manly, L. L. McDonald, and G. W. Garner. 1996. Assessing habitat selection when availability changes. Ecology 77: 215–227.

Avgar, T., S. R. Lele, J. L. Keim, and M. S. Boyce. 2017. Relative selection strength: quantifying effect size in habitat and step-selection inference. Ecology and Evolution 7:5322–5330.

Batary, P., and A. Baldi. 2004. Evidence of an edge effect on avian nesting success. Conservation Biology 18:389–400.

Beck, J. L., K. P. Reese, J. W. Connelly, and M. B. Lucia. 2006. Movements and survival of juvenile greater sage-grouse in southeastern Idaho. Wildlife Society Bulletin 34:1070–1078.

Blomberg, E. J., J. S. Sedinger, M. T. Atamian, and D. V. Nonne. 2012. Characteristics of climate and landscape disturbance influence the dynamics of greater sage-grouse populations. Ecosphere 3:article 55.

Boyce, M. S., P. R. Vernier, S. E. Nielsen, and F. K. A. Schmiegelow. 2002. Evaluating resource selection functions. Ecological Modelling 157: 281–300.

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

Connelly, J. W., M. A. Schroeder, A. R. Sands, and C. E. Braun. 2000. Guidelines to manage sage grouse populations and their habitats. Wildlife Society Bulletin 28:967–985.

Conover, M. R., J. S. Borgo, R. E. Dritz, J. B. Dinkins, and D. K. Dahlgren. 2010. Greater sage-grouse select nest sites to avoid visual predators but not olfactory predators. Condor 112:331–336.

Eng, R. L. 1955. A method for obtaining sage grouse age and sex ratios from wings. Journal of Wildlife Management 19:267–272.

Gibson, D., E. J. Blomberg, M. T. Atamian, S. P. Espinosa, and J. S. Sedinger. 2018. Effects of power lines on habitat use and demography of greater sage-grouse (*Centrocercus urophasianus*). Wildlife Monographs 200:1–41.

Giesen, K. M., T. J. Schoenberg, and C. E. Braun. 1982. Methods for trapping sage grouse in Colorado. Wildlife Society Bulletin 10:224–231.

Giles, E. F., and K. L. Brown. 2015. UDI directory of electric power producers and distributors. 123rd edition of the electrical world directory. Platts, McGraw Hill Financial, New York, New York, USA.

Green, R. H. 1979. Sampling design and statistical methods for environmental biologists. Wiley and Sons, New York, New York, USA.

Hansen, E. P., A. C. Stewart, and S. N. Frey. 2016. Influence of transmission line construction on winter sage-grouse habitat use in southern Utah. Human-Wildlife Interactions 10:169–187.

Homer, C. G., C. L. Aldridge, D. K. Meyer, M. J. Coan, and Z. H. Bowen. 2009. Multiscale sagebrush rangeland habitat modeling in southwest Wyoming. U.S. Geological Survey Open-File Report 2008-1027, Reston, Virginia, USA.

Homer, C. G., C. L. Aldridge, D. K. Meyer, and S. J. Schell. 2012. Multiscale remote sensing sagebrush characterization with regression trees over Wyoming, USA: laying a foundation for monitoring. International Journal of Applied Earth Observation and Geoinformation 14:233–244.

Johnson, D. H., M. J. Holloran, J. W. Connelly, S. E. Hanser, C. L. Amundson, and S. T. Knick. 2011. Influences of environmental and anthropogenic features on greater sage-grouse populations, 1997-2007. Pages 407–450 *in* S. T. Knick and J. W. Connelly, editors. Greater

Appendix D

sage-grouse: ecology and conservation of a landscape species and its habitat. Studies in Avian Biology, volume 38. University of California Press, Berkeley, USA.

Kirol, C. P., J. L. Beck, S. V. Huzurbazar, M. J. Holloran, and S. N. Miller. 2015. Identifying greater sage-grouse source and sink habitats for conservation planning in an energy development landscape. Ecological Applications 25:968–990.

Kohl, M. T., T. A. Messmer, B. A. Crabb, M. R. Guttery, D. K. Dahlgren, R. T. Larsen, S. N. Frey, S. Liguori, and R. Baxter. 2019. The effects of electric power lines on the breeding ecology of greater sage-grouse. PLoS ONE 14(1):e0209968.

Kurzejeski, E. W., L. D. Vangilder, and J. B. Lewis. 1987. Survival of wild turkey hens in north Missouri. Journal of Wildlife Management 51:188–193.

LeBeau, C. W., G. D. Johnson, M. J. Holloran, J. L. Beck, R. M. Nielson, M. E. Kauffman, E. J. Rodemaker, and T. L. McDonald. 2017. Greater sage-grouse habitat selection, survival, and wind energy infrastructure. Journal of Wildlife Management 81:690–711.

Liebezeit, J. R., J. Kendall, S. Brown, C. B. Johnson, P. Martin, T. L. McDonald, D. C. Payer, C. L. Rea, B. Streever, A. M. Wildman, and S. Zack. 2009. Influence of human development and predators on nest survival of tundra birds, Arctic Coastal Plain, Alaska. Ecological Applications 19:1628–1644.

Manly, B. F. J. 2006. Randomization, bootstrap and Monte Carlo methods in biology. Third edition. Chapman and Hall/CRC, Boca Raton, Florida, USA.

Manly, B. F. J., L. L. McDonald, and D. Thomas, editors. 1993. Resource selection by animals: statistical design and analysis for field studies. Chapman & Hall, London, United Kingdom.

Manly, B. F. J., L. L. McDonald, D. L. Thomas, T. L. McDonald, and W. P. Erickson. 2002. Resource selection by animals: statistical design and analysis for field studies. Springer, Dordrecht, Netherlands.

McDonald, T. L., B. F. J. Manly, R. M. Nielson, and L. V. Diller. 2006. Discrete-choice modeling in wildlife studies exemplified by northern spotted owl nighttime habitat selection. Journal of Wildlife Management 70:375–383.

Naugle, D. E., K. E. Doherty, B. L. Walker, M. J. Holloran, and H. E. Copeland. 2011. Energy development and greater sage-grouse. Pages 489–503 *in* S. T. Knick and J. W. Connelly, editors. Greater sage-grouse: ecology and conservation of a landscape species and its habitats. Studies in Avian Biology, volume 38. University of California Press, Berkeley, USA.

Nur, N., A. L. Holmes, and G. R. Geupel. 2004. Use of survival time analysis to analyze nesting success in birds: an example using loggerhead shrikes. Condor 106:457–471.

Qian, S. S., R. S. King, and C. J. Richardson. 2003. Two statistical methods for the detection of environmental thresholds. Ecological Modelling 166:87–97.

R Core Team. 2016. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Rotella, J. J., S. J. Dinsmore, and T. L. Shaffer. 2004. Modeling nest-survival data: a comparison of recently developed methods that can be implemented in Mark and SAS. Animal Biodiversity and Conservation 27:187–205.

Schroeder, M. A. 2010. Greater sage-grouse and power lines: reasons for concern. Washington Department of Fish and Wildlife, Bridgeport, USA.

Schroeder, M. A., J. R. Young, and C. E. Braun. 1999. Sage grouse (*Centrocercus Urophasianus*). Account 425 *in* A. Poole and F. Gill, editors. The birds of North America. The Birds of North America, Inc., Philadelphia, Pennsylvania, USA.

Shirk, A. J., M. A. Schroeder, L. A. Robb, and S. A. Cushman. 2015. Empirical validation of landscape resistance models: insights from the greater sage-grouse (*Centrocercus urophasianus*). Landscape Ecology 30:1837–1850.

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.

Therneau, T. M. 2015. coxme: mixed effects Cox models. R package version 2.2-4. http://CRAN.R-project.org/package¼coxme. Accessed 2 Jul 2018.

Therneau, T. M., B. Atkinson, and B. Ripley. 2019. Rpart: recursive partitioning and regression trees. R package version 4.1-00. http://CRAN.R-project.org/package=rpart. Accessed 2 Jan 2019.

Thomas, D. L., and E. J. Taylor. 2006. Study designs and tests for comparing resource use and availability II. Journal of Wildlife Management 70:324–336.

U.S. Department of Agriculture. 2009. NAIP Imagery-1m (RGBIR)-Wyoming (2009). USDA Farm Service Agency Aerial Photography Field Office, Salt Lake City, Utah, USA.

U.S. Department of Agriculture. 2012. NAIP Imagery-1m (RGBIR)-Wyoming (2012). USDA Farm Service Agency Aerial Photography Field Office, Salt Lake City, Utah, USA.

U.S. Geological Survey. 2015. National Elevation Dataset (NED). Raster digital data. USGS, Sioux Falls, South Dakota, USA. http://nationalmap.gov. Accessed Dec 2014.

Wakkinen, W. L., K. P. Reese, J. W. Connelly, and R. A. Fischer. 1992. An improved spotlighting technique for capturing sage grouse. Wildlife Society Bulletin 20:425–426.

Wallestad, R. O., and D. B. Pyrah. 1974. Movement and nesting of sage grouse hens in central Montana. Journal of Wildlife Management 38:630–633.

Walters, K., K. Kosciuch, and J. Jones. 2014. Can the effect of tall structures on birds be isolated from other aspects of development? Wildlife Society Bulletin 38:250–256.

Westover, M., J. Baxter, R. Baxter, C. Day, R. Jensen, and S. Petersen. 2016. Assessing greater sage-grouse selection of brood-rearing habitat using remotely-sensed imagery: can readily available high-resolution imagery be used to identify brood-rearing habitat across a broad landscape? PLoS ONE 11(5):e0156290.

Wisinki, C. L. 2007. Survival and summer habitat selection of male greater sage-grouse (*Centrocercus urophasianus*) in southwestern Montana. Thesis, Montana State University, Bozeman, USA.

Associate Editor: Timothy Fulbright.

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article at the publisher's website.