From:	Kelly Fuller
To:	EFSEC (UTC)
Subject:	Badger Mountain Solar Project comments
Date:	Friday, January 21, 2022 2:51:27 PM
Attachments:	WWP Badger Mtn comments 1.21.22.pdf Blickley-and-Patricelli-2010.pdf Blickley et al 2012a.pdf Blickley et al 2012b.pdf Blickley and Patricelli 2012.pdf Gibson et al 2018 power lines & GRSG.pdf NvMA Eagle Plan 8-18 - Final.pdf

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External Email

Dear Mr. Chisolm and EFSEC staff:

Western Watersheds Project would like to submit the attached comments on the Badger Mountain Solar Project for the Council's consideration. Some of the references cited in the letter are not readily available online, so they are attached also.

Thank you for considering our comments.

Best wishes,

--
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Working to protect and restore Western Watersheds and Wildlife

January 21, 2022 *Via email*

Sean Chisholm
Washington Energy Facility Site Evaluation Council
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Olympia, WA 98504-3172
efsec@utc.wa.gov

SUBJECT: Comments on the Badger Mountain Solar Project

Dear Mr. Chisolm:

These comments concern the proposed Badger Mountain Solar Project and are submitted by Western Watersheds Project (WWP), a non-profit organization with more than 12,000 members and supporters. Our mission is to protect and restore western watersheds and wildlife through education, public policy initiatives and legal advocacy. WWP has a long-standing interest in greater sage-grouse and has litigated to protect the species. Western Watersheds Project is concerned about the Badger Mountain Solar Project's potential impacts on wildlife, especially greater sage-grouse and golden eagles.

Greater Sage-Grouse:

The world is not only in a climate crisis, but also in a biodiversity and extinction crisis. In the last 50 years, the world has lost more than two-thirds of its wildlife, in respect to population sizes (WWF 2020, p. 6). Furthermore, the world's current extinction rate is hundreds or possibly even thousands of times greater than the natural baseline rate (Smithsonian National Museum of Natural History). This means that in order to pass on a livable world to future generations, humans must address the climate crisis and the biodiversity and extinction crisis at the same time. As the Intergovernmental Panel on Climate Change pointed out in a 2021 report, "technology-based measures that are effective for climate change mitigation can pose serious threats to biodiversity" (Pörtner et al. 2021, p. 19). On a practical level, this translates to an urgent need for renewable energy project siting that does not exacerbate the biodiversity and extinction crisis.

Careful renewable energy siting is especially important for Washington greater sage-grouse, which are state-listed as endangered, have lost 92% of their habitat, and declined in population more than 50% between 1970 and 2012.[1] Decreases in Washington greater sage-

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[1] *See* page 1 of U.S. Fish and Wildlife Service. Undated. Greater Sage-Grouse Conservation in Washington. Available at https://www.fws.gov/greatersagegrouse/factsheets/WAGrSGFactSheet_FINAL%20(1).pdf. *See also* page 1-1 of Washington Department of Fish and Wildlife. 2015. Washington's State Wildlife Action Plan: 2015 Update. Washington Department of Fish and Wildlife, Olympia, Washington, USA. Available at https://wdfw.wa.gov/sites/default/files/publications/01742/3_Chapter1.pdf.

grouse numbers have continued since then.[2] Unlike greater sage-grouse in other states, Washington sage-grouse are heavily reliant on private lands for habitat.[3] However, we are concerned not only about habitat loss, but also about the negative impacts of project noise on the nearby lek. Noise can mask the breeding vocalizations of sage grouse (Blickley and Patricelli 2012), displace grouse from leks (Blickley et al. 2012a), and cause stress to the birds that remain (Blickley et al. 2012b). According to Blickley et al. (2010), "The cumulative impacts of noise on individuals can manifest at the population level in various ways that can potentially range from population declines up to regional extinction. If species already threatened or endangered due to habitat loss avoid noisy areas and abandon otherwise suitable habitat because of a particular sensitivity to noise, their status becomes even more critical." In addition, sage-grouse have been shown to avoid habitat near power lines, and negative effects on reproduction have also been demonstrated (Gibson et al. 2018).

Golden Eagles:

The Washington Department of Wildlife has designated the golden eagle as a candidate for status as Endangered, Threatened, or Sensitive. Golden eagles are protected under the federal Bald and Golden Eagle Protection Act (BGEPA), which prohibits take of bald or golden eagles without a U.S. Fish and Wildlife Service permit. Under the Fish and Wildlife Service's eagle permitting rules, incidental take includes not only non-purposeful killing or injuring eagles, but also disturbing them. Activities that disturb eagles are those that cause or are likely to cause injury, decrease breeding productivity, or result in nest abandonment. As a result, eagle incidental take permits are not just for wind energy projects and not just for facilities that will kill eagles. Solar and mining companies have applied to the U.S. Fish and Wildlife Service for eagle incidental take permits when their projects threatened to cause nonlethal take by triggering nest abandonment or damaging or destroying foraging habitat used by eagles seeking food for their chicks. These permits can be long term or temporary, for instance over a 30-year period or during a single breeding season. Examples include the California Flats Solar Project,[4] Silicon Exploration Project,[5] and the Thacker Pass Lithium Mine.[6] In fact, the Nevada Mining Association has created a guide to assist mining companies in determining whether to apply for golden eagle incidental take permits (Nevada Mining Association 2018).[7]

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[2] Washington Department of Fish and Wildlife Greater Sage-Grouse (*Centrocercus urophasianus*) Website. Available at https://wdfw.wa.gov/species-habitats/species/centrocercus-urophasianus#desc-range. Last accessed January 19, 2021.

[3] *See* page 1 of U.S. Fish and Wildlife Service. Undated. Greater Sage-Grouse Conservation in Washington. Available at https://www.fws.gov/greatersagegrouse/factsheets/WAGrSGFactSheet_FINAL%20(1).pdf.

[4] *See* https://www.fws.gov/cno/conservation/MigratoryBirds/California_Flats_Solar_Project/California_Flats.html.

[5] *See* https://www.fws.gov/cno/conservation/MigratoryBirds/Silicon-Exploration-Project/.

[6] *See* https://www.govinfo.gov/content/pkg/FR-2020-12-04/pdf/2020-26738.pdf.

[7] This guide is not readily available online, so we are submitting it with our comments.

U.S. Fish and Wildlife Service eagle take permits are relevant to the Badger Mountain Solar Project because the project would overlap two occupied golden eagle territories, and there are recently used golden eagle nests within 0.1 and 0.8 miles of the project. [8] The U.S. Fish and Wildlife Service's Great Basin Region has published guidance on golden eagle nest buffer distances to avoid disturbing breeding eagles or causing nest abandonment; it recommends a one-mile no-disturbance nest buffer for solar development and power line construction. Although this guidance is for the Great Basin region where golden eagle breeding season dates may differ from eastern Washington, the fundamental principle of using a no-disturbance nest buffer zone to avoid disturbance to golden eagles is still relevant. If companies are unable or unwilling to apply a no disturbance nest buffer zone during the golden eagle breeding season, they can avoid liability under BGEPA and its implementing regulations by obtaining a U.S. Fish and Wildlife Service eagle incidental take permit. However, as of January 3, 2021, Avangrid had not applied for an eagle take permit for the Badger Mountain Solar Project, and the U.S. Fish and Wildlife Service's permit contact did not know if Avangrid intended to apply.[9] This raises a serious question as to whether the Badger Mountain Solar Project would conform to BGEPA and its implementing regulations if construction of the portions of the project that are near the recently used golden eagle nests took place during eagle breeding season.

Conclusion:

The Badger Mountain Solar Project would clearly have adverse, significant impacts, and an Environmental Impact Statement should be prepared. We agree with the Washington Department of Fish and Wildlife's recommendation that the Badger Mountain Solar Project be moved to a less sensitive location.[10] If the applicant is unwilling to move the project, a U.S. Fish and Wildlife Service golden eagle incidental take permit may be necessary for conformity with BGEPA and its implementing regulations.

Sincerely yours,

Kelly Fuller

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[8] *See* page 2 of the Washington Department of Fish and Wildlife's December 10, 2021 comment letter on the Badger Mountain Solar Project.

[9] Personal comms., Kelly Fuller (Western Watersheds Project) and Matthew Stuber (U.S. Fish and Wildlife Service).

[10] *See* page 2 of the Washington Department of Fish and Wildlife's December 10, 2021 comment letter on the Badger Mountain Solar Project.

cc: Matthew Stuber, U.S. Fish and Wildlife Service.

References:

Blickley, J.L. and Patricelli, G.L. 2010. Impacts of Anthropogenic Noise on Wildlife: Research Priorities for the Development of Standards and Mitigation. Journal of International Wildlife Law & Policy, 13: 4, 274-292. DOI: 10.1080/13880292.2010.524564.

Blickley, J.L. and Patricelli, G.L. 2012. Potential Acoustic Masking of Greater Sage-Grouse (*Centrocercus urophasianus)* Display Components by Chronic Acoustic Noise. Ornithological Monographs. Volume (2012), No. 74, 23-35.

Blickley, J.L. et al. 2012a. Experimental Evidence for the Effects of Chronic Anthropogenic Noise on Abundance of Greater Sage-Grouse at Leks. Conservation Biology, Volume 26, No. 3, 461–471. DOI: 10.1111/j.1523-1739.2012.01840.x.

Blickley, J.L. et al. 2012b. Experimental Chronic Noise Is Related to Elevated Fecal Corticosteroid Metabolites in Lekking Male Greater Sage-Grouse (*Centrocercus urophasianus.* PLoS ONE 7(11): e50462. doi:10.1371/journal.pone.0050462.

Gibson, D., et al. 2018. Effects of Power Lines on Habitat Use and Demography of Greater Sage-Grouse (*Centrocercus urophasianus*). Wildlife Monographs 200:1–41; 2018; DOI: 10.1002/wmon.1034.

Nevada Mining Association. 2018. Golden Eagle Protection Best Practices: Nevada Mineral Exploration and Mining Industry.

Pörtner, H.O., *et al*. 2021. IPBES-IPCC co-sponsored workshop report on biodiversity and climate change; Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) and Intergovernmental Panel on Climate Change (IPCC). DOI:10.5281/zenodo.4782538. Available at https://www.iis-rio.org/wp-content/uploads/2021/06/20210609_workshop_report_embargo_3pm_CEST_10_june_0.pdf

Smithsonian National Museum of Natural History. "Extinction Over Time." Available at https://naturalhistory.si.edu/education/teaching-resources/paleontology/extinction-over-time. Last accessed January 19, 2022

U.S. Fish and Wildlife Service. Undated. Greater Sage-Grouse Conservation in Washington. Available at https://www.fws.gov/greatersagegrouse/factsheets/WAGrSGFactSheet_FINAL%20(1).pdf.

U.S. Fish and Wildlife Service, Great Basin Region, Migratory Birds Program. May 2021. Recommended Buffer Zones for Ground-based Human Activities around Nesting Sites of Golden Eagles in California and Nevada. https://www.fws.gov/Cno/conservation/MigratoryBirds/pdf-files/USFWS-Pacific-Southwest-Region-golden-eagle-nest-buffer-recommendations-May2021.pdf

Washington Department of Fish and Wildlife. 2015. Washington's State Wildlife Action Plan: 2015 Update. Washington Department of Fish and Wildlife, Olympia, Washington, USA. Available at https://wdfw.wa.gov/sites/default/files/publications/01742/3_Chapter1.pdf.

Washington Department of Fish and Wildlife. October 2021. State Listed Species. Available at https://wdfw.wa.gov/sites/default/files/2021-10/statelistedcandidatespecies_10132021.pdf.

Washington Department of Fish and Wildlife. December 10, 2021. Comments on on the Badger Mountain Solar Project

WWF. 2020. Living Planet Report 2020: Bending the Curve of Biodiversity Loss. Available at https://www.zsl.org/sites/default/files/LPR%202020%20Full%20report.pdf.

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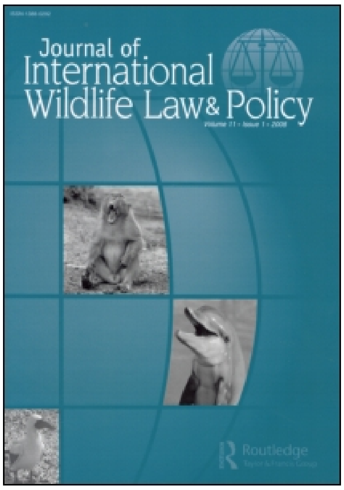

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Impacts of Anthropogenic Noise on Wildlife: Research Priorities for the Development of Standards and Mitigation

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Impacts of Anthropogenic Noise on Wildlife: Research Priorities for the Development of Standards and Mitigation

JESSICA L. BLICKLEY[1]
GAIL L. PATRICELLI[2]

1. INTRODUCTION

Human development introduces anthropogenic noise sources into the environment across many elements of the modern terrestrial landscape, including roads, airports, military bases, and cities. The impacts of these introduced noise sources on wildlife are less well studied than many of the other effects human activities have on wildlife, the most well known of which are habitat fragmentation and the introduction of invasive species. A growing and substantial body of literature suggests, however, that noise impacts may be more important and widespread than previously imagined.[3] They range in effects from mild to severe. They can impact wildlife species at both the individual and population levels. The types of impacts run the gamut from damage to the auditory system, the masking of sounds important to survival and reproduction, the imposition of chronic stress and associated physiological responses, startling, interference with mating, and population declines.

Anthropogenic noise is a global phenomenon, with the potential to affect wildlife across all continents and habitat types. Despite the widespread

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[3] For a review of noise impacts on birds and other wildlife, see P. A. KASELOO & K. O. TYSON, SYNTHESIS OF NOISE EFFECTS ON WILDLIFE POPULATIONS (U.S. Department of Transportation, Federal Highway Administration, 2004); ROBERT J. DOOLING & ARTHUR N. POPPER, THE EFFECTS OF HIGHWAY NOISE ON BIRDS (California Department of Transportation, Division of Environmental Analysis, 2007).

distribution of noise, the bulk of research on the effects of noise on terrestrial wildlife has been limited to European countries and the United States. This geographic bias in research may limit the application of the results from previous studies on a global basis, since the impacts may differ among habitats and species.[4]

Since much human development involves the introduction of noise, separating out and understanding the impacts of noise pollution is a critical step in developing effective wildlife policy, particularly the setting of standards and the use of mitigation measures. The first step typically is to determine the overall impact on the population demography of a species, by measuring population declines and birth rates. Mitigation requires that the mechanisms of this effect then be understood. From an initial determination, for example, that roads decrease songbird population densities, there must next be an estimation of the extent to which noise, dust, chemical pollution, habitat fragmentation, invasive weeds, visual disturbance, or road mortality are partial and contributory causes of that impact before effective mitigation measures aimed at noise can be chosen. Quieter pavements will not help songbirds if the true cause of the problem is visual disturbance. The key challenge, then, is to measure the contribution of noise to observed impacts on animal populations while controlling for other variables.

In this article, we address three questions: what are the common sources of anthropogenic noise; what is known about the mechanisms by which noise impacts wildlife; and how can we use observational and experimental approaches to estimate the impacts of noise on whatever species are of concern?

In answering these questions we deal at length with both observational and experimental methods, the latter including both laboratory and field work. We describe observational field studies on animal abundance and reproduction in impacted areas and a method for estimating the potential of noise sources to mask animal vocalizations. We address both the feasibility and value of laboratory and field experiments and describe a case study based on an ongoing noise-playback experiment we have designed to quantify the impacts of noise from energy development on greater sage-grouse (*Centrocercus urophasianus)* in Wyoming.

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[4] The geographic bias in research has lead to a focus on species that live in temperate zones, with little to no study of tropical species. Also of concern, many of the landscapes that have been the focus of research on noise and wildlife in these industrialized nations have already been profoundly influenced by human development such that the species or individuals living in these areas may be more tolerant of disturbance. Application of the results of studies from developed to less developed landscapes would potentially lead to an underestimation of the effects of noise. Anthropogenic changes to the environment are occurring at an unprecedented rate in developing nations in tropical latitudes, however, we do not yet know whether the results from existing research are applicable in these regions.

Our focus, then, is on noise impacts on animals in the terrestrial environment,[5,6] especially birds, which are the subjects of most terrestrial studies.[7] We also outline directions for future research and in a final section emphasize the importance of this research for developing flexible wildlife management strategies in landscapes that are increasingly subject to human encroachment.

2. SOURCES OF NOISE

Noise is associated with most phases in the cycle of human development activity, from early construction to the daily operation of a completed project. Transportation systems are one of the most pervasive sources of noise across all landscapes, including common sources like roads and their associated vehicular traffic, airports and airplanes, off-road vehicles, trains, and ships. Roads deserve special attention, because they are a widespread and rapidly increasing terrestrial noise source. Although the surface area covered by roads is relatively small, the ecological effects of roads, including noise, extend far beyond the road itself, impacting up to one-fifth of the land area of the United States, for example.[8] Industrial noise sources, such as military bases, factories, mining operations, and wind farms may be more localized in the landscape, but are problematic for wildlife because the noise produced can be very loud.

The characteristics of noise vary substantially among sources. Each source type exhibits variance in amplitude (i.e., loudness), frequency profile

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[5] Many terrestrial noise sources produce noise that travels through the ground as well as the air. Seismic noise is likely to impact fossorial animals and animals that possess specialized receptors for seismic detection, many of which communicate by seismic signals. We do not address seismic noise in this paper, but it is an issue that warrants further discussion.

[6] For recent treatments of noise in the marine environment, its impacts on marine species, and legal and policy responses, see *Noise Pollution and the Oceans: Legal and Policy Responses Part 1*, 10 J. INT'L WILDLIFE L. & POL'Y (2007) 101–199 and *Noise Pollution and the Oceans: Legal and Policy Responses Part 2*, 10 J. INT'L WILDLIFE L. & POL'Y (2007) 219–288. See also, Committee on Characterizing Biologically Significant Marine Mammal Behavior, Marine Mammal Populations and Ocean Noise, DETERMINING WHEN NOISE CAUSES BIOLOGICALLY SIGNIFICANT EFFECTS 142 (Ocean Studies Board, Division on Earth and Life Studies, National Research Council, The National Academies, 2005).

[7] Birds have often been used in noise research because birds are generally easy to study due to their high detectability, most species use vocal communication (making them likely to be impacted by noise) and they are generally of high conservation importance.

[8] R.T.T. Forman & R.D. Deblinger, *The Ecological Road-Effect Zone of a Massachusetts (U.S.A.) Suburban Highway*, 14 CONS. BIOL. 36–46 (2000); R.T.T. Forman, *Estimate of the Area Affected Ecologically by the Road System in the United States*, 14 CONS. BIOL. 31–35 (2000); R.T.T. Forman, B. Reineking, and A.M. Hersberger, *Road Traffic and Nearby Grassland Bird Patterns in a Suburbanizing Landscape*, 29 ENVT'L. MGMT. 782–800 (2002). Due to its ubiquity, road noise is the most commonly studied type of terrestrial noise. Road noise is, in general, similar to other types of anthropogenic noise and affects a wide range of species and habitat types, so the research techniques and results can be applied to many other types of anthropogenic noise.

(i.e., pitch), and spatial and temporal patterns. The interaction of these characteristics is what determines in a narrow sense the impact of noise on wildlife, setting aside the possibly confounding influence of contextual variables.

Intuitively, loud noise is more disruptive than quiet noise[9] and noise with frequencies similar to animal vocalizations is more likely to interfere with (i.e., mask) communication than noise with different frequencies.[10] Most anthropogenic noise sources have energy concentrated in low frequencies (<250 Hz), which can travel long distances with relatively little energy loss. Such noise is also more difficult to control using traditional noise-abatement structures, such as noise reflecting or absorbing walls along highways or surrounding other fixed noise sources, such as industrial sites.[11] Spatial patterning of noise may also affect the level of disturbance. A highly localized point source, like a drilling rig, will generally impact a smaller area than a linear source, such as a highway, although the area of impact will also depend on the amplitude and frequency structure of the noise. The temporal patterning of noise can also be important, because animal behaviors are often temporally patterned. Rush hour traffic, for example, often coincides with the dawn chorus of bird song,[12] an important time for birds because this is when mates are attracted and territories defended.[13]

Environmental noise is not an entirely new problem for animals, nor is human activity the exclusive cause of it. Natural environments have numerous sources of ambient noise, such as wind, moving water, and sounds produced by other animals. There is also evidence that animals living in naturally noisy areas have made adaptations through the use of signals and signaling behaviors to overcome the masking impacts of noise.[14] However, if anthropogenic noise

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[9] M.E. Weisenberger et al., *Effects of Simulated Jet Aircraft Noise on Heart Rate and Behavior of Desert Ungulates*, 60 J. WILDLIFE MGMT. 52–61 (1996).

[10] Bernard Lohr et al., *Detection and Discrimination of Natural Calls in Masking Noise by Birds: Estimating the Active Space of a Signal*, 66 ANIMAL BEHAV. 703–710 (2003).

[11] S.P. SINGAL, NOISE POLLUTION AND CONTROL STRATEGY (2005).

[12] R.A. Fuller et al., *Daytime Noise Predicts Nocturnal Singing in Urban Robins*, 3 BIOL. LETTERS 368–370 (2007).

[13] C.K. CATCHPOLE & PETER J.B. SLATER, BIRD SONG: THEMES AND VARIATIONS (1995).

[14] For example, the structural and temporal properties of many acoustic signals are adapted—by evolution or through individual plasticity—to maximize the propagation distance and/or minimize interference from natural noise sources. R. Haven Wiley & Douglas G. Richards, *Adaptations for Acoustic Communication in Birds: Sound Transmission and Signal Detection*, *in* 1 ACOUSTIC COMMUNICATION IN BIRDS 131–181 (D. Kroodsma & E.H. Miller eds., 1982); H. Brumm, *Signalling through Acoustic Windows: Nightingales Avoid interspecific Competition by Short-Term Adjustment of Song Timing*, 192 J. COMP. PHYSIOL. A 1279–1285 (2006); Henrik Brumm & Hans Slabbekoorn, *Acoustic Communication in Noise*, 35 ADVANCES STUDY BEHAV. 151–209 (2005); Hans Slabbekoorn & Thomas B. Smith, *Habitat-Dependent Song Divergence in the Little Greenbul: An Analysis of Environmental Selection Pressures on Acoustic Signals*, 56 EVOLUTION 1849–1858 (2002); G.M. Klump, *Bird Communication in the Noisy World*, *in* ECOLOGY AND EVOLUTION OF ACOUSTIC COMMUNICATION IN BIRDS 321–338 (D. Kroodsma & E.H. Miller eds., 1996); Eugene S. Morton, *Ecological Sources of Selection on Avian Sounds*, 109 AM. NATURALIST 17–34 (1975).

differs enough from natural noise in frequency, amplitude, or daily/seasonal patterns, animal adaptations to natural noise can be overwhelmed. Furthermore, the extensive introduction of anthropogenic noise into the environment on a large scale is a relatively recent phenomenon, so that animals have had only a limited opportunity to adapt to widespread and sometimes drastic changes in their acoustic environments.[15]

3. THE POTENTIAL IMPACTS OF NOISE ON WILDLIFE

Animals exhibit a variety of responses to noise pollution (also called introduced noise), depending on the characteristics of the noise and the animal's ability to tolerate or adapt to it. Noise impacts on wildlife can be observed at the individual and population levels, which we now consider in turn.

3.1 Individual-Level Impacts

Some of the most dramatic impacts of noise on individuals are acute and need to be distinguished from chronic effects. Acute impacts include physiological damage, masking of communication, disruption of behavior, and startling. The most direct physiological impact affects an animal's ability to hear, either by permanently damaging the auditory system, in which case it produces what is called a permanent threshold shift (PTS) in hearing, or by causing temporary decreases in hearing sensitivity, which are called temporary threshold shifts (TTS).[16] The noise levels required for PTS and TTS are quite loud,[17] making hearing damage unlikely in most terrestrial situations. Even extremely loud sound sources will only cause PTS and TTS over a small area, because on land sound attenuates very quickly with distance.[18] This is why most studies

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[15] G. Patricelli & J. Blickley, *Avian Communication in Urban Noise: Causes and Consequences of Vocal Adjustment*, 123 THE AUK 639–649 (2006); Paige S. Warren et al., *Urban Bioacoustics: It's Not Just Noise*, 71 ANIMAL BEHAV. 491–502 (2006); Lawrence A. Rabin et al., *Anthropogenic Noise and Its Effects on Animal Communication: An Interface Between Comparative Psychology and Conservation Biology*, 16 INT'L J. COMP. PSYCHOL. 172–192 (2003); Lawrence A. Rabin & Correigh M. Greene, *Changes to Acoustic Communication Systems in Human-Altered Environments*, 116 J. COMP. PSYCHOL. 137–141 (2002); H. Slabbekorn & E.A.P. Ripmeester, *Birdsong and Anthropogenic Noise: Implications and Applications for Conservation*, 17 MOLECULAR ECOLOGY 72–83 (2008).

[16] P. Marler et al., *Effects of Continuous Noise on Avian Hearing and Vocal Development*, 70 PROC. NAT'L ACAD. SCI. 1393–1396 (1973); J. Saunders & R. Dooling, *Noise-Induced Threshold Shift in the Parakeet (*Melopsittacus undulatus), 71 PROC. NAT'L ACAD. SCI. 1962–1965 (1974); Brenda M. Ryals et al., *Avian Species Differences in Susceptibility to Noise Exposure*, 131 HEARING RES. 71–88 (1999).

[17] PTS in birds may result from sound levels of ~125 dBA SPL for multiple impulsive sounds and ~140 dBA SPL for a single impulsive sound. TTS can result from continuous noise levels of ~93 dBA SPL. The term "dBA SPL" refers to the A-weighted decibel, the most common unit for noise measurements. It adjusts for human perception of sound and is scaled relative to the threshold for human hearing.

[18] Sound levels drop by approximately 6 dB (measured using dBA SPL, or any other decibel measure), which represents a halving of loudness, with every doubling in distance from a point source, and 3 dB with every doubling of distance from a linear source, such as a highway.

of impacts from highway and urban noise do not directly address PTS and TTS, although they may need to be considered in extremely noisy areas.

Other acute impacts of noise, such as masking and behavioral disruption, occur over a much larger area. Masking occurs when the perception of a sound is affected by the presence of background noise, with high levels of background noise decreasing the perception of a sound.[19] One possible consequence of masking is a decrease in the efficacy of acoustic communication. Many animals use acoustic signals to attract and retain mates, settle territorial disputes, promote social bonding, and alert other individuals to predators. Disruption of communication can, therefore, have dramatic impacts on survival and reproduction.[20] In one laboratory study, high environmental noise reduced the strength of the pair bond in monogamous zebra finches, *Taeniopygia guttata,* likely because females either had increased difficulty identifying mates or pair-bond maintenance calls were masked.[21] The broader consequence of this finding is that females in noisy areas may be more likely to copulate with extra-pair partners, and this in turn can change the social and genetic dynamics of a population.

In other research, birds have been found to change their songs and calls in response to noise in urban areas, which may reduce masking of communication.[22] However, the consequences of this vocal adjustment on reproduction in a species remain unclear. One outcome may be that populations using urban dialects have a better chance to thrive in urban areas. But by the same token they may experience a decrease in mate recognition and/or gene flow with populations in non-urban areas.[23]

Beyond interfering with communication, introduced background noise can also mask the sounds of approaching predators or prey, and increase the perception of risk from predation. Studies have yet to compare predation rates or hunting success in noisy and quiet areas while controlling for other confounding factors. The degree to which noise affects predator/prey relations

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[19] Lohr et al., *supra* note 5.

[20] M.A. Bee & E.M. Swanson, *Auditory Masking of Anuran Advertisement Calls by Road Traffic Noise*, 74 ANIMAL BEHAV. 1765–1776 (2007); Henrik Brumm, *The Impact of Environmental Noise on Song Amplitude in a Territorial Bird*, 73 J. ANIMAL ECOLOGY 434–440 (2004); L. Habib et al., *Chronic Industrial Noise Affects Pairing Success and Age Structure of Ovenbirds* Seiurus aurocapilla, 44 J. APPLIED ECOLOGY 176–184 (2007); Frank E. Rheindt, *The Impact of Roads on Birds: Does Song Frequency Play a Role in Determining Susceptibility to Noise Pollution?*, 144 J. ORNITHOLOGIE 295–306 (2003).

[21] J.P. Swaddle & L.C. Page, *Increased Amplitude of Environmental White Noise Erodes Pair Preferences in Zebra Finches: Implications for Noise Pollution*, 74 ANIMAL BEHAV. 363–368 (2007).

[22] Slabbekorn & Ripmeester, *supra* note 10; Brumm, *supra* note 15; Hans Slabbekoorn & Margriet Peet, *Birds Sing at a Higher Pitch in Urban Noise*, 424 NATURE 267 (2003); William E. Wood & Stephen M. Yezerinac, *Song Sparrow (*Melozpiza melodia*) Song Varies with Urban Noise*, 123 THE AUK 650–659 (2006).

[23] Patricelli & Blickley, *supra* note 10; Warren et al. *supra* note 10; Slabbekoorn & Peet, *supra* note 17.

in any species, therefore, remains largely unexplored.[24] One study found that birds nesting near noisy natural gas pads had higher nesting success, likely due to reduced presence of the most common nest predator, the western scrub jay.[25] As suggested by these authors, the higher nesting success of birds in noisy areas provides a mechanism by which noise-tolerant species could become more common in a noisy world. Noise also causes short-term disruptions in behavior, such as startling or frightening animals away from food or other resources.[26]

In addition to the acute effects of noise, animals may suffer chronic effects, including elevated stress levels and associated physiological responses. Over the short term, chronic stress can result in elevated heart rate.[27] Longer-term stress can be associated with the ability to resist disease, survive, and successfully reproduce.[28] Good measures of chronic stress come from elevated stress hormones, like corticosterone, in blood or fecal samples.[29] In noise-stressed laboratory rats, elevated corticosterone was linked with reduced food consumption and decreased weight gain,[30] raising the possibility that for some individuals there may be longer-term welfare and survival consequences from the elevated stress associated with noise introduction.

3.2 Population Level Impacts

The cumulative impacts of noise on individuals can manifest at the population level in various ways that can potentially range from population declines up to

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[24] Quinn found that chaffinchs (*Fringilla coelebs*) perceived an increased risk of predation while feeding in noisy conditions, likely due to a reduced ability to detect auditory cues from potential predators. L. Quinn et al*., Noise, Predation Risk Compensation and Vigilance in the Chaffinch* Fringilla coelebs, 37 J. AVIAN BIOL. 601–608 (2006). Research on greater sage-grouse also highlights the potential for noise to contribute to predation. One of the methods for capturing sage-grouse is to mask the sound of researcher footfalls using a noise source such as a stereo or a chain saw. With such masking, the grouse can be easily approached and netted in their night roosts for banding or blood sampling. Presumably, predators would be equally fortunate in noisy areas, though the ability of predators to use acoustic cues for hunting could be diminished by masking as well.

[25] Clinton D. Francis et al., *Noise Pollution Changes Avian Communities and Species Interactions*, 19 CURRENT BIOL. 1–5 (2009).

[26] Dooling & Popper, *supra* note 1; N. Kempf & O. Huppop, *The Effects of Aircraft Noise on Wildlife: A Review and Comment*, 137 J. ORNITHOLOGIE 101–113 (1996); D.K. Delaney et al., *Effects of Helicopter Noise on Mexican Spotted Owls*, 63 J. WILDLIFE MGMT. 60–76 (1999); L.A. Rabin, R.G. Coss, & D.H. Owings, *The Effects of Wind Turbines on Antipredator Behavior in California Ground Squirrels* (Spermophilus beecheyi), 131 BIOL. CONS. 410–420 (2006).

[27] Weisenberger et al., *supra* note 4.

[28] J.C. Wingfield & R.M. Sapolsky, *Reproduction and Resistance to Stress: When and how*, 15 J. NEUROENDOCRINOL, 711 (2003); A. Opplinger et al., *Environmental Stress Increases the Prevalence and Intensity of Blood Parasite Infection in the Common Lizard* Lacerta vivipara, 1 ECOLOGY LETTERS 129–138 (1998).

[29] Wingfield & Sapolsky, *supra* note 23; S.K. Wasser et al., *Noninvasive Physiological Measures of Disturbance in the Northern Spotted Owl*, 11 CONS. BIOL. 1019–1022 (1997); D.M. Powell et al., *Effects of Construction Noise on Behavior and Cortisol Levels in a Pair of Captive Giant Pandas (*Ailuropoda melanoleuca*)*, 25 ZOO BIOL. 391–408 (2006).

[30] P. Alario et al., *Body Weight Gain, Food Intake, and Adrenal Development in Chronic Noise Stressed Rats*, 40 PHYSIOL. BEHAV. 29–32 (1987).

regional extinction. If species already threatened or endangered due to habitat loss avoid noisy areas and abandon otherwise suitable habitat because of a particular sensitivity to noise, their status becomes even more critical. As discussed below, numerous studies have documented reduced habitat use and lower breeding success in noisy areas by a variety of animals.[31]

4. MEASURING THE IMPACTS OF NOISE ON SPECIES OF CONCERN

Species vary widely in their ability to tolerate introduced noise and can exhibit very different responses to altered acoustic environments. This variability in response to noise makes generalizations about noise impacts among species and among noise sources difficult. Generalizations relevant to a single species can also be hard to make, because the ability to tolerate noise may vary with reproductive status, prior exposure to noise, and the presence of other stressors in the environment. This is why more measurements of noise impacts and associated variables are needed for a wider range of species.

Measuring the effects of noise at the individual and population levels is, however, extremely challenging. As we noted earlier, noise is typically accompanied by other changes in the environment that may also have physiological, behavioral, and population level effects. For example, habitat fragmentation is a side effect of road development, and fragmentation alone has been shown to cause population declines and changes in communication and other behaviors.[32] So, can we measure the impacts of noise on wildlife in ways that will support biologically relevant noise standards?

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[31] Affected animals include birds, mammals, reptiles, and amphibians. Forman et al., *supra* note 6; Rheindt, *supra* note 15; Rien Reijnen et al., *The Effects of Car Traffic on Breeding Bird Populations in Woodland. III. Reduction of Density in Relation to the Proximity of Main Roads*, 32 J. APPLIED ECOLOGY 187–202 (1995); Rien Reijnen et al., *The Effects of Traffic on the Density of Breeding Birds in Dutch Agricultural Grasslands*, 75 BIOL. CONS. 255–260 (1996); S.J. Peris & M. Pescador, *Effects of Traffic Noise on Passerine Populations in Mediterranean Wooded Pastures*, 65 APPLIED ACOUSTICS 357–366 (2004); R.T.T. Forman & L.E. Alexander, *Roads and Their Major Ecological Effects*, 29 ANN. REV. ECOLOGY SYSTEMATICS 207–231 (1998); E. Stone, *Separating the Noise from the Noise: A Finding in Support of the "Niche Hypothesis," That Birds Are Influenced by Human-Induced Noise in Natural Habitats*, 13 ANTHROZOOS 225–231 (2000); Ian Spellerberg, *Ecological Effects of Roads and Traffic: A Literature Review*, 7 GLOBAL ECOLOGY BIOGEOG. LETTERS 317–333 (1998); David Lesbarrères et al., *Inbreeding and Road Effect Zone in a Ranidae: The Case of Agile Frog,* Rana dalmatina *Bonaparte 1840*, 326 COMPTES RENDUS BIOLOGIES 68–72 (2003).

[32] See, *e.g.*, Jeffrey A. Stratford & W. Douglas Robinson, *Gulliver Travels to the Fragmented Tropics: Geographic Variation in Mechanisms of Avian Extinction*, 3 FRONTIERS ECOLOGY & ENV'T 91–98 (2005); P. Laiolo & J. L. Tella, *Erosion of Animal Cultures in Fragmented Landscapes*, 5 FRONTIERS ECOLOGY & ENV'T 68–72 (2007).

4.1 The Observational Approach

4.1.1 Relating wildlife abundance to noise levels

Much of the evidence for noise impacts on animals comes from field observations of animal density, species diversity, and/or reproductive success in relation to noise sources. Most studies focus on the presence or absence of wildlife near roads, finding lower population densities of many birds,[33] lower overall diversity for birds, reptiles, and amphibians,[34] and road avoidance in large mammals.[35] Most of this work does not separate the impacts of noise from other road effects or measure spatial and temporal variations in noise levels along transects where animals were studied.

One influential series of studies in the Netherlands did find, however, a negative relationship between noise exposure along roadways and both bird diversity and breeding densities.[36] Noise exposure better explained decreased density and diversity than either visual or chemical disturbance. These Dutch studies have been criticized for research design and statistical analysis problems,[37] underscoring the fact that researchers in different countries have different assumptions about how to measure noise and evaluate its impacts.[38] On their own, the Dutch studies are an inadequate basis for establishing internationally standardized noise regulations, but they are among the few analyses that set measurements of noise levels beside data on species presence/absence and diversity.

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[33] Forman & Deblinger, *supra* note 3; Rheindt, *supra* note 15; Peris & Pescador, *supra* note 26; M. Kuitunen et al., *Do Highways Influence Density of Land Birds?* 22 ENVTL. MGMT. 297–302 (1998); A.N. van der Zande et al., *The Impact of Roads on the Densities of Four Bird Species in an Open Field Habitat—Evidence of a Long-Distance Effect*, 18 BIOL. CONS. 299–321 (1980).

[34] C.S. Findlay & J. Houlahan, *Anthropogenic Correlates of Species Richness in Southeastern Ontario Wetlands*, 11 CONS. BIOL. 1000–1009 (1997).

[35] Studies in large mammals typically find road avoidance, but many small mammals are found in higher densities near roads, due to increased dispersal and reduced numbers of predators. Forman & Deblinger, *supra* note 3; F. J. Singer, *Behavior of Mountain Goats in Relation to US Highway 2, Glacier National Park, Montana*, 42 J. WILDLIFE MGMT. 591–597 (1978); G.R. Rost & J.A. Bailey, *Distribution of Mule Deer and Elk in Relation to Roads*, 43 J. WILDLIFE MGMT. 634–641 (1979); L.W. Adams & A.D. Geis, *Effects of Roads on Small Mammals*, 20 J. APPLIED ECOLOGY 403–415 (1983).

[36] Reijnen et al., *supra* note 29; R. Foppen & R. Reijnen, *The Effects of Car Traffic on Breeding Bird Populations in Woodland. II. Breeding Dispersal of Male Willow Warblers (*Phylloscopus trochilus*) in Relation to the Proximity of a Highway*, 31 J. APPLIED ECOLOGY 95–101 (1994).

[37] N. Sarigul-Klign, D.C. Karnoop, & F.A. Bradley, *Environmental Effect of Transportation Noise. A Case Study: Criteria for the Protection of Endangered Passerine Birds, Final Report* (Transportation Noise Control Center (TNCC), Department of Mechanical and Aeronautical Engineering, University of California, Davis, 1977); G. Bieringer & A. Garniel, Straßenalärm und Vögel—eine kurze Übersicht über die Literatur mit einer Kritik einflussreicher Arbeiten. Bundesministerium für Verkehr, Innovation und Technologie. Schriftenreihe Straßenforschung. Unpublished manuscript, Vienna, 2010 (copy on file with the authors).

[38] Noise is commonly measured in dBA SPL, a unit that is measured differently in different countries, making extrapolation difficult. Bieringer & Garniel, *supra* note 32.

The value of observational studies of presence/absence and diversity also needs to be assessed in context. One would not want to use information about reduced occupancy of a noisy area, for example, as the only indication that noise was having population-level impacts. It is conceivable that, if noise results in increased mortality or decreased reproduction, noisy areas could become population sinks,[39] and a detriment to conservation efforts across the range of the species. But this conclusion would be premature unless the presence/absence data are assessed in the context of other measures of impact, such as breeding success, stress response, startling and other behavioral changes.

So, while observational studies can be and have been helpful in identifying noise as a conservation problem, their policy relevance and value is constrained if they are unable to separate the effects of noise from the many other confounding disturbances that can affect animal densities near roads and other human development. When Fahrig et al.[40] documented reduced densities of frogs and toads near high traffic roads compared to low traffic roads, noise was a potential causal factor. After controlling for other variables, however, their evidence suggested that differences in density more likely reflected varying levels of traffic-associated road mortality.

One way to reduce, though not eliminate, the problem of confounding variables is to compare behaviors and other response variables in the presence and absence of noise. Animals can be observed, for example, before and after noise sources are introduced, or when noise is intermittent. This approach has been used to demonstrate the impact (or lack of impact) of noise from aircraft, machinery, and vehicles on animal behavior and reproductive success.[41] Spatial variation in noise may also allow researchers to control for some confounding factors. One study examined ovenbirds (*Seiurus aurocapilla)* along the edges of clearings containing either compressor stations or gas-producing wells.[42] Both clearings had a similar level of surface disturbance and human activity, but compressors produced high-amplitude noise whereas the wells were relatively quiet. Near compressors, the analysis found reduced pairing success and evidence that the habitat was non-preferred.[43]

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[39] Sinks are areas where successful reproduction is insufficient to maintain the population without immigration. H.R. Pulliam, *Sources, Sinks, and Population Regulation*, 132 AM. NATURALIST 652–661 (1988).

[40] L. Fahrig et al., *Effect of Road Traffic on Amphibian Density*, 73 BIOL. CONS. 177–182 (1995).

[41] Delaney et al., *supra* note 24; D. Hunsaker, J. Rice, & J. Kern, *The Effects of Helicopter Noise on the Reproductive Success of the Coastal California Gnatcatcher*, 122 J. ACOUSTICAL SOC. AM. 3058 (2007); Jennifer W. C. Sun & Peter M. Narins, *Anthropogenic Sounds Differentially Affect Amphibian Call Rate*, 121 BIOL. CONS. 419–427 (2005).

[42] L. Habib, E.M. Bayne, & S. Boutin, *Chronic Industrial Noise Affects Pairing Success and Age Structure of Ovenbirds* Seiurus aurocapilla, 44 J. APPLIED ECOLOGY 176–184 (2007).

[43] Habib et al. found an increased proportion of juveniles in noisy areas, suggesting that the area is undesirable for breeding adults. *Id.*

An additional observational approach is to include noise as a factor in habitat-selection models. These spatially explicit models, typically produced in GIS (Geographic Information Systems), relate species distribution data to information about landscape characteristics in order to determine the impact of disturbance or habitat quality on habitat usage by wildlife.[44] Multiple habitat layers can be added to the model to determine what factors best predict habitat usage. While few studies have incorporated noise into these types of models, GIS layers of noise can readily be created using commercially available and freeware programs. These types of models may be the best option for measuring noise impacts on a large scale and can also be useful in predicting future areas of conflict with human activities.

Ideally, future observational studies encompassing a variety of noise sources, habitats, and species will measure noise exposure levels and then relate observed impacts to noise exposure while controlling for confounding variables. When effects cannot properly be controlled for in a single study design, a second-best choice is to use replicated studies and let statistical modeling separate out the impacts of noise. To date, only a handful of studies follow this approach.[45]

4.1.2 Estimating the masking potential of noise

There is a relatively simple technique for addressing possible noise impacts on signal detection. It involves estimating the potential of a noise source to mask communication signals and other important sounds, such as the sounds of predators or prey. Masking occurs when background noise is loud relative to the signal, such that it cannot be detected by the receiver.

The estimation of masking requires knowledge of the physiology and behavior of the organism and the nature of the noise. Masking is frequency-specific, so an acoustic signal will only be masked by the portion of the background noise that is in a similar frequency band as the signal.[46] An

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[44] J.B. Dunning et al., *Spatially Explicit Population Models: Current Forms and Future Uses*, 5 ECOLOGICAL APPLICATIONS 3–11 (1995).

[45] Forman, Reineking, & Hersberger, *supra* note 6; Reijnen et al. (1995), *supra* note 29; Reijnen et al. (1996), *supra* note 29; Foppen & Reijnen, *supra* note 34; R. Reijnen & R. Foppen, *The Effects of Car Traffic on Breeding Bird Populations in Woodland. I. Evidence of Reduced Habitat Quality for Willow Warblers (*Phylloscopus trochilus*) Breeding Close to a Highway*, 31 J. APPLIED ECOLOGY 95–101 (1994).

[46] Lohr et al*., supra* note 8; E.A. Brenowitz, *The Active Space of Red-Winged Blackbird Song*, 147 J. COMP. PHYSIOLOGY 511–522 (1982); R.J. Dooling & B. Lohr, *The Role of Hearing in Avian Avoidance of Wind Turbines, in* PROC. NAT'L AVIAN-WIND PLANNING MEETING IV 115–134 (S.S. Schwartz ed., for the Avian Subcommittee, National Wind Coordinating Committee, 2001).

estimation of masking requires,[47] first, the audiogram of the focal species;[48] second, the absolute amplitude and frequency spectrum of the noise;[49] third, the absolute amplitude and frequency spectrum of the vocalization or sound of interest; and fourth, the critical ratio for the focal species.[50]

With this information, masking is estimated by determining how introduced noise changes the "active space" of the signal, which is the area around the sender where the signal can be detected by receivers.[51] Intuitively, there is less masking when signals have a different frequency profile than noise, when noise is quiet, when signals are loud and/or when animals are close together when communicating. Conversely, masking is most problematic when signal and noise have similar frequency profiles, when noise is loud, when calls are quiet, and/or when calls are used over large distances.[52]

There are, however, limitations to masking estimations. The method described addresses only the potential impacts of masking animal vocalizations or other sounds and cannot estimate other impacts of noise, such as startling or chronic stress. Further, in the absence of specific information about the auditory physiology and behaviors of the focal species, estimates of masking using this method may be either too conservative or too liberal. Estimates can be too conservative, for example, in situations in which the mere detection of a vocalization is an insufficient basis for extracting necessary information from the sound.[53] Estimates can be too liberal if as part of their communication

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[47] For detailed methods on calculating masking potential, *see* R.J. Dooling & J.C. Saunders, *Hearing in the Parakeet (*Melopsittacus undulatus*): Absolute Thresholds, Critical Ratios, Frequency Difference Limens, and Vocalizations*, 88 J. COMP. PHYSIOL. 1–20 (1975).

[48] A measure of how hearing sensitivity varies with the frequency of the sound. In general, birds do not hear as well as mammals in very low or high frequencies, or use them to communicate. Dooling & Popper, *supra* note 1.

[49] A measure of how much energy is present in each frequency band of the sound.

[50] This is the difference in amplitude between signal and noise necessary for detection of the signal. For a generalized bird, the critical threshold ranges from approximately 26 to 28 dB between 2 and 3 kHz, meaning that a typical bird cannot hear a 2–3 kHz vocalization unless the vocalization exceeds the background noise in that frequency range by 26–28 dB. In general, birds have higher critical ratios than mammals, making them worse at discriminating signals in noise. If measurements for these parameters are not available for the focal species, then information from closely related species may be used as a substitute. However, this may be misleading if the species of interest has particularly strong or poor hearing capabilities relative to the substitute species. Dooling & Popper, *supra* note 1; Lohr et al., *supra* note 8; Dooling & Saunders, *supra* note 45.

[51] Lohr et al.*, supra* note 5; Brenowitz, *supra* note 39.

[52] Lohr et al.*, supra* note 5; Bee & Swanson, *supra* note 15; G. Ehret & H.C. Gerhardt, *Auditory Masking and Effects of Noise on Responses of the Green Treefrog (*Hyla cinerea*) to Synthetic Mating Calls*, 141 J. COMP. PHYSIOL. A 13–18 (1980); T. Aubin & P. Jouventin, *Cocktail-Party Effect in King Penguin Colonies* 265 PROC. R. SOC. B 1665–1673 (1998).

[53] This would happen when humans can detect human voices, but not discriminate the identity of the speaker or the words being said. *See* Lohr et al., *supra* note 5, for a discussion of the difference between detection and discrimination.

animals use spatial cues,[54] co-modulation of frequencies,[55] or adjust their vocalizations to reduce masking.[56]

Because so many factors affect the degree of masking, there is a critical need for additional field studies to validate estimation techniques. The available work relating the potential for masking to observed individual- and population-level impacts[57] is just not a sufficient basis for knowing whether masking potential is a reliable predictor of how noise will impact wildlife. If the predictive power of measuring masking potential can be shown, researchers will then have a low-cost tool for predicting impacts in species about which little is known. Otherwise, masking analysis is most informative when used in concert with field studies that assess actual noise impacts. If a disruption of communication or decreased rates of prey capture in noisy areas can be demonstrated, then an analysis of the masking potential of a new noise source could be used to determine the area over which individuals are likely to be affected by that new source.[58]

4.2 The Experimental Approach

Experimental manipulations of noise in the laboratory and the field are more powerful than observational studies in isolating the effects of noise and identifying the underlying causes of noise impacts because they deal more effectively with the problem of controlling for confounding variables. The following sections discuss their advantages and limitations.

4.2.1. Laboratory experiments

Laboratory studies introduce noise to captive animals and measure the impacts in a controlled environment. Studies using captive animals are the basis for much of what we know about the hearing range and sensitivity of a number of animal taxa[59] and about the ability of animals to detect and

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[54] The ability to hear sounds is improved if they are separated spatially. M. Ebata, T. Sone, & T. Nimura, *Improvement of Hearing Ability by Directional Information*, 43 J. ACOUSTICAL SOC. AM. 289–297 (1968); J.J. Schwartz & H.C. Gerhardt, *Spatially Mediated Release From Auditory Masking in an Anuran Amphibian*, 166 J. COMP. PHYSIOL. A 37–41 (1989).

[55] Masking is reduced when the noise has amplitude modulation patterns that make it distinct from the signal. G.M. Klump & U. Langemann, *Co-Modulation Masking Release in a Songbird*, 87 HEARING RES. 157–164 (1995).

[56] Patricelli & Blickley, *supra* note 10; Rabin & Greene, *supra* note 10; Warren et al., *supra* note 10; Slabbekoorn & Peet, *supra* note 17.

[57] Rheindt, *supra* note 18.

[58] Lohr et al., *supra* note 8.

[59] Dooling & Saunders, *supra* note 45; K. Okanoya & Robert F. Dooling, *Hearing in the Swamp Sparrow,* Melospiza georgiana, *and the Song Sparrow,* Melospiza melodia, 36 ANIMAL BEHAV. 726–732 (1988); H.E. Heffner et al., *Audiogram of the Hooded Norway Rat*, 73 HEARING RES. 244–247 (1994); H.E. Heffner & R.S. Heffner, *Hearing Ranges of Laboratory Animals*, 46 J. AM. ASS'N LABORATORY ANIMAL SCI. 20–22 (2007).

discriminate sounds in the presence of background noise.[60] These psychoacoustic studies are critical for assessing masking potential, and provide a physiological and morphological basis for predicting which species are most likely to be impacted by introduced noise.[61] Laboratory studies also provide insight into the physiological and behavioral impacts of noise, and the potential consequences of masking for breeding individuals.[62] As noted earlier, they demonstrate impacts on pair-bonding[63] and the amplitude at which vocalizations are produced.[64] They do not address, however, the long-term consequences of these behavioral changes, which remain unclear and need further study both in the laboratory and in the field.

Traditionally, psychoacoustic studies use white noise or pure tones to measure hearing ability and noise effects.[65] Recent studies also address the effects of anthropogenic noise directly, increasing their relevance to conservation. Lohr and colleagues, for example, measured the masked thresholds of natural contact calls for budgerigars (*Melopsittacus undulates)* and zebra finches, in the lab using simulated traffic noise, allowing them to predict how traffic noise affects the distance at which vocalizations can be detected by receivers.[66]

The environmental control that gives laboratory studies their analytic power can also be a disadvantage, if there is reason to believe that the response of animals to noise in a laboratory setting will be different from that of animals in the wild, where natural variations in the environment and in animal populations can affect the impact of noise. When increased physiological stress from noise is experienced, for example, in combination with habitat loss, synergistic effects on animals will magnify the overall impact of development.

Laboratory studies also must be careful not to extrapolate findings from animals that thrive in captivity to endangered animals, particularly since the

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[60] Lohr et al*.*, *supra* note 8; Dooling & Saunders, *supra* note 45; Klump & Langemann, *supra* note 53; L. Wollerman, *Acoustic Interference Limits Call Detection in a Neotropical frog* Hyla ebraccata, 57 Animal Behav. 529–536 (1999).

[61] Dooling & Popper, *supra* note 1.

[62] Marler et al*.*, *supra* note 14; Ryals et al*.*, *supra* note 14; J. Syka & N. Rybalko, *Threshold Shifts and Enhancement of Cortical Evoked Responses After Noise Exposure in Rats*, 139 Hearing Res. 59–68 (2000); D. Robertson & B.M. Johnstone, *Acoustic Trauma in the Guinea Pig Cochlea: Early Changes in Ultrastructure and Neural Threshold*, 3 Hearing Res. 167–179 (1980).

[63] Swaddle & Page, *supra* note 19.

[64] J. Cynx, et al., *Amplitude Regulation of Vocalizations in Noise by a Songbird,* Taeniopygia guttata, 56 Animal Behav. 107–113 (1998); Marty L. Leonard & Andrew G. Horn, *Ambient Noise and the Design of Begging Signals*, 272 Proc. R. Soc. B 651–656 (2005). This finding has been corroborated with studies of birds in the field in Brumm, *supra* note 18.

[65] Dooling & Saunders, *supra* note 45; Klump & Langemann, *supra* note 53; Wollerman, *supra* note 53; J.B. Allen & S.T. Neely, *Modeling the Relation between the Intensity Just-Noticeable Difference and Loudness for Pure Tones and Wideband Noise*, 102 J. Acoustical Soc. Am. 3628–3646 (1997).

[66] Lohr et al*.*, *supra* note 8. For other studies that introduce anthropogenic noise, see Weisenberger et al*.*, *supra* note 7; Bee & Swanson, *supra* note 18.

animals chosen for laboratory study are often domesticated or otherwise show tolerance for human disturbance. Endangered animals, by contrast, are often driven to rarity due to their inability to tolerate environmental change, which may include sensitivity to noise.[67] The use of surrogate species would be unnecessary if the species of concern could be tested in the lab for noise response. But small population sizes and narrow tolerances often make it impossible to bring threatened or endangered species into the lab for such tests.

The use of anthropogenic noise in laboratory studies of noise effects, particularly noise that is likely to be affecting wild animals, increases the conservation applicability of such research and should be a future priority. Laboratory experiments must also be supplemented with field studies and other methods to fully understand the impacts of noise on wildlife.

4.2.2. Noise introduction experiments in the field

Field experiments are another method for isolating and quantifying the impacts of noise on animals under natural conditions. The controlled introduction of noise can be accomplished either by creating noise in the field or by playing back the associated noise through speakers. The first approach has been used to investigate the impacts on wildlife of aircraft, machinery, and vehicles.[68] As is the case with observational studies, interpretations of this type of research are complicated by the problem of controlling for confounding variables, such as the visual and other disturbances, in addition to noise, associated with many sorts of environmental change. Compared to observational studies, however, field experiments offer greater opportunities to examine interactions among multiple associated stressors. They are also generally a more efficient use of scarce research resources and provide the ability to control for (or examine) seasonal effects, time-of-day effects, and other factors influencing responses to noise.

The second experimental approach, playing back noise that has been recorded from a source of interest or synthesized to match that source,[69] has the advantage that noise effects can be easily separated from other aspects of disturbance. Because noise introduction on a large spatial and temporal scale is logistically challenging in natural habitats, studies to date have been short-term and relatively small in scale. A short-term experiment may be appropriate

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[67] T. Caro, J. Eadie, & A. Sih, *Use of Substitute Species in Conservation Biology*, 19 CONS. BIOL. 1821–1826 (2005).

[68] Delaney, et al., *supra* note 24; P. R. Krausman, et al., *Effects of Jet Aircraft on Mountain Sheep*, 62 J. WILDLIFE MGMT. 1246–1254 (1998); A. Frid, *Dall's Sheep Responses to Overflights by Helicopter and Fixed-Wing Aircraft*, 110 BIOL. CONS. 387–399 (2003).

[69] Sun & Narins, *supra* note 39; A.L. Brown, *Measuring the Effect of Aircraft Noise on Sea Birds*, 16 ENV'T INT'L 587–592 (1990).

for studying dynamic behaviors, such as call rate, startling, or avoidance,[70] but cannot address the longer-term individual- or population-level consequences of noise.

To illustrate study design for a long-term and large-scale noise introduction experiment, we describe our ongoing experiment in Wyoming, addressing the noise impacts of energy development on greater sage-grouse.

4.2.2.1 Noise impacts on sage-grouse: A long-term field experiment

Populations of this species are declining throughout their range in the interior West of the United States,[71] enough to merit consideration for listing under the federal Endangered Species Act. Coal-bed methane (CBM) and deep natural gas extraction are increasing rapidly in sage-grouse habitats, and recent studies document dramatic declines in sage-grouse populations in areas of energy development.[72] However, incomplete knowledge of the causes of these declines is hampering the creation of effective management strategies.

Among the number of disturbances associated with energy development that impact sage-grouse, noise is particularly problematic in breeding areas downwind of development when it causes declines in male attendance, although attendance was not affected by visual disturbance from development.[73] In addition, the life history of sage-grouse makes them particularly vulnerable to disturbance from noise pollution. In the breeding season, males gather on communal breeding grounds (leks) to perform complex acoustic displays, used by females to locate leks and choose mates. The risk is that anthropogenic noise in sage-grouse habitat masks male vocalizations and interferes with reproduction. While there are rules governing the noise emitted during drilling of natural gas wells, exemptions are often granted and there has been little research demonstrating that stipulated noise levels reduce the impacts of development on sage-grouse, as well as other sensitive species.

Our multi-year, noise-introduction experiment on sage-grouse leks in an otherwise undisturbed area tries to separate the impacts of noise from other potential impacts of energy development. Two types of noise are of

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[70] Weisenberger et al., *supra* note 7; Sun & Narins, *supra* note 39; Leonard & Horn, *supra* note 62; Brown, *supra* note 67.

[71] J.W. Connelly et al., Conservation Assessment of Greater Sage-Grouse and Sagebrush Habitats, Western Association of Fish and Wildlife Agencies. Unpublished Report. Cheyenne, Wyoming, 2004. Copy online at http://www.ndow.org/wild/conservation/sg/resources/greate_sg_cons_assessment.pdf

[72] M.J. Holloran, Greater Sage-Grouse (*Centrocercus urophasianus*) Population Response to Natural Gas Field Development in Western Wyoming (2005) (unpublished Ph.D. dissertation, University of Wyoming) (accessible online from http://www.sagebrushsea.org/th_energy_sage_grouse_study2.htm); Brett L. Walker et al., *Greater Sage-Grouse Population Response to Energy Development and Habitat Loss*, 71 J. WILDLIFE MGMT. (2007); Dooling & Popper, *supra* note 1.

[73] Other factors at work include habitat loss, fragmentation, dust, air pollution, and West Nile virus. Connelly et al*, supra* note 64; Holloran, *supra* note 70; D.E. Naugle et al., *West Nile Virus: Pending Crisis for Greater Sage-Grouse*, 7 ECOLOGY LETTERS 704–713 (2004).

primary interest, road noise and drilling noise. Both types are dominated by low frequencies, but drilling noise is high intensity, continuous noise, whereas road noise is intermittent with gradual increases and decreases in amplitude. Monitored leks are divided into pairs of control leks and leks with experimentally introduced noise.[74] Ideally, noise would be introduced at different levels on different leks to determine the noise threshold at which an impact can be observed. However, such a "dose-response" experiment would require a large sample of leks and that is logistically infeasible. The experiment, instead, creates a noise gradient across each lek, so that the effect of noise level on microhabitat use and behavior can be measured and noise-tolerance thresholds estimated.

This experimental approach isolates and makes it possible to assess the impacts of noise on lekking sage-grouse at both the individual and population levels. The individual effects are analyzed from audio and video recordings, to determine whether individuals change the rate, frequency structure, and amplitude of their displays in the presence of noise, as has been found in other species.[75] A non-invasive technique compares the relative stress levels of birds on experimental and control leks through analysis of stress hormones in feces.[76] Population-levels effects of noise derive from comparison of lek attendance patterns on experimental and control leks over multiple seasons. This allows detection of noise impacts while controlling for natural variations in behavior, physiology, and larger-scale fluctuations in the population.

Although introducing noise in the wild is a powerful tool for measuring noise impacts on animals, it is only appropriate in certain circumstances. Noise introduction requires access, for example, to a population of animals residing in a relatively undisturbed area. Such a population may be unavailable in some species of concern, or the species may be too sensitive or rare to risk such an experimental manipulation. In addition, animals must be at fairly high densities in order to collect sufficient data for analysis, because it is difficult to create a noise disturbance over a large area using speakers.[77] During the breeding season, noise introduction can rely on battery-powered speakers, because leks are relatively small and have a high density of birds. This same

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[74] Paired leks have similar size and location and are visited by researchers for counts on the same days. Noise is introduced at 70 dBF SPL (unweighted decibels) at 16 meters using three to four battery-powered outdoor speakers. This is similar to noise levels measured at $\frac{1}{4}$-mile from drilling rigs and main haul roads in Pinedale, Wyoming. Control leks have dummy speakers and are visited for "battery changes" with the same frequency as experimental leks.

[75] Patricelli & Blickley, *supra* note 13; Warren et al., *supra* note 13; Rabin et al., *supra* note 13; Rabin & Greene, *supra* note 13; Slabbekoorn & Peet, *supra* note 20.

[76] *See*, *e.g.,* Wasser et al., *supra* note 27.

[77] Most anthropogenic noise sources are very large, and it is extremely difficult to replicate loud noise over a large area from small speakers, since amplitude (and thus propagation) is limited by source size. This challenge is even greater when speakers are powered by batteries in remote field locations.

approach is less able, however, to address noise impacts on nesting or overwintering behaviors, when sage-grouse are more dispersed.

In some situations, the use of semi-captive populations reaps some of the benefits of both field and laboratory studies, by increasing animal density in a more natural setting than is afforded by laboratory animal colonies. This approach is outside the scope of our current study. Another limitation of the experimental approach is that it underestimates (or even misses) the impacts of noise that occur in interaction with other forms of disturbance, such as the combination of noise pollution with an increase of raptor perches in energy development areas.[78] The combined effects will be larger than that attributable to either disturbance alone, but they can only be examined in observational studies and noise-source introduction experiments. This highlights, again, the need for multiple research approaches to measuring wildlife noise impacts.

There are very few experimental studies that use either noise-source introductions or noise playbacks, even though these experimental tools, used in a field setting or in naturalistic captive settings, are among the most powerful for understanding noise impacts on wild populations. Large-scale field experiments are expensive and logistically challenging. They do, however, appear to be warranted, particularly when observational studies and measurements of masking potential suggest a likely role for noise in impacting wild animals. Future field research should also focus on validating results and methods from laboratory studies, thus increasing the ability to apply lab studies and estimates of masking potential to the development of effective mitigation measures and predictions about the impacts future development is likely to have on wildlife.

5. FUTURE DIRECTIONS AND POLICY RELEVANCE

Even though the rapid spread of human development and associated anthropogenic noise have impacts on wildlife, it is not always logistically, politically, or economically feasible to eliminate or even minimize noise. The more common policy approach is to set noise standards, in the hope of limiting the levels of noise that development produces. The production of noise can then be reduced structurally[79] or operationally[80] to meet these standards. Road noise, for example, can be reduced through the use of certain types of asphalt, although these road surfaces can also have lower durability, lower traction, and higher cost than noisier varieties. Road noise can also be decreased by noise barriers, but these may cut off migration routes and exacerbate rather than

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[78] Connelly et al., *supra* note 69.

[79] Noise can be reduced structurally by using alternative materials and architecture, such as noise barriers, to reduce sound production and propagation.

[80] Noise can be reduced operationally through limitations on the timing and frequency of noisy activities, for example, by avoiding shift changes that occur at 7:00 a.m., in the peak lekking hours of sage-grouse.

reduce overall road impacts.[81] Regulations necessarily balance the economic and environmental trade-offs involved in allowing development to proceed and as a general rule the more information that can be brought to bear on this balancing process the better.

There can be no doubt that the first priority in the development of most current noise standards is the protection of human welfare. They use human criteria of disturbance, generated primarily in areas where humans are impacted.[82] These standards protect animal species with noise tolerances and distributions similar to those of humans. They are not effective, however, in reducing the impacts of noise on sensitive species of wildlife. So what should be our goal in the development of effective noise standards for the protection of wildlife? Environmental managers typically prefer a single noise standard that covers all situations. But since species differ in their ability to tolerate noise, a single noise standard is bound to be conservative for some species and insufficient for others. [83] Simply erring on the side of more conservative standards could do more harm than good in cases where it diverts money from more appropriate types of mitigation, and when noise mitigation measures introduce other environmental and economic costs, as discussed above. Rather than a single standard, a set of standards is needed, based on the measured sensitivities of indicator species and species of concern in a particular habitat type or location. Recently, a panel of experts developed a set of general and species-specific recommendations for marine mammal noise exposure criteria.[84] The development of such a set of standards for terrestrial species will require information about sensitivity to noise pollution in both abundant and rare species; the research priorities outlined here will help to achieve this goal.

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[81] Forman, Reineking, and Hersberger, *supra* note 6.

[82] Dooling & Popper, *supra* note 1; SINGAL, *supra* note 9.

[83] A single noise standard, for example, might establish a maximum acceptable noise level of 49 dBA at a one quarter mile from a noise source.

[84] B.L. Southall, A.E. Bowles, & W.T. Ellison, *Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations*, 125 J. ACOUSTICAL SOC. AM. 2517 (2009). There is no equivalent set of recommendations for terrestrial animals.

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CHAPTER 3

POTENTIAL ACOUSTIC MASKING OF GREATER SAGE-GROUSE (*CENTROCERCUS UROPHASIANUS*) DISPLAY COMPONENTS BY CHRONIC INDUSTRIAL NOISE

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Abstract.—Anthropogenic noise can limit the ability of birds to communicate by masking their acoustic signals. Masking, which reduces the distance over which the signal can be perceived by a receiver, is frequency dependent, so the different notes of a single song may be masked to different degrees. We analyzed the individual notes of mating vocalizations produced by Greater Sage-Grouse (*Centrocercus urophasianus*) and noise from natural gas infrastructure to quantify the potential for such noise to mask Greater Sage-Grouse vocalizations over both long and short distances. We found that noise produced by natural gas infrastructure was dominated by low frequencies, with substantial overlap in frequency with Greater Sage-Grouse acoustic displays. Such overlap predicted substantial masking, reducing the active space of detection and discrimination of all vocalization components, and particularly affecting low-frequency and low-amplitude notes. Such masking could increase the difficulty of mate assessment for lekking Greater Sage-Grouse. We discuss these results in relation to current stipulations that limit the proximity of natural gas infrastructure to leks of this species on some federal lands in the United States. Significant impacts to Greater Sage-Grouse populations have been measured at noise levels that predict little or no masking. Thus, masking is not likely to be the only mechanism of noise impact on this species, and masking analyses should therefore be used in combination with other methods to evaluate stipulations and predict the effects of noise exposure.

Key words: acoustic masking, *Centrocercus urophasianus*, Greater Sage-Grouse, industrial noise.

Enmascaramiento Acústico Potencial de Mayor Sage-Grouse (*Centrocercus urophasianus*) Mostrar Componentes por Ruido Industrial Crónica

Resumen.— Antropógena ruido puede limitar la capacidad de las aves para comunicarse por enmascarar sus señales acústicas. Enmascaramiento, que reduce la distancia sobre la que se puede percibir la señal por un receptor, es frecuencia dependiente, por lo que las diferentes notas de una canción pueden enmascararse en diferentes grados. Analizamos las notas individuales de apareamiento vocalizaciones producidas por mayor Sage-Grouse (Centrocercus urophasianus) y el ruido de infraestructura de gas natural para cuantificar el potencial de tal ruido a vocalizaciones de mayor Sage-urogallo de máscara en distancias cortas y largas. Hemos encontrado que ruido producido por la infraestructura de gas natural fue dominado por las frecuencias bajas, con considerable superposición en frecuencia con pantallas acústicas de mayor Sage-urogallo. Tal superposición predijo enmascaramiento sustancial, reduciendo el espacio activo de detección y discriminación de todos los componentes de vocalización y que afectan particularmente a notas de baja frecuencia y baja amplitud. Estas máscaras podrían aumentar la dificultad de evaluación de mate para lekking mayor Sage-urogallo. Analizaremos estos resultados en relación con las actuales disposiciones que limitan la proximidad de la infraestructura de gas natural a leks de esta especie en algunas tierras federales en los Estados Unidos. Impactos

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significativos a las poblaciones de mayor Sage-urogallo han sido medidos en los niveles de ruido que predicen el enmascaramiento de poca o ninguna. Así, enmascaramiento no es probable que sea el único mecanismo de impacto de ruido en esta especie, y enmascaramiento análisis debe por lo tanto, utilizarse en combinación con otros métodos para evaluar las estipulaciones y predecir los efectos de la exposición al ruido. Así, enmascaramiento no es probable que sea el único mecanismo de impacto de ruido en esta especie, y enmascaramiento análisis debe por lo tanto, utilizarse en combinación con otros métodos para evaluar las estipulaciones y predecir los efectos de la exposición al ruido.

Birds use acoustic signals to communicate with conspecifics for a host of biologically important functions, including mate attraction, territory defense, parent–offspring communication, and predator avoidance. In order for this communication to be successful, the signal must travel from the signaler to the receiver through the local environment. The local physical and acoustic environment, therefore, plays an important role in determining the active space of a signal, the area in which a receiver can successfully perceive it (Brenowitz 1982, Dooling et al. 2009). Background noise, a conspicuous feature of most natural environments, can result in acoustic masking if this noise is loud in relation to the signal of interest. Animals have numerous acoustic and behavioral adaptations to maximize the active space of their signals in the presence of natural background noise. For example, the structural and temporal properties of many acoustic signals appear to be adapted to maximize the propagation distance and minimize masking from abiotic and biotic noise sources in the environment (Marten and Marler 1977, Wiley and Richards 1982, Ryan and Brenowitz 1985, Brumm 2006). However, the spread of humans into natural landscapes has resulted in the proliferation of anthropogenic noise sources, with the potential to affect many of the animal species that live and communicate in these environments (Barber et al. 2010). Acoustic signals that are adapted to deal with natural noise sources may still be susceptible to masking from anthropogenic noise sources if the anthropogenic noise differs enough from natural noise sources in frequency, duration, or daily or seasonal pattern.

Effective communication requires that a receiver be able to detect a given signal, discriminate that signal from other possible signals, and recognize features that may convey information about the specific signaler. The active space of a signal may be different for each of these receiver tasks (Lohr et al. 2003). Detection provides the receiver with the lowest level of information—simply that a signal is present—and requires the lowest contrast between the signal and background noise. For a signal to be successfully detected in a noisy environment requires that the ratio of the signal to the background noise (i.e., signal-to-noise ratio [SNR], the difference between signal and noise amplitudes measured in decibels) within a frequency band exceed a critical detection threshold (Klump 1996). The critical detection threshold for a "typical bird" ranges from 18 dB to 37 dB across frequency bands. Discrimination of the signal from other signals, as would be required to identify the species of the sender or the functional category of the signal, requires a higher SNR than detection. In a laboratory study of two bird species, Lohr et al. (2003) found that discrimination of conspecific song required an SNR approximately 3 dB higher than the levels required for detection. An even more challenging task for a receiver is signal recognition, discerning variation among signals within a category, such as information about individual identity or reproductive quality. For example, receivers may use the acoustic features of the signal such as frequency structure, relative amplitude of notes, and note duration to recognize the identity of the signaling individual. Signal recognition may require an even higher SNR (Dooling and Popper 2007); however, we do not yet know how much higher the signal must be for recognition to occur.

The fitness consequences of being able to detect a signal versus discriminate or recognize a signal is likely to be signal specific. For example, a predator alert call, which functions to alert a conspecific to danger, may be effective so long as it exceeds the critical ratio for detection. However, a mate-attraction call that is used by females to assess the quality of a potential mate may need to exceed the critical recognition threshold in order to be effective. For example, the ability to recognize individual signals is critical to mate choice in the Swamp Sparrow (*Melospiza georgiana*): females use song features such as trill rate and frequency bandwidth to assess the quality of potential mates (Ballentine et al. 2004). Introduced noise has been demonstrated to weaken pair bonds in captive Zebra Finches (*Taeniopygia guttata*; Swaddle and Page 2007), which suggests that reduced recognition can have fitness consequences.

Active space can vary within a given signal as well as among signals. Many bird vocalizations are highly complex and are composed of multiple acoustic components (bouts, phrases, syllables, or notes). Some multicomponent signals may encode either distinct ("multiple messages hypothesis") or redundant ("redundancy hypothesis") information about the signaler (Møller and Pomiankowski 1993, Hebets and Papaj 2005). For example, the trill note and note complex of White-crowned Sparrow (*Zonotrichia leucophrys*) song each convey distinct information about dialect and individual identity, respectively (Nelson and Poesel 2007). Each component can vary in frequency structure, duration, and relative amplitude; these factors interact with the local physical and acoustic environment to determine the active space of the signal component (Patricelli et al. 2008). The result of this variation is that each component of a complex vocalization may have a different active space and be uniquely susceptible to masking by a given noise source.

Anthropogenic noise is typically dominated by low frequencies, so low-frequency signal components and features are most susceptible to masking (Brumm and Slabbekoorn 2005, Slabbekoorn and Ripmeester 2008). Even if a signal is not completely masked, low-frequency background noise could distort a signal, resulting in a higher-frequency note being perceived as having higher relative amplitude than a masked lower-frequency note. Such distortion could result in increased difficulty in assessment or identification.

Our focal species, the Greater Sage-Grouse (*Centrocercus urophasianus*; hereafter "sage-gouse"), is a medium-bodied gallinaceous bird that has long been used as a model system for studies of sexual selection and communication (Wiley 1973; Gibson 1989, 1996). During the breeding season, males gather on strutting grounds (leks) where they establish small display territories that are visited by females for courtship. Males produce a complex visual and acoustic display. Sound is critical to the breeding system on both large and small spatial scales because females use the acoustic component of the display to locate strutting males and, once on a lek, to select a male (Gibson 1989, 1996; Patricelli and Krakauer 2010).

The sage-grouse vocal display is composed of three major note types: a series of low-frequency "coo" notes, two broadband "pops," and a frequency-modulated "whistle" (Fig. 1). The rate of display (strut rate) is positively correlated with male success in mating (Gibson and Bradbury 1985, Gibson 1996, Patricelli and Krakauer 2010). In addition, the time interval between the two pop notes during which the whistle note occurs, the inter-pop interval (IPI), is positively correlated with mating success (Gibson et al. 1991, Gibson 1996). This suggests that assessment of the two pop notes might be particularly critical in female mating decisions. Whistles may also be important in female choice. Gibson and Bradbury (1985) found that the time interval from the first pop to the whistle peak as well as the maximum frequency of the whistle at the apex are related to male mating success. Female sage-grouse also may assess amplitude of the whistle; unpublished results suggest that whistle amplitude may be positively correlated with mating success (J. W. Bradbury pers. comm.), and males orient during courtship so that the highly directional whistle is beamed toward females (Dantzker et al. 1999). This female preference for male-display quantity

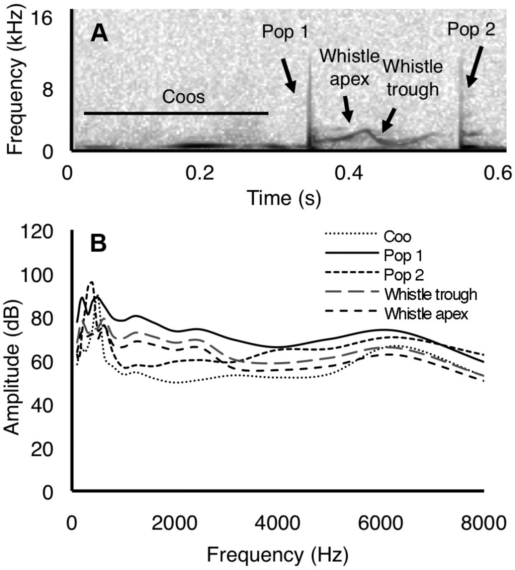

FIG. 1. Spectrogram and (B) power spectra of a male Greater Sage-Grouse strut display with distinct display components labeled. Low-frequency coos are followed by a broadband pop (pop 1), a frequency-modulated whistle with an apex of ~2,500 Hz (whistle apex) and a minimum of ~630 Hz (whistle trough), and another broadband pop (pop 2).

and quality suggests that masking of one or all of these notes by background noise may negatively affect a female's ability to assess males on the lek.

Sage-grouse populations are declining across their range (Connelly et al. 2004, Garton et al. 2011), leading sage-grouse to be listed as endangered under Canada's Species at Risk Act and designated as a candidate species for listing in the United States under the federal Endangered Species Act. Natural gas development has expanded rapidly over the past decade and has been implicated in contributing to population declines (Holloran 2005, Walker et al. 2007, Copeland et al. 2009, Holloran et al. 2010). In particular, noise associated with energy development has been demonstrated to result in reduced attendance on leks (Blickley et al. 2012) and is associated with increased stress hormones in males on noisy leks (J. L. Blickley and G. L. Patricelli unpubl. data). Masked communication has been suggested as a mechanism of this impact, so understanding the potential for introduced noise sources to mask signals used in mating could lead to improved management of vulnerable sage-grouse populations.

The present study addresses the potential for noise pollution from natural gas development to mask or distort acoustic signals that are used in breeding by sage-grouse. We analyzed the individual acoustic components of sage-grouse vocalizations (Fig. 1) and noise from natural gas infrastructure (a compressor station, generator, and drilling rig; Fig. 2) to quantify the potential for such noise to mask sage-grouse vocalizations over both long and short distances. We compared the effect of such noise on the level of both detection and discrimination and discuss the utility of this approach for predicting the impacts of noise on this and other species. For the masking analysis, we focused primarily on noise measurements at 75 m and 400 m (~1/4 mile), which represent a typical distance to the edge of surface disturbance (the pad) from a compressor station or drilling rig and the distance stipulated as the minimum surface-disturbance buffer around leks in our study region, respectively (Bureau of Land Management 2008).

METHODS

Field recordings and measurements.—Between 1 and 5 May 2010, we collected field recordings and vocal amplitude measurements from adult male sage-grouse on Preacher Reservoir lek (42°53.597′N, 108°28.417′W) in Fremont County, Wyoming. Recordings and amplitude measurements were collected simultaneously from a blind on the lek using a handheld Larson Davis 824 sound level meter (software version 3.12) using the logging function with a time-history resolution of 1/32 s and an amplitude resolution of 0.1 dB. A Marantz PMD670 portable solid-state recorder continuously recorded the audio stream from the SPL meter (through the AC/DC output) at 16-bit linear PCM format at 44.1 kHz. Each sound level measurement started prior to the initiation of a display by an individual male. The SPL meter measured and logged the average and peak amplitude in unweighted decibels (dB) at each time interval (0.03 s). Immediately after the vocalization was recorded, the distance between the vocalizing bird and the microphone was measured with a range finder (Leupold RX750). Sage-grouse strut displays are highly directional (Dantzker et al. 1999), so the orientation of the bird and distance to the microphone were also noted for each display measured. We used only high-quality and comparable measurements

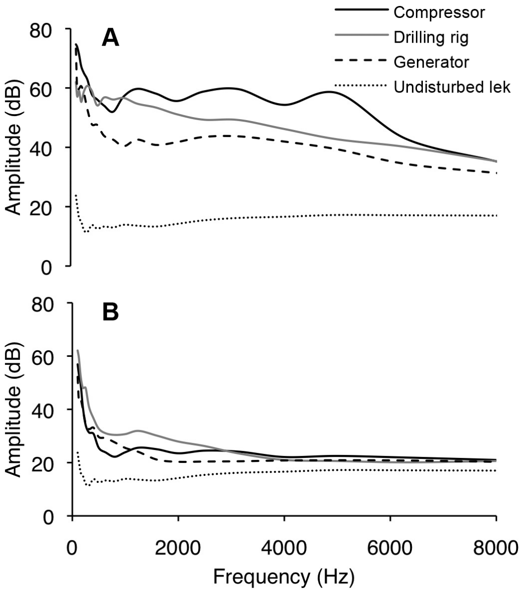

FIG. 2. Power spectra of ambient noise levels at (A) 75 m and (B) 400 m from a natural gas compressor station, natural gas drilling rig, and generator in Sublette County, Wyoming, and on an undisturbed lek (quiet) in Fremont County, Wyoming. Values were interpolated if a measurement for that distance was not available. Noise was dominated by low frequencies at both short and medium distances from the source.

in the analysis, including only vocalizations that we recorded from individuals in a small range of orientations and at similar distances in relation to the microphone. All vocalizations included in the analysis were from individuals with side-facing orientations ranging from 30 to 90 degrees (if zero degrees reflects an orientation with the bird directly facing the observer). We did not use recordings if there was temporal overlap with other strutting males or background noises, such as songbirds. Because of the difficulty of obtaining such recordings, a total of only 6 vocalizations, collected from 2 individuals (2 from one male, 4 from the other), were used in the final analysis.

Ambient noise levels were measured on Chugwater Reservoir lek (42°47.192′N, 108°26.292′W), a lek with little human disturbance in Fremont County, Wyoming. Noise was quantified as a 2-min L_{eq} (equivalent sound pressure level); this is a type of average, defined as the equivalent steady sound level that would produce the energetic equivalent of the actual fluctuating sound levels over the defined 2-min period. The sound level meter calculated an overall L_{eq} for the noise level as well as the 2-min L_{eq} for each 1/3-octave band frequency, which was used for SNR analysis (see below). Ambient measurements were made after lekking in the morning. Ambient noise levels tend to be slightly higher during this time than during the lekking hours (J. L. Blickley and G. L. Patricelli unpubl. data), so this measure is a slight overestimate of ambient levels on an undisturbed lek, leading to a slight underestimate of masking on disturbed leks.

Sound level measurements were made on a large compressor station (Falcon Compressor, which consisted of two Ariel JGC-4 compressors driven by 3,500-HP engines; 42°31.319′N, 109°40.271′W) and a deep natural-gas drilling rig (Questar Drilling Rig no. 232; 42°43.501′N, 109°50.876′W) on the Pinedale Anticline Project Area in Sublette County, Wyoming, and at a generator (East Litton Generator, a 300-kW MQ Power diesel generator powered by a Volvo engine; 43°31.501′N, 105°25.573′W) in the Powder River Basin, Campbell County, Wyoming. These noise sources are all commonly found in areas of natural gas development and typically operate 24 h day–1, year round. Noise was measured along one transect extending from each noise source. Noise measurements were taken at points 75, 200, 300, and 400 m from the Falcon Compressor; at points 8, 16, 32, 64, 128, 256, and 512 m from the East Litton Generator; and at points 75 and 400 m from the Questar Drilling Rig. At each point, distance from the source was measured with a laser range finder (Bushnell Yardage Pro). Noise levels were measured using a Larson Davis 824 sound level meter. During measurements, the sound level meter was held 25 cm from the ground, similar to the height of a grouse. The sound level meter calculated an overall L_{eq} for the noise level as well as the 2-min L_{eq} for each 1/3-octave band frequency. Noise levels are reported in unweighted decibels (reported as dB) re 20 µPa because an unweighted measure of amplitude is required for the estimation of masking potential; A-weighted values (dB[A]) are also presented for comparison. All noise measurements were made in the early morning, before the wind rose to detectable levels. Because of the similarity of noise from each of these sources (see Fig. 2), only noise measurements from the Falcon Compressor were used in the masking analysis; results from other noise sources should be very similar. Noise levels were estimated at distances >400 m from Falcon Compressor using NMSIM software (Wyle Laboratories, Arlington, Virginia). NMSIM generates spatially explicit estimates of noise propagation utilizing input topography, ground impedance, and source spectra. We developed a custom source spectrum for Falcon Compressor using noise measurements from transect data and modeled propagation from the source across flat and open ground using a topographic layer from a location at similar elevation to our study site at 200 rayls ground impedance and –1.1°C air temperature. We used NMSim to estimate the noise spectra at receiver points placed along a transect extending from the source.

Sound analysis.—Individual vocalizations were identified from a spectrogram of the field recording using RAVEN, version 1.3 beta (Cornell Lab of Ornithology, Ithaca, New York; Hann window function, FFT = 512 with 50% overlap). Audio recordings were synchronized with SPL measurements by identifying distinctive high-frequency device noise produced by the SPL meter with the initiation of the measurement; this allowed us to identify the 1/32-s sample(s) in the SPL-meter output that corresponds to each note on the spectrogram and measure the overall amplitude of that note. Each vocalization was then extracted and low-pass filtered at 8.0 KHz to exclude this device noise. For each vocalization, the amplitude of the 1/3-octave band frequencies was measured at intervals of 0.004 s using SPECTRAPLUS (Pioneer Hill Software, Poulsbo, Washington). Call components were identified in the audio recordings in RAVEN and matched with the corresponding overall amplitude measurement from synchronized SPL measurement data. The absolute amplitude of each component was calibrated using the equation

$$\text{Peak dB} = \sum 10^{(aX/10)}$$

where a represents a scaling factor and X represents the average amplitude for each 1/3-octave band frequency. By adjusting the value of the scaling factor, we could adjust the overall average amplitude (dB) of the vocalization while maintaining the same relative power at each frequency band. The scaling factor was adjusted to yield different overall average amplitudes (dB) for each vocalization for analysis of masking potential at different source levels. Frequency-specific amplitudes for each call component were averaged across vocalizations.

In order to determine the masking potential of the noise sources at different distances from the vocalizing bird and the noise source, SNRs were calculated for each vocalization by subtracting the average amplitude (dB) for 1/3-octave band frequencies of noise sources (taken from 2-min L_{eq} measurements; see above) from the average amplitude (dB) for 1/3-octave band frequencies of vocalizations as measured in SPECTRAPLUS. Each note of the sage-grouse vocalizations was calibrated to absolute amplitude measures made using the SPL meter (see above). We calculated the expected amplitude of the vocalization at distances 2, 4, 8, 16, 32, 64, and 128 m from the vocalizing bird, based on a 6-dB decrease in amplitude for every doubling of distance due to spherical spreading and frequency-specific rate of excess attenuation. Excess attenuation is attenuation caused by propagation of sound through the environment and is determined by habitat characteristics (e.g., groundcover, temperature) and distance of the vocalizing bird from the ground. To model propagation of vocalizations, we estimated frequency-specific rates of excess attenuation by comparing the overall rate of sound attenuation measured along noise transects with predicted amplitude loss due to spherical spreading alone. These estimated amplitudes were used to scale the vocalizations (see scaling equation above), in order to calculate the SNR for the maximum SNR frequency at different distances from the bird and from the noise source. Vocalizations were defined as "masked" if the SNR of the peak SNR frequency did not exceed the minimum threshold (critical ratio) for detection or discrimination (Dooling 2002, Lohr et al. 2003). Minimum masked distance was used to estimate the maximum detection or discrimination distance (active space). Estimates of sage-grouse critical ratios for detection were drawn from the average critical ratios for detection of 15 bird species, the only ones that have been measured to date (Dooling 2002), and ranged from 22 dB at 400–630 Hz to 27 dB at 2,500 Hz. The critical ratios for discrimination at each frequency band were estimated to be 3 dB higher than the critical ratio for detection in that band (Lohr et al. 2003). The critical ratios for detection and discrimination have not been measured specifically for sage-grouse, but there is relatively little variation in hearing abilities among bird species tested thus far, so estimates of the critical ratio are likely to be accurate to within 5 dB (Dooling 2002). All results are presented ± SE unless otherwise noted.

Results

Noise measurements.—Noise produced by Falcon Compressor was 48.9 dB louder than ambient levels at an undisturbed lek at a distance of 75 m from the source and 34.2 dB louder than ambient at a distance of 400 m (Table 1). Noise produced by the Questar Drilling Rig was 43.5 dB louder than ambient levels at a distance of 75 m from the source and 31.8 dB louder than ambient at a distance of 400 m. Noise produced by East Litton Generator was 24.9 dB louder than ambient levels at a distance of 75 m from the source and 18.4 dB louder than ambient at a distance of 400 m (Table 1). The noise produced by all noise sources was dominated by low frequencies (Fig. 2).

Vocalization measurements.—Individual components of the sage-grouse vocal display varied in amplitude and peak frequency (the frequency at which amplitude was the highest; Table 2). The pop 1 and pop 2 components had the highest peak amplitudes, with measures of 96 ± 2.1 and 98 ± 1.6 dB at 1 m, respectively. The coo components had an overall peak amplitude of 94 ± 1.3 dB at 1 m. The whistle component, by far the quietest component, had a peak amplitude of 84 ± 0.9 dB for the whistle trough (lowest frequency of the whistle component) and 82 ± 1.5 dB for the

TABLE 1. Overall noise levels (2-min L_{eq} measurements) measured along a transect extending from Falcon Compressor in Sublette County, Wyoming. For comparison, values from an undisturbed lek of Greater Sage-Grouse after the birds departed in late morning are also included (Chugwater Reservoir lek in Fremont County, Wyoming).

Distance	Amplitude (dB[F])	Amplitude (dB[A])
75 m	89.4	70.4
200 m	82.8	58.1
300 m	77.9	52.9
400 m	74.7	47.7
Undisturbed lek (quiet)	40.5	30.5

whistle apex (highest frequency of the whistle component) at 1 m. All vocal components had peak frequencies (400–630 Hz) overlapping with noise produced by natural gas infrastructure, except the apex of the frequency-modulated whistle, which had a peak frequency (2,500 Hz) above most of the noise.

Masking analysis.—We estimated the masking potential of compressor noise for five components of the sage-grouse vocalization: the coos, pop 1, pop 2, whistle trough, and whistle apex. Across all conditions modeled, the maximum detection and discrimination distance (i.e., the active space) for the highest-amplitude frequency band was greatest for the pop 2 component, the loudest note of the display. Overall amplitude of the note was not necessarily an indicator of greater active space—the coo component had a greater maximum detection distance than the pop 1 component (Fig. 3) despite lower overall amplitude, due to the higher amplitude of the maximum frequency. Active space of detection and discrimination for all components was substantially reduced at the noise levels found within 400 m of the compressor station in relation to the ambient conditions on an undisturbed lek (Fig. 3). At 75 m from the noise source, the maximum detection distance and maximum discrimination distance were reduced by 97% and 98%, respectively, for the coo; by 98% and 98% for pop 1; by 97% and 97% for pop 2; by 98% and 98% for the whistle trough; and by 100% and 100% for the whistle apex, in relation to the maximum distances on an undisturbed lek. At 400 m from the noise source, the maximum detection distance and maximum discrimination distance were reduced by 59% and 65%, respectively, for the coo; by 48% and 47% for pop 1; by 59% and 63% for pop 2; by 54% and 57% for the whistle trough; and by 64% and 58% for the whistle apex, in relation to the maximum distances on an undisturbed lek.

The distance from the source at which the active space for detection and discrimination were equal to that in ambient conditions (i.e., the maximum active space) varied for each component. The whistle apex reached maximum active space at 600 m from the noise source. The whistle trough reached maximum active space at 700 m from the source, whereas the coo and pop 1 required a minimum of 700 m from the source before they reached maximum active space. Pop 2 did not reach maximum active space until a minimum of 1,000 m from the noise source.

The SNR varied across frequencies for each component. Peak frequencies for coos, pops, and the whistle trough were relatively low (<1,000 Hz), leading to high overlap with the low-frequency noise produced by the Falcon Compressor and other natural gas infrastructure (Figs. 2 and 4). The SNR was substantially reduced at low frequencies at both short and medium distances to the compressor in relation to quiet lek conditions for all components (Fig. 4). For the whistle, coo, and pop 2 components, the frequency with the peak SNR remained the same under all noise conditions, indicating that no signal distortion would be expected. For the pop 1 component, the frequency with the peak SNR differed under different noise conditions, shifting from 400 Hz under quiet

TABLE 2. Amplitude and frequency characteristics of Greater Sage-Grouse vocalizations recorded in Fremont County, Wyoming. Measurements are normalized to 1 m from the source.

Note	Peak amplitude (dB)	Peak amplitude range (dB)	Frequency range (Hz)	Peak frequency (Hz, ⅓-octave band)
Coo	94 ± 1.3	89–98	100–800	500
Pop 1	96 ± 2.1	87–99	100–10,500	500
Pop 2	98 ± 1.6	90–100	100–11,500	400
Whistle apex	82 ± 1.3	76–87	2,200–2,600	2,500
Whistle trough	84 ± 0.9	81–87	450–800	630

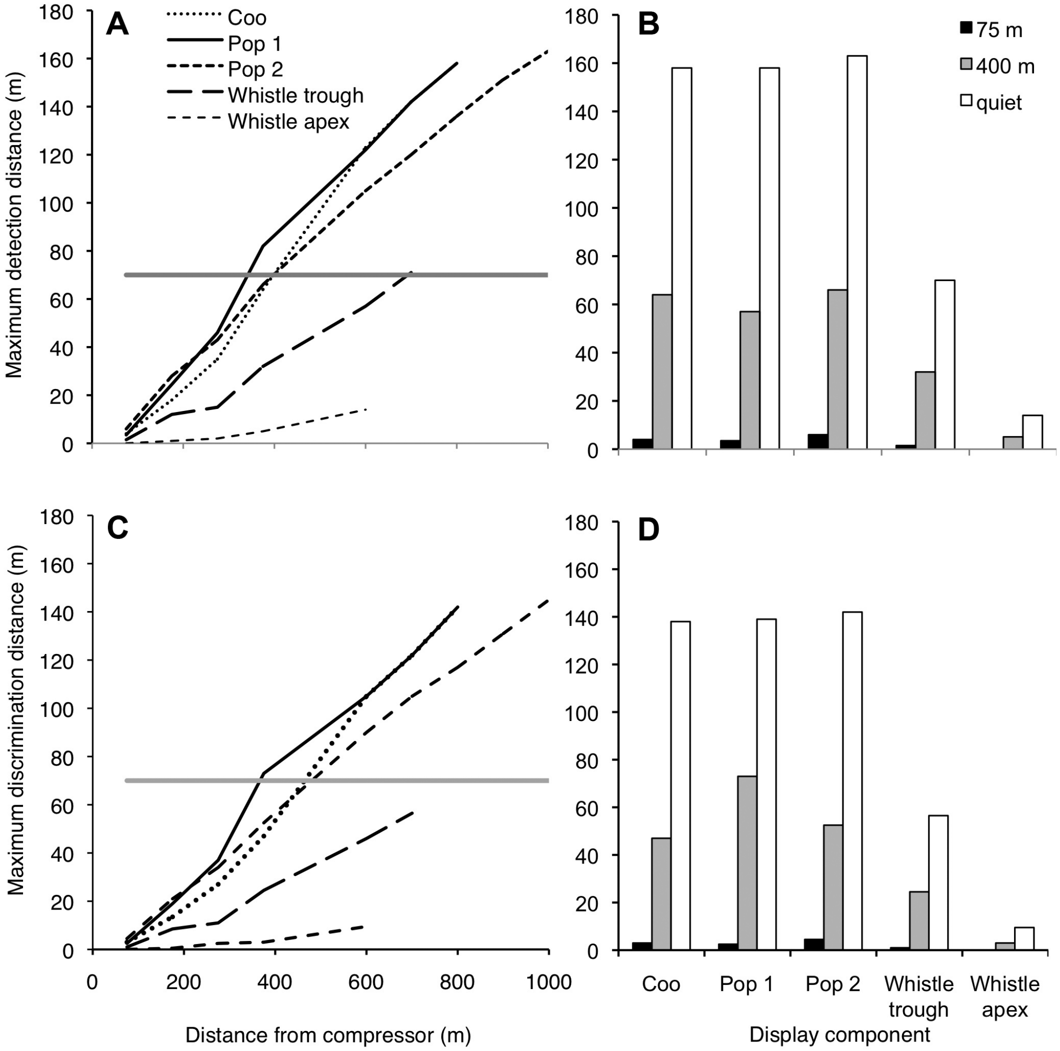

FIG. 3. Maximum (A) detection and (C) discrimination distance of Greater Sage-Grouse strut display components at varying distances from a natural gas compressor station. Gray solid line represents half the length of a typical lek in Fremont County, Wyoming. Lines end at the point where the active space is equal to that under quiet ambient conditions. Maximum (B) detection and (D) discrimination distance of vocalization components at points 75 and 400 m from a natural gas compressor station and under quiet ambient conditions.

conditions to 500 Hz in noisy conditions (Fig. 4B), potentially causing distortion of the signal.

DISCUSSION

We assessed the potential impact of anthropogenic noise on the transmission of sage-grouse vocalizations used for mate attraction (Wiley 1973; Gibson 1989, 1996; Patricelli and Krakauer 2010). Our results indicate that there are marked differences in the active space of individual notes of the sage-grouse acoustic display, both in noisy and quiet conditions. These differences in active space are primarily determined by the frequency structure and amplitude of the different notes of the sage-grouse vocalization, and by differences in the amplitude of the background noise. These factors and their effects on the active space for detection and discrimination are discussed below.

Frequency structure.—The active space of a vocalization is determined, in part, by the frequency structure—including peak frequency and

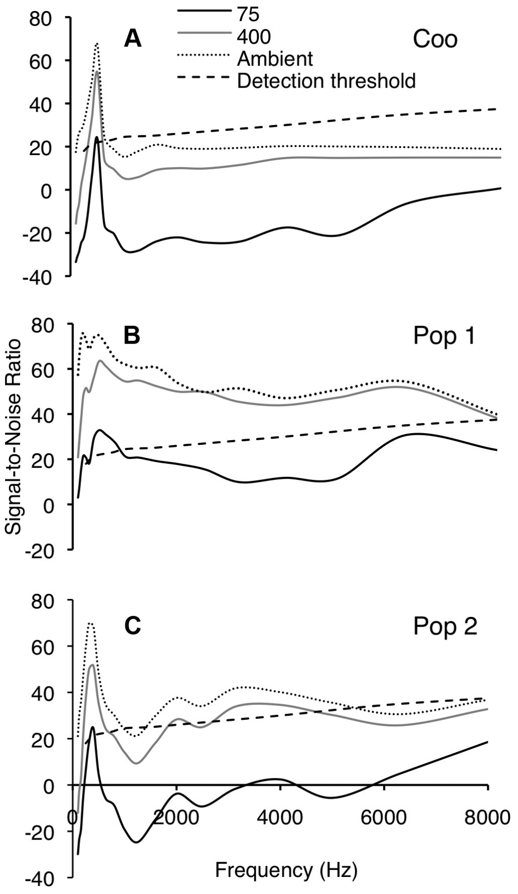

FIG. 4. Signal-to-noise ratio (SNR) of Greater Sage-Grouse acoustic display components (A) coo, (B) pop 1, and (C) pop 2 at a distance of 5 m from the vocalizing male (average close courtship distance) in ambient noise conditions measured 75 and 400 m from a natural gas compressor and on an undisturbed lek. Frequencies with an SNR that exceed the critical ratio for detection (dashed line) can be detected by a receiver. For pop 1, the frequency with the highest SNR is different in noisy and quiet environments, potentially leading to distortion of the vocalization.

frequency range—of both the acoustic signal and the background noise (Lohr et al. 2003). Both of these measures of frequency structure differed among the notes of the sage-grouse display vocalization. Notes with low peak frequencies (the coos, pops, and whistle trough) had high overlap with the noise produced by the Falcon Compressor and other natural gas infrastructure (Figs. 2 and 4), leading to predictions of a substantial reduction in active space of detection and discrimination for these notes in noisy conditions (Fig. 2). The whistle apex had a peak frequency above most of the compressor noise energy, but was still masked because of its lower source amplitude, as discussed below.

The frequency range of a note is also important in determining the degree of overlap with background noise. The coo note of the sage-grouse display is tonal and has a very small frequency range, so the entire note is likely to be masked by low-frequency noise (Fig. 4A). For notes with a broad frequency range, like the broadband pops and the frequency-modulated whistle, some of the higher-frequency energy of the signal is likely to be detectable above background noise that is predominantly low frequency. However, higher frequencies suffer greater attenuation over distance than lower frequencies (Marten and Marler 1977), which reduces the advantage of high-frequency signals in maximizing active space. Because most anthropogenic noise is dominated by low frequencies, species that have low-frequency vocalizations, such as the sage-grouse, will disproportionately experience masking. Indeed, several studies have found that anthropogenic noise more severely affects species with lower-frequency vocalizations (Rheindt 2003; Francis et al. 2009, 2011; Goodwin and Shriver 2011).

Amplitude.—The amplitude of each note is also important in determining the active space, such that quieter notes suffer increased masking at a given distance from the noise source and vocalizing individual. Pops and coos could be detected at greater distances than the whistle apex and whistle trough, despite greater overlap with the background noise, because of greater source amplitudes. The whistle apex, which had the lowest source amplitude, had the smallest active space in noise despite the low overlap with the noise frequencies.

The acoustic directionality of a vocalization may also affect the degree to which masking reduces the overall active space. Many vocalizations radiate from the signaler in a directional pattern, such that the amplitude varies with the orientation of the vocalizing individual. Because of our small sample size, we did not include the effects of directionality on active space in our analysis, but instead assessed the impact of noise on the average active space of the signal across multiple orientations. The whistle is highly directional, with differences of up to 22 dB depending on the relative orientation of the individual (Dantzker et al. 1999). We used values from the loudest orientations of those that we measured;

therefore, masking in the quieter orientations may be much greater than described here. Given that the loudest orientation can vary for different strut components (Dantzker et al. 1999), it is possible that using this small range and averaging across vocalizations may have underestimated the maximum active space for some components. Males that adjust their orientation to beam a highly directional vocalization toward a female may gain an advantage over other males, even under quiet conditions (Brumm 2002, Brumm and Todt 2003, Patricelli and Krakauer 2010); this advantage may be even more pronounced in a noisy environment.

Potential consequences of masking.—Reductions in the active space of detection and discrimination, as predicted by our analysis, could have significant effects on the fitness of individuals in noisy landscapes. Female sage-grouse use acoustic signals to locate lekking males (Bradbury et al. 1989); thus, their ability to find leks could be compromised in noisy environments because of the reduced active space of detection. Once on the lek, females can detect males visually, making detection using acoustic signals less critical. Discrimination and recognition are likely to be more critical on this smaller spatial scale. Female sage-grouse use the acoustic components of the display to select a mate (Gibson et al. 1991, Gibson 1996). In particular, acoustic features such as the IPI, and possibly the whistle, are thought to play a role in attracting females from across the lek (Gibson 1996). Thus, noise that reduces the maximum distance of discrimination to less than half the length of leks in our study population (half average lek length = ~70 m; J. L. Blickley unpubl. data) could negatively affect a male's ability to attract females. Further, background noise could make active comparison of males difficult for females if the maximum discrimination distance is reduced to less than the average distance between males (Forrest and Raspet 1994).

If the interfering noise only overlaps partially with a vocalization, the frequency with the maximum active space may be different under noisy conditions than under normal ambient conditions, leading to the reception of a signal that is distorted. For example, in the pop 1 component of the sage-grouse display, we found that the frequency with the maximum active space was different in noisy compared with quiet conditions. Therefore, a receiver hearing pop 1 under noisy conditions would hear a call dominated by frequencies in the 500 Hz 1/3-octave band; but under quiet conditions, the receiver would hear a call dominated by frequencies in the 200 Hz 1/3-octave band. Depending on which characteristics of the vocalization are assessed by females or competing males, this distortion may lead to difficulty in discrimination or recognition. Previous studies have suggested that female sage-grouse do not assess natural variation among males in peak frequency during mate choice (Gibson et al. 1991), but further behavioral studies would be needed to determine what, if any, effect such distortion might have on female response to male sage-grouse vocalizations. Distortion may have more significant effects on species in which mate choice is based on the frequency of the signal. For example, in species in which females prefer males with low-frequency song (Halfwerk et al. 2011) or assess the fundamental frequency of song as an indicator of male body size, (Ryan and Brenowitz 1985), distortion may lead to increased difficulty in comparing potential mates.

Ultimately, increased difficulty in finding leks or assessing males on the leks may lead to lower female attendance on noisy leks compared with quieter locations. Males may also avoid leks with high levels of noise if they perceive that their vocalizations are masked. Blickley et al. (2012) found lower male and female attendance on leks with experimentally introduced noise from roads and drilling rigs, both of which produce primarily low-frequency sounds similar to the compressor station modeled here. These declines may be due in part to masking, which would be predicted given the substantial overlap in the frequency range of the introduced noise and the sage-grouse strut display. However, the average level of introduced noise across leks in this experiment was relatively low, especially on leks with intermittent road noise, so masking is not likely the only cause of the observed declines. As discussed below, masking is only one possible effect of noise, and other effects may have a larger impact.

Masking in the context of noise regulations.—Are current noise regulations predicted to limit the impact of masking on sage-grouse? Outside of the breeding season, energy development activities are limited within 400 m (1/4 mile) of active sage-grouse leks on federal lands at our study site (Bureau of Land Management 2008). Our analysis indicates that a compressor station, or a similar noise source such as a drilling rig, placed at or inside this stipulated minimum surface-disturbance buffer would have a substantial effect on the ability of sage-grouse to detect a nearby lek and, potentially, to discriminate among individuals on the lek.

Regulations also institute a 2-mile (3.2-km) buffer around leks for permanent infrastructure and lekking-season drilling activities on federal lands in this region (Bureau of Land Management 2008). Our results suggest that the masking footprint of a single compressor station or drilling rig is unlikely to exceed this buffer. Within the range of the peak frequencies for sage-grouse vocalizations (400–2,500 Hz), the noise produced by the compressor station was estimated to drop to ambient levels ≤1,000 m. Even if noise travels farther during temperature inversions common in the early morning, when sage-grouse are actively lekking (Sutherland and Daigle 1998), masking on the lek is likely to be negligible for sources outside the 2-mile (3.2-km) buffer. However, off-lek communication, such as parent–offspring communication, occurs well beyond the boundaries of a lek (Lyon and Anderson 2003) and may still be susceptible to masking. Further, our analysis considered the masking impact of only a single, stationary noise source, but many developed areas contain a network of such sources connected by roads; this will lead to a much greater area of total impact.

Mechanisms to reduce masking.—Features of sound perception and flexibility in signal production may improve the ability of animals to detect signals in noise beyond the active-space predictions calculated by this method. Animals may use directional cues to separate a sound from background noise if the two sound sources are spatially separated (Schwartz and Gerhardt 1989, Dent et al. 1997). Amplitude fluctuations across the spectrum of a sound, or comodulation, may also increase the detectability of the sound against background noise, especially if the noise is relatively constant (Klump and Langemann 1995) like the noise sources investigated here. Animals in noisy areas may adjust their vocalizations to compensate for the increased background noise (Patricelli and Blickley 2006), increasing the amplitude (Brumm 2004) or redundancy (Brumm and Slater 2006) or shifting the peak or minimum frequencies to reduce overlap with background noise frequencies (e.g., Slabbekoorn and Peet 2003, Wood and Yezerinac 2006, Potvin et al. 2011). The potential for these forms of compensation is species specific; the degree to which hearing ability and vocal adjustment affect the active space of sage-grouse vocalizations is unknown.

Noise impacts beyond masking.—Masking is one potential effect of noise on wildlife, but it is certainly not the only one (Barber et al. 2010, Blickley and Patricelli 2010, Kight and Swaddle 2011). Blickley et al. (2012) found strong evidence that sage-grouse leks with experimentally introduced intermittent road noise experienced much greater declines in male attendance than those with more continuous drilling noise, despite the lower masking potential of road noise. Even light vehicular traffic (1–12 vehicles day^{-1}) has been found to substantially reduce nest initiation rates and increase the distance of nests from lek sites in sage-grouse (Lyon and Anderson 2003), despite minimal opportunity for masking. Together, these studies suggest that masking is not the only potential effect of noise or noisy infrastructure on sage-grouse. So, although a masking analysis can be powerful in making predictions about the effects of noise on lek communication in sage-grouse, this type of analysis may not provide sufficient predictive power for estimating the overall impact of the noise on this species.

Noise pollution has been found to induce stress, disrupt physiological processes and behaviors, cause physical trauma to the auditory system, or mask other natural sounds important to survival and reproduction, such as the sound of predator approach, in a variety of species (Marler et al. 1973, Bowles 1995, Kight and Swaddle 2011). For sage-grouse, these effects may extend beyond the area in which masking of the strut display is an issue, particularly for time spent off lek. Wildlife managers that seek to reduce the overall impact of anthropogenic noise on sage-grouse and other species affected by human encroachment must address all the potential effects of noise, including masking potential.

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Literature Cited

Ballentine, B., J. Hyman, and S. Nowicki. 2004. Vocal performance influences female response to male bird song: An experimental test. Behavioral Ecology 15:163–168.

Barber, J. R., K. R. Crooks, and K. M. Fristrup. 2010. The costs of chronic noise exposure for terrestrial organisms. Trends in Ecology & Evolution 25:180–189.

Blickley, J. L., D. Blackwood, and G. L. Patricelli. 2012. Experimental evidence for the effects of chronic anthropogenic noise on abundance of Greater Sage-Grouse at leks. Conservation Biology 26: in press.

Blickley, J. L., and G. L. Patricelli. 2010. Impacts of anthropogenic noise on wildlife: Research priorities for the development of standards and mitigation. Journal of International Wildlife Law and Policy 13:274–292.

Bowles, A. E. 1995. Responses of wildlife to noise. Pages 109–156 *in* Wildlife and Recreationists: Coexistence through Management and Research (R. L. Knight and K. J. Gutzwiller, Eds.). Island Press, Washington, D.C.

Bradbury, J. W., R. M. Gibson, C. E. McCarthy, and S. L. Vehrencamp. 1989. Dispersion of displaying male sage grouse. II. The role of female dispersion. Behavioral Ecology and Sociobiology 24:15–24.

Brenowitz, E. A. 1982. The active space of Red-winged Blackbird song. Journal of Comparative Physiology 147:511–522.

Brumm, H. 2002. Sound radiation patterns in nightingale (*Luscinia megarhynchos*) songs. Journal für Ornithologie 143:468–471.

Brumm, H. 2004. The impact of environmental noise on song amplitude in a territorial bird. Journal of Animal Ecology 73:434–440.

Brumm, H. 2006. Signalling through acoustic windows: Nightingales avoid interspecific competition by short-term adjustment of song timing. Journal of Comparative Physiology A 192:1279–1285.

Brumm, H., and H. Slabbekoorn. 2005. Acoustic communication in noise. Advances in the Study of Behavior 35:151–209.

Brumm, H., and P. J. B. Slater. 2006. Ambient noise, motor fatigue, and serial redundancy in chaffinch song. Behavioral Ecology and Sociobiology 60:475–481.

Brumm, H., and D. Todt. 2003. Facing the rival: Directional singing behaviour in nightingales. Behaviour 140:43–53.

Bureau of Land Management. 2008. Pinedale Anticline Project Area Supplemental Environmental Impact Statement Record of Decision. U.S. Department of Interior, Bureau of Land Management, Pinedale Field Office, Wyoming.

Connelly, J. W., S. T. Knick, M. A. Schroeder, and S. J. Stiver. 2004. Conservation assessment of Greater Sage-Grouse and sagebrush habitats. Western Association of Fish and Wildlife Agencies, Cheyenne, Wyoming. [Online.] Available at www.ndow.org/wild/conservation/sg/resources/greate_sg_cons_assessment.pdf.

Copeland, H. E., K. E. Doherty, D. E. Naugle, A. Pocewicz, and J. M. Kiesecker. 2009. Mapping oil and gas development potential in the US intermountain west and estimating impacts to species. PLoS One 4:e7400.

Dantzker, M. S., G. B. Deane, and J. W. Bradbury. 1999. Directional acoustic radiation in the strut display of male sage grouse *Centrocercus urophasianus*. Journal of Experimental Biology 202:2893–2909.

Dent, M. L., O. N. Larsen, and R. J. Dooling. 1997. Free-field binaural unmasking in Budgerigars (*Melopsittacus undulatus*). Behavioral Neuroscience 111:590–598.

Dooling, R. [J.] 2002. Avian hearing and the avoidance of wind turbines. Technical Report NREL/TP-500-30844. National Renewable Energy Lab, Golden, Colorado.

Dooling, R. J., M. Leek, and E. West. 2009. Predicting the effects of masking noise on communication distance in birds. Journal of the Acoustical Society of America 125:2517.

Dooling, R. J., and A. N. Popper. 2007. The Effects of Highway Noise on Birds. [Report prepared for the California Department of Transportation, Sacramento; Jones and Stokes Associates.] [Online.] Available at www.dot.ca.gov/hq/env/bio/files/caltrans_birds_10-7-2007b.pdf.

Forrest, T. G., and R. Raspet. 1994. Models of female choice in acoustic communication. Behavioral Ecology 5:293–303.

Francis, C. D., C. P. Ortega, and A. Cruz. 2009. Noise pollution changes avian communities and species interactions. Current Biology 19:1415–1419.

Francis, C. D., C. P. Ortega, and A. Cruz. 2011. Noise pollution filters bird communities based on vocal frequency. PLoS One 6:e27052.

Garton, E. O., J. W. Connelly, J. S. Horne, C. A. Hagen, A. Moser, and M. A. Schroeder. 2011. Greater Sage-Grouse population dynamics and probablity of persistence. Pages 293–382 *in* Greater Sage-Grouse: Ecology and Conservation of a Landscape Species and Its Habitats (S. T. Knick and J. W. Connelly, Eds.). Studies in Avian Biology, no. 38.

Gibson, R. M. 1989. Field playback of male display attracts females in lek breeding sage grouse. Behavioral Ecology and Sociobiology 24:439–443.

Gibson, R. M. 1996. Female choice in sage grouse: The roles of attraction and active comparison. Behavioral Ecology and Sociobiology 39:55–59.

Gibson, R. M., and J. W. Bradbury. 1985. Sexual selection in lekking grouse: Phenotypic correlates of male strutting success. Behavioral Ecology and Sociobiology 18:117–123.

Gibson, R. M., J. W. Bradbury, and S. L. Vehrencamp. 1991. Mate choice in lekking sage grouse revisited: The roles of vocal diplay, female site fidelity, and copying. Behavioral Ecology 2:165–180.

Goodwin, S. E., and W. G. Shriver. 2011. Effects of traffic noise on occupancy patterns of forest birds. Conservation Biology 25:406–411.

Halfwerk, W., S. Bot, J. Buikx, M. van der Velde, J. Komdeur, C. ten Cate, and H. Slabbekoorn. 2011. Low-frequency songs lose their potency in noisy urban conditions. Proceedings of the National Academy of Sciences USA 108:14549–14554.

Hebets, E. A., and D. R. Papaj. 2005. Complex signal function: Developing a framework of testable hypotheses. Behavioral Ecology and Sociobiology 57:197–214.

Holloran, M. J. 2005. Greater Sage-Grouse (*Centrocercus urophasianus*) population response to natural gas field development in western Wyoming. Ph.D. dissertation, University of Wyoming, Laramie.

Holloran, M. J., R. C. Kaiser, and W. A. Hubert. 2010. Yearling Greater Sage-Grouse response to energy development in Wyoming. Journal of Wildlife Management 74:65–72.

Kight, C. R., and J. P. Swaddle. 2011. How and why environmental noise impacts animals: An integrative, mechanistic review. Ecology Letters 14:1052–1061.

Klump, G. M. 1996. Bird communication in the noisy world. Pages 321–338 *in* Ecology and Evolution of Acoustic Communication in Birds (D. E. Kroodsma and E. H. Miller, Eds.). Cornell University Press, Ithaca, New York.

Klump, G. M., and U. Langemann. 1995. Comodulation masking release in a songbird. Hearing Research 87:157–164.

Lohr, B., T. F. Wright, and R. J. Dooling. 2003. Detection and discrimination of natural calls in masking noise by birds: Estimating the active space of a signal. Animal Behaviour 65:763–777.

Lyon, A. G., and S. H. Anderson. 2003. Potential gas development impacts on sage grouse nest initiation and movement. Wildlife Society Bulletin 31:486–491.

Marler, P., M. Konishi, A. Lutjen, and M. S. Waser. 1973. Effects of continuous noise on avian hearing and vocal development. Proceedings of the National Academy of Sciences USA 70:1393–1396.

Marten, K., and P. Marler. 1977. Sound transmission and its significance for animal vocalization. I. Temperate habitats. Behavioral Ecology and Sociobiology 2:271–290.

Møller, A. P., and A. Pomiankowski. 1993. Why have birds got multiple sexual ornaments? Behavioral Ecology and Sociobiology 32:167–176.

Nelson, D. A., and A. Poesel. 2007. Segregation of information in a complex acoustic signal: Individual and dialect identity in White-crowned Sparrow song. Animal Behaviour 74:1073–1084.

Patricelli, G. L., and J. L. Blickley. 2006. Avian communication in urban noise: Causes and consequences of vocal adjustment. Auk 123:639–649.

Patricelli, G. L., M. S. Dantzker, and J. W. Bradbury. 2008. Acoustic directionality of Red-winged Blackbird (*Agelaius phoeniceus*) song relates to amplitude and singing behaviours. Animal Behaviour 76:1389–1401.

Patricelli, G. L., and A. H. Krakauer. 2010. Tactical allocation of effort among multiple signals in sage grouse: An experiment with a robotic female. Behavioral Ecology 21:97–106.

Potvin, D. A., K. M. Parris, and R. A. Mulder. 2011. Geographically pervasive effects of urban noise on frequency and syllable rate of songs and calls in Silvereyes (*Zosterops lateralis*). Proceedings of the Royal Society of London, Series B 278:2464–2469.

Rheindt, F. E. 2003. The impact of roads on birds: Does song frequency play a role in determining susceptibility to noise pollution? Journal für Ornithologie 144:295–306.

Ryan, M. J., and E. A. Brenowitz. 1985. The role of body size, phylogeny, and ambient noise in the evolution of bird song. American Naturalist:87–100.

Schwartz, J. J., and H. C. Gerhardt. 1989. Spatially mediated release from auditory masking in an anuran amphibian. Journal of Comparative Physiology A 166:37–41.

Slabbekoorn, H., and M. Peet. 2003. Birds sing at a higher pitch in urban noise—Great Tits hit the high notes to ensure that their mating calls are heard above the city's din. Nature 424:267.

Slabbekoorn, H., and E. A. Ripmeester. 2008. Birdsong and anthropogenic noise: Implications and applications for conservation. Molecular Ecology 17:72–83.

Sutherland, L. C., and G. A. Daigle. 1998. Atmospheric Sound Propagation. Wiley, New York.

Swaddle, J. P., and L. C. Page. 2007. High levels of environmental noise erode pair preferences in Zebra Finches: Implications for noise pollution. Animal Behaviour 74:363–368.

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

Wiley, R. H. 1973. Territoriality and non-random mating in sage grouse (*Centrocercus urophasianus*). Animal Behaviour Monographs 6:85–169.

Wiley, R. H., and D. G. Richards. 1982. Adaptations for acoustic communication in birds: Sound transmission and signal detection. Pages 131–181 *in* Acoustic Communication in Birds (D. E. Kroodsma, E. H. Miller, and H. Ouellet, Eds.). Academic Press, New York.

Wood, W. E., and S. M. Yezerinac. 2006. Song Sparrow (*Melospiza melodia*) song varies with urban noise. Auk 123:650–659.

Conservation Biology

Contributed Paper

Experimental Evidence for the Effects of Chronic Anthropogenic Noise on Abundance of Greater Sage-Grouse at Leks

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Abstract: *Increasing evidence suggests that chronic noise from human activities negatively affects wild animals, but most studies have failed to separate the effects of chronic noise from confounding factors, such as habitat fragmentation. We played back recorded continuous and intermittent anthropogenic sounds associated with natural gas drilling and roads at leks of Greater Sage-Grouse (*Centrocercus urophasianus*). For 3 breeding seasons, we monitored sage grouse abundance at leks with and without noise. Peak male attendance (i.e., abundance) at leks experimentally treated with noise from natural gas drilling and roads decreased 29% and 73%, respectively, relative to paired controls. Decreases in abundance at leks treated with noise occurred in the first year of the study and continued throughout the experiment. Noise playback did not have a cumulative effect over time on peak male attendance. There was limited evidence for an effect of noise playback on peak female attendance at leks or male attendance the year after the experiment ended. Our results suggest that sage-grouse avoid leks with anthropogenic noise and that intermittent noise has a greater effect on attendance than continuous noise. Our results highlight the threat of anthropogenic noise to population viability for this and other sensitive species.*

Keywords: chronic noise, energy development, *Centrocercus urophasianus*, roads

Evidencia Experimental de los Efectos de Ruido Antropogénico Crónico sobre la Abundancia de *Centrocercus urophasianus* en Leks

Resumen: *El incremento de evidencias sugiere que el ruido crónico de actividades humanas afecta negativamente a los animales silvestres, pero la mayoría de los estudios no separan los efectos del ruido crónico de los factores de confusión, como la fragmentación del hábitat. Reprodujimos sonidos antropogénicos intermitentes y continuos asociados con la perforación de pozos de gas natural y caminos en leks de* Centrocercus urophasianus. *Durante 3 épocas reproductivas, monitoreamos la abundancia de* C. urophasianus *e leks con y sin ruido. La abundancia máxima de machos (i.e., abundancia) en leks tratados con ruido de la perforación de pozos de gas natural y caminos decreció 29% y 73% respectivamente en relación con los controles pareados. La disminución en abundancia en leks tratados con ruido ocurrió en el primer año del estudio y continuó a lo largo del experimento. La reproducción de ruido no tuvo efecto acumulativo en el tiempo sobre la abundancia máxima de machos. Hubo evidencia limitada para un efecto de la reproducción de ruido sobre la abundancia máxima de hembras en los leks o sobre la asistencia de machos el año después de que concluyó el experimento. Nuestros resultados sugieren que* C. urophasianus *evita leks con ruido anropogénico y que el ruido intermitente tiene un mayor efecto sobre la asistencia que el ruido continuo. Nuestros*

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resultados resaltan amenaza del ruido antropogénico para la viabilidad poblacional de esta y otras especies sensibles.

Palabras Clave: *Centrocercus urophasianus*, desarrollo energético, ruido crónico, caminos

Introduction

Noise associated with human activity is widespread and expanding rapidly in aquatic and terrestrial environments, even across areas that are otherwise relatively unaffected by humans, but there is still much to learn about its effects on animals (Barber et al. 2009). Effects of noise on behavior of some marine organisms are well-documented (Richardson 1995). In terrestrial systems, the effects of noise have been studied less, but include behavioral change, physiological stress, and the masking of communication signals and predator sounds (Slabbekoorn & Ripmeester 2008; Barber et al. 2009). These effects of noise on individual animals may lead to population decreases if survival and reproduction of individuals in noisy habitats are lower than survival and reproduction of individuals in similar but quiet habitats (Patricelli & Blickley 2006; Warren et al. 2006; Slabbekoorn & Ripmeester 2008). Population declines may also result if animals avoid noisy areas, which may cause a decrease in the area available for foraging and reproduction.

There is evidence of variation among species in their sensitivity to noise. Noise sensitivity may also differ with the type of noise, which varies in amplitude, frequency, temporal pattern, and duration (Barber et al. 2009). Duration may be particularly critical; most anthropogenic noise is chronic and the effects of chronic noise may differ substantially from those of short-term noise in both severity and response type. For example, brief noise exposure may cause elevated heart rate and a startle response, whereas chronic noise may induce physiological stress and alter social interactions. Therefore, when assessing habitat quality for a given species, it is critical to understand the potential effects of the full spectrum of anthropogenic noise present in the species' range.

The effects of noise on wild animals are difficult to study because noise is typically accompanied by other environmental changes. Infrastructure that produces noise may be associated with fragmentation of land cover, visual disturbance, discharge of chemicals, or increased human activity. Each of these factors may affect the physiology, behavior, and spatial distribution of animals, which increases the difficulty of isolating the effects of the noise.

Controlled studies of noise effects on wild animals in terrestrial systems thus far have focused largely on birds. Recent studies have compared avian species richness, occupancy, and nesting success near natural gas wells operating with and without noise-producing compressors. In these studies, spatial variation in noise was used to control for confounding visual changes due to infrastructure (Habib et al. 2007; Bayne et al. 2008; Francis et al. 2009). Results of these studies show that continuous noise affects density and occupancy of a range of bird species and leads to decreases or increases in abundance of some species and has no effect on other species (Bayne et al. 2008; Francis et al. 2009; Francis et al. 2011). Results of these studies also show that noise affects demographic processes, such as reproduction, by reducing the pairing or nesting success of individuals (Habib et al. 2007; Francis et al. 2009).

Although these studies in areas near natural gas wells controlled for the effects of most types of disturbance besides noise, they could not address the effect of noise on naïve individuals in areas without natural gas wells and compressors. Furthermore, there have been no controlled experiments that address the effects of chronic but intermittent noise, such as traffic, which may be more difficult for species to habituate. Road noise may have large negative effects because it is widespread (affecting an estimated 20% of the United States) (Forman 2000) and observational studies indicate that noise may contribute to decreases in abundance of many species near roads (e.g., Forman & Deblinger 2000).

Noise playback experiments offer a way to isolate noise effects on populations from effects of other disturbances and to compare directly the effects of noise from different sources. Playback experiments have been used to study short-term behavioral responses to noise, such as effects of noise on calling rate of amphibians (Sun & Narins 2005; Lengagne 2008), heart rate of ungulates (Weisenberger et al. 1996), diving and foraging behavior of cetaceans (Tyack et al. 2011), and song structure of birds (Leonard & Horn 2008), but have not been used to study effects of chronic noise on wild animals because producing long-term noise over extensive areas is challenging. We conducted a playback experiment intended to isolate and quantify the effects of chronic noise on wild animals. We focused on the effects of noise from natural gas drilling on Greater Sage-Grouse (*Centrocercus urophasianus*).

Greater Sage-Grouse occur in the western United States and Canada and have long been a focus of sexual selection studies (Wiley 1973; Gibson 1989; Gibson 1996). Greater Sage-Grouse populations are decreasing in density and number across the species' range, largely due to extensive habitat loss (Connelly et al. 2004; Garton et al. 2010). The species is listed as endangered under Canada's

Species at Risk Act and is a candidate species for listing under the U.S. Endangered Species Act. Deep natural gas and coal-bed methane development have been expanded rapidly across the species' range since 2000 and substantial evidence suggests that these processes may contribute to observed decreases in the number of Greater Sage-Grouse (Holloran 2005; Walker et al. 2007; Holloran et al. 2010). Many factors associated with deep natural gas and coal-bed methane development are thought to lead to these decreases, including habitat loss, increased occurrence of West Nile Virus, and altered fire regimes due to the expansion of nonnative invasive species (Naugle et al. 2004; Walker et al. 2007; Copeland et al. 2009).

The noise created by energy development may also affect sage grouse by disrupting behavior, causing physiological stress, or masking biologically important sounds. During the breeding season (February–May), male sage grouse gather on communal breeding grounds called leks. Male attendance (number of male birds on the lek) at sage grouse leks downwind of deep natural gas development decreases up to 50% per year compared with attendance at other leks, which suggests noise or aerial spread of chemical pollution as factors contributing to these decreases (Holloran 2005).

We sought to test the hypothesis that lek attendance by male and female sage grouse is negatively affected by both chronic intermittent and continuous noise from energy development. To do so, we conducted a noise playback experiment in a population that is relatively unaffected by human activity. Over 3 breeding seasons (late February to early May), we played noise recorded from natural gas drilling rigs and traffic on gas-field access roads at sage grouse leks and compared attendance patterns on these leks to those on nearby control leks.

We conducted our experiment at leks because lekking sage grouse are highly concentrated in a predictable area, which makes them good subjects for a playback experiment. More importantly, sage grouse may be particularly responsive to noise during the breeding season, when energetic demands and predation risk are high (Vehrencamp et al. 1989; Boyko et al. 2004). Additionally, noise may mask sexual communication on the lek. Lekking males produce a complex visual and acoustic display (Supporting Information) and females use the acoustic component of the display to find lekking males and select a mate (Gibson 1989; Gibson 1996; Patricelli & Krakauer 2010). Furthermore, lek attendance is commonly used as a metric of relative abundance of sage grouse at the local and population level (Connelly et al. 2003; Holloran 2005; Walker et al. 2007). We used counts of lek attendance (lek counts) to assess local abundance relative to noise versus control treatments.

Methods

Study Site and Lek Monitoring

Our study area included 16 leks (Table 1 & Supporting Information) on public land in Fremont County, Wyoming, U.S.A. (42° 50′, 108° 29′). Dominant vegetation in this region is big sagebrush (*Artemisia tridentata wyomingensis*) with a grass and forb understory. The primary land use is cattle ranching, and there are low levels of recreation and natural gas development.

We paired leks on the basis of similarity in previous male attendance and geographic location (Table 2 & Supporting Information). Within a pair, one lek was

Table 1. Pairing, treatment type, location, and baseline attendance for leks used in noise playback experiment.

Lek	*Pair*	*Pair noise type*	*Noise or control*	*Years of playback*	*Baseline attendance**
Gustin	A	drilling	control	3	26
Preacher Reservoir	A	drilling	noise	3	49
North Sand Gulch	B	road	control	3	32
Lander Valley	B	road	noise	3	67
East Twin Creek	C	drilling	control	3	44
Coal Mine Gulch	C	drilling	noise	3	83
East Carr Springs	D	road	control	3	67
Carr Springs	D	road	noise	3	92
Powerline	E	drilling	control	2	49
Conant Creek North	E	drilling	noise	2	44
Monument	F	road	control	2	53
Government Slide Draw	F	road	noise	2	55
Nebo	G	drilling	control	2	18
Arrowhead West	G	drilling	noise	2	24
Onion Flats 1	H	road	control	2	41
Ballenger Draw	H	road	noise	2	38

**Baseline attendance is the average peak male attendance value (annual maximum number of males observed averaged across years) for that lek from 2002 to 2005.*

Table 2. Mixed-effect candidate models used to assess change in peak attendance of male Greater Sage-Grouse at leks from pre-experiment baseline attendance during the natural gas drilling noise playback (2006–2008) and after the experiment (2009).

Model (year)[a]	K[b]	ΔAIC_c[c]	w_i[d]
Male experiment (2006–2008)			
treatment × type+season[e]	9	0	0.64
treatment × type[e]	7	1.8	0.26
treatment+experiment year	6	6.1	0.03
treatment+season	7	6.8	0.02
treatment	5	7.3	0.02
treatment × experiment year	7	8.0	0.01
treatment × type+treatment × season+experiment year	12	8.6	<0.01
treatment × type+treatment × season	11	9.9	<0.01
treatment × type+treatment × season+treatment × experiment year	13	10.0	<0.01
treatment+type	6	10.4	<0.01
treatment × season	9	16.2	<0.01
null- random effects only	4	57.0	<0.01
Male after experiment (2009)			
null, random effects only[e]	3	0.0	0.84
treatment	4	3.3	0.16

[a] *All models contain pair as a random effect, and experiment (2006–2008) models also include year as a random effect. Covariates: treatment, lek treatment (noise or control) assigned to individual leks within a pair; type, pair noise treatment type (road or drilling assigned to pair); season, time of year (early [late February to 1 week prior to peak female attendance for that lek; female peak ranged from 15 March to 6 April], mid [1 week before and after female peak], and late [starting 1 week after female peak]); experiment year, years of experimental noise exposure.*

[b] *Number of parameters in the model.*

[c] *Difference in AIC_c (Akaike's information criterion for small sample size) values from the model with lowest AIC_c.*

[d] *Akaike weight.*

[e] *Model with substantial support ($\Delta AIC_c < 2$).*

randomly assigned to receive experimental noise treatment and the other lek was designated a control. We randomly assigned the experimental leks to receive playback of either drilling or road noise. In 2006, we counted attendance at 8 leks (2 treated with drilling noise, 2 treated with road noise, and 4 control). In both 2007 and 2008, we included an additional 8 leks for a total of 16 leks (4 treated with drilling noise, 4 treated with road noise, and 8 controls).

Throughout the breeding season, we counted males and females on leks with a spotting scope from a nearby point selected to maximize our visibility of the lek. We visited paired leks sequentially on the same days between 05:00 and 09:00, alternating the order in which each member of the pair was visited. We visited lek pairs every day during the breeding season in 2006 and, after expanding our sample size in 2007, every 2–4 days in 2007 and 2008. Peak estimates of male attendance from >4 visits are a highly repeatable measure of abundance at individual leks (Garton et al. 2010), so the lower frequency of visits in 2007 and 2008 was unlikely to have a substantial effect on estimates of peak male attendance. At a minimum, we conducted 2 counts per visit at 10- to 15-min intervals. The annual peak attendance was the highest daily attendance value at each lek for the season for males or females. For males we also calculated the peak attendance in 3 nonoverlapping date ranges: early (late February to 1 week prior to peak female attendance for that lek; female peak ranged from 15 March to 6 April), mid (1 week before and after female peak), and late (starting 1 week after female peak).

Noise Introduction

We recorded noise used for playback near natural gas drilling sites and gas-field access roads in a region of extensive deep natural gas development in Sublette County, Wyoming (Pinedale Anticline Gas Field and Jonah Gas Field). We recorded drilling noise in 2006 within 50 m of the source on a digital recorder (model PMD670, 44.1 kHz/16 bit; Marantz, Mahwah, New Jersey) with a shotgun microphone (model K6 with an ME60 capsule; Sennheiser, Old Lyme, Connecticut). We recorded road noise in 2005 with a handheld computer (iPAQ h5550 Pocket PC, 44.1 KHz/16 bit; Hewlett Packard, Palo Alto, California) and omnidirectional microphone (model K6 with an ME62 capsule; Sennheiser). Drilling noise is relatively continuous and road noise is intermittent (Supporting Information). Both types of noise are predominantly low frequency (<2 kHz).

We played noise on experimental leks from 2 to 4 rock-shaped outdoor speakers (300 W Outdoor Rock Speakers; TIC Corporation, City of Industry, California) hooked to a car amplifier (Xtant1.1; Xtant Technologies, Phoenix, Arizona) and an MP3 player (Sansa m240; SanDisk, Milpitas, California). The playback system was powered with 12 V batteries that we changed every 1–3 days when no birds were present. We placed the speakers

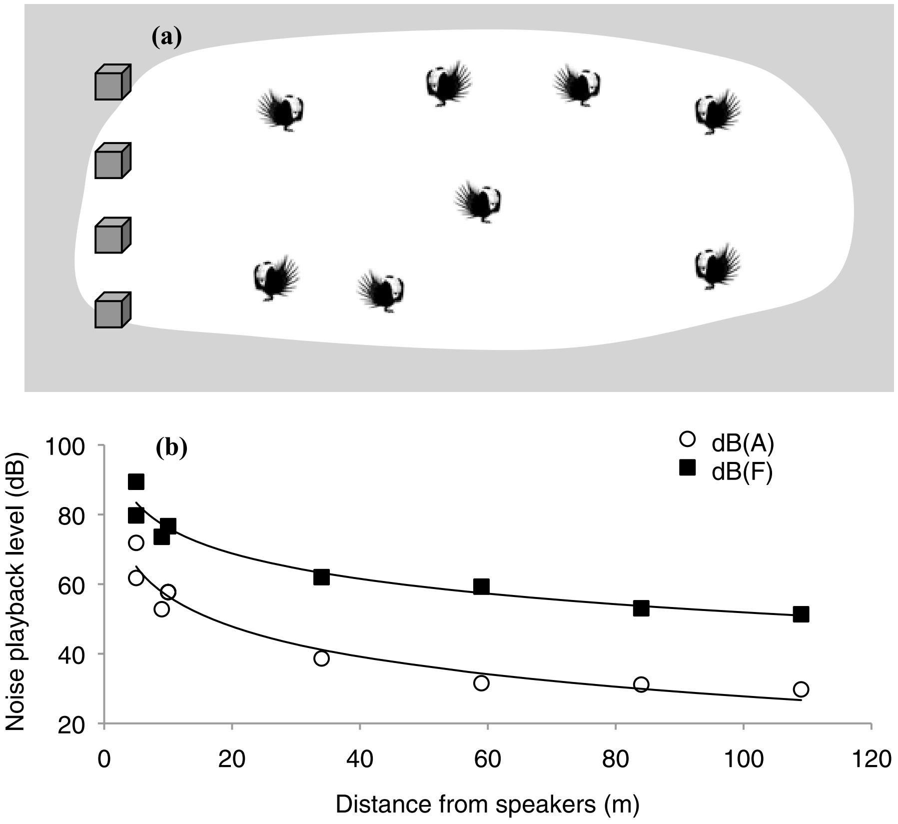

Figure 1. (a) Placement of speakers (on noise-treated leks) or dummy speakers (on control leks) (boxes) at Greater Sage-Grouse leks. (b) Mean maximum noise level (unweighted decibels, dB[F], and A-weighted decibels, dB[A], measured in Lmax [highest root-mean-square sound pressure level within the measurement period]) at Greater Sage-Grouse leks measured on transects at 25-m intervals from the line of speakers on a typical lek treated with road noise. Playback levels of natural gas drilling noise (measured in Leq) followed the same pattern. Ambient levels of noise at control leks ranged from 30 to 35 dB(A).

in a straight line across one end of the lek (Fig. 1a). In 2006 we placed 3 speakers at leks treated with drilling noise and 2 speakers at leks treated with road noise. In 2007 and 2008, we increased the number of speakers, placing 4 at each noise-treated lek to increase the area in which noise was present on the lek. At control leks, we placed dummy speakers of similar size and color to playback speakers (68-L plastic tubs). Within each lek pair, dummy and real speakers were placed in similar configurations. To control for playback-related disturbance, the leks in each pair were visited an equal number of times during the morning for counts of birds and in the afternoon for battery changes.

We played drilling noise and road noise on leks at 70 dB(F) sound pressure level (unweighted decibels) measured 16 m directly in front of the speakers (Fig. 1 & Supporting Information). This is similar to noise levels measured approximately 400 m from drilling rigs and main access roads in Pinedale (J. L. Blickley and G. L. Patricelli, unpublished data). Four hundred meters (0.25 miles) is the minimum surface disturbance buffer around leks at this location (BLM 2008). We calibrated and measured noise playback levels with a hand-held meter that provides sound-pressure levels (System 824; Larson-Davis, Depew, New York) when wind was <9.65 k/h. On drilling-noise-treated leks, where noise was continuous, we calibrated the noise playback level by measuring the average sound level (Leq [equivalent continuous sound level]) over 30 s. On leks treated with road noise, where the amplitude of the noise varied during playback to simulate the passing of vehicles, we calibrated the playback level by measuring the maximum sound level (Lmax [highest root-mean-square sound pressure level within the measurement period]).

For leks treated with drilling noise, recordings from 3 drilling sites were spliced into a 13-min mp3 file that played on continuous repeat. On leks treated with road noise, we randomly interspersed mp3 recordings of 56 semitrailers and 61 light trucks with 170 thirty-second silent files to simulate average levels of traffic on an access road (Holloran 2005). Noise playback on experimental leks continued throughout April in 2006, from mid February or early March through late April in 2007, and from late February through late April in 2008. We played back noise on leks 24 hours/day because noise from deep natural gas drilling and vehicular traffic is present at all times. This experimental protocol was reviewed and approved by the Animal Care and Use Committee at University of California, Davis (protocol 16435).

To measure noise levels across experimental leks, we measured the average amplitude (15 s Leq) of white-noise played at 1–5 points along transects that extended across the lek at 25-m intervals roughly parallel to the line of speakers. We calibrated white-noise measurements by measuring the noise level of both the white noise and either a representative clip of drilling noise or a semitrailer

10 m directly in front of each speaker. To minimize disturbance, we took propagation measurements during the day. Daytime ambient noise levels are typically 5–10 dBA higher than those in the early morning (J. L. Blickley and G. L. Patricelli, unpublished data) and are likely higher than those heard by birds at a lek.

After the experiment, we counted individuals on all leks 2–6 times from 1 March through 30 April 2009. In 2009 we continued to play noise on 2 experimental leks as part of a related experiment, so we did not include these lek pairs in our analysis of postexperiment male attendance at a lek.

Response Variables and Baseline Attendance Levels

Sage grouse leks are highly variable in size and, even within pairs, our leks varied up to 50% in size. To facilitate comparison of changes in attendance on leks of different sizes, we calculated the attendance relative to attendance levels before treatment (i.e., baseline attendance levels). We obtained male baseline abundance from the Wyoming Game and Fish Department. We used the standard lek-count protocol (Connelly et al. 2003) to count birds at leks approximately 3 times/breeding season. Due to the small number of counts in pre-experiment years, we calculated male baseline attendance by averaging the annual peak male attendance at each individual lek over 4 years (2002–2005). We assessed changes in early-, mid-, and late-season peak male attendance from this 4-year baseline attendance. Female attendance was highly variable throughout the season with a short (1–3 day) peak in attendance at each lek. Due to the limited number of annual counts, female counts from 2002 to 2005 were not reliable estimates of peak female attendance and could not be used as baseline attendance levels. Because we introduced noise to experimental leks after the peak in female attendance in 2006, we used maximum female counts from 2006 as a baseline for each of the 8 leks monitored that year. We assessed changes in annual peak female attendance from this 1-year baseline attendance. The 8 leks added to the experiment in 2007 were not included in statistical analyses of female attendance due to the lack of a baseline.

Statistical Analyses

We used an information-theoretic approach to evaluate the support for alternative candidate models (Table 2). All candidate models were linear mixed-effect models that assessed the relation between covariates and the proportional difference in annual and within-season peak attendance and baseline attendance (both males and female) (Tables 2 & 3). We ranked models on the basis of differences in Akaike's information criterion for small sample sizes (ΔAIC_c) (Burnham & Anderson 2002). Akaike weights (w_i) were computed for each model on the basis of ΔAIC_c scores. We calculated model-averaged variable coefficients, unconditional 95% CI, and variable importance (weight across models) for variables contained in models that were strongly supported ($\Delta AIC_c < 2$). All statistical analyses were performed in R (version 2.12.1) (R Development Team 2010).

Table 3. Mixed-effect candidate models used to assess change in peak annual attendance of female Greater Sage-Grouse at leks from pre-experiment baseline attendance in 2006 during noise playback.

Model[a]	K[b]	ΔAIC_c[c]	w_i[d]
Null, random effects only[e]	4	0	0.71
Treatment[e]	5	1.9	0.27
Treatment+experiment year	6	8	0.01
Treatment×experiment year	7	14	<0.001

[a] *All models contained pair and year as random effects. Due to the small sample size (4 pairs), pair type variable (road versus drilling) was not included in the model set. Covariates: treatment, lek treatment (noise or control assigned to individual leks within a pair); experiment year, years of experimental noise exposure.*
[b] *Number of parameters in the model.*
[c] *Difference in AIC_c (Akaike's information criterion for small sample size) values from the most strongly supported (lowest AICc) model.*
[d] *Akaike weight.*
[e] *Model with substantial support ($\Delta AIC_c < 2$).*

The detection probability for males and females is likely to vary across a season and among leks (Walsh et al. 2004). We sought to minimize sources of error and maximize detection by conducting frequent counts from locations with a clear view of the lek and by implementing a paired treatment design (each noise lek is compared with a similar control lek, monitored by the same observer on the same days). To ensure that detection probability did not differ among noise and control leks, we corrected our data for detection probability. First, we used detection error rates, estimated as difference between the maximum count and the count immediately before or after the maximum count within a day (for both males and females), and then we applied the bounded-count method (for males only; Walsh et al. 2004). With the multiple-count estimator, estimates of detection between noise and control leks did not differ (males: $t = 1.02$, df $= 6$, $p = 0.35$; females: $t = 0.21$, df $= 3$, $p = 0.84$). We analyzed both corrected and uncorrected counts and found that neither correction qualitatively changed our results; therefore, results are presented for uncorrected counts.

Results

Male Attendance

Peak male attendance at both types of noise leks decreased more than attendance at paired control leks, but the decreases varied by noise type. In the most strongly supported models of the candidate set ($w_i = 0.90$, all

Table 4. Model-averaged parameter direction and effect sizes and variable importance for all variables present in strongly supported models ($\Delta AIC_c < 2$ in Table 2) of changes in peak attendance of male greater sage-grouse at leks from baseline attendance during experimental noise playback.

Variable	*Percent effect size (SE)*	*Variable importance*[*]
Intercept	31 (22)	1.0
Treatment, noise	−29 (7)	0.91
Type, road	33 (22)	0.91
Treatment, noise∗type, road	−40 (10)	0.91
Season, mid	18 (6)	0.66
Season, late	23 (6)	

[*] *Variable importance is the summed weight of all models containing that variable.*

other models $\Delta AIC_c > 6.1$) (Table 2), there was an interaction of the effects of experimental treatment (control versus noise) and noise type (drilling versus road) on annual peak male attendance. At leks treated with road noise, decreases in annual peak male attendance were greater (73%), relative to paired controls, than at drilling noise leks (29%). As indicated by the effect size for the main effect of pair type, attendance at control leks paired with road noise leks was 33% greater relative to the baseline than control leks paired with drilling noise leks (Table 4). However, changes in attendance were compared within a pair to control for such differences. Male attendance increased over the course of a season, with 18% and 23% increases in peak male attendance in mid and late season from the early-season peaks, but seasonal increases were similar across noise and control leks (Table 4 & Fig. 2b).

There was no evidence that the effect of noise on attendance changed as years of exposure to noise increased. The models with substantial support did not contain a main effect of years of exposure or an interaction of years of exposure and treatment type (control versus noise) (Table 2). In spite of decreases in attendance throughout the experiment, peak male attendance exceeded baseline attendance on all leks in 2006, 13 leks in 2007, and 11 leks in 2008 (Table 4 & Fig. 2c). There was an increase in sage grouse abundance regionally in 2006 (Fig. 3).

After the experiment (2009), attendance at leks we experimentally exposed to drilling and road noise was lower relative to paired controls (Table 2). The model that included the treatment variable showed an effect size of −30% (across road and drilling noise leks) but had only moderate support ($\Delta AIC_c = 3.3$) relative to the null model.

Female Attendance

Peak female attendance at leks treated with noise in 2007 and 2008 decreased from the 2006 baseline, relative to control leks (Table 3). The most strongly supported model in the set was the null model; however, the model that included noise treatment was highly supported ($\Delta AIC_c < 2$). The effect size of noise treatment on female attendance was −48% (10% SE), which is similar to the effect of noise on male attendance averaged across both noise types (51%).

Discussion

Results of previous studies show abundance of Greater Sage-Grouse decreases when natural gas and coal-bed methane fields are developed (Holloran 2005; Walker et al. 2007; Doherty et al. 2008). Our results suggest that chronic noise may contribute to these decreases. Peak male attendance relative to the baseline was lower on noise leks than paired control leks, and the decrease was larger at road noise leks (73% decrease in abundance compared with paired controls) than drilling noise leks (29%; Fig. 3). These decreases were immediate and sustained. The effects of noise occurred in the first year of the study and were observed throughout the experiment, although patterns of male attendance within a season were similar at noise and control leks. Differences in male attendance between noise and control leks in the year after the experiment were not supported in the top models, which suggests attendance rebounded after noise ceased. However, the sample size for this analysis was small, and the effect size (30% average decreases in male attendance for both noise types) suggests a residual effect of noise.

There are 2 mechanisms by which noise may reduce male attendance. First, males on noise leks may have had higher mortality than males on control leks. Noise playback was not loud enough to cause direct injury to individuals, but mortality could be increased indirectly by noise playback if the sounds of predators (coyotes [*Canis latrans*] or Golden Eagles [*Aquila chrysaetos*]) were masked by noise. However, on-lek predation events were rare. We observed ≤1 predation event per lek per season during the experiment (observations of sage-grouse carcasses or feathers at a lek [J. L. Blickley, personal observation]). The cumulative effect of rare predation events would lead to a gradual decrease in attendance, rather than the rapid and sustained decrease we observed. Furthermore, experimental noise was likely too localized to substantially affect off-lek predation because noise levels decreased exponentially as distance to the speakers increased (Fig. 1b). To date, increased predation risk of adults due to anthropogenic noise has not been demonstrated in any species, but some species increase vigilance when exposed to noise, leaving less time for feeding, displaying, and other important behaviors (Quinn et al. 2006; Rabin et al. 2006). Noise may also affect off-lek mortality indirectly. For example, noise-stressed males may be more susceptible to disease due to a suppressed

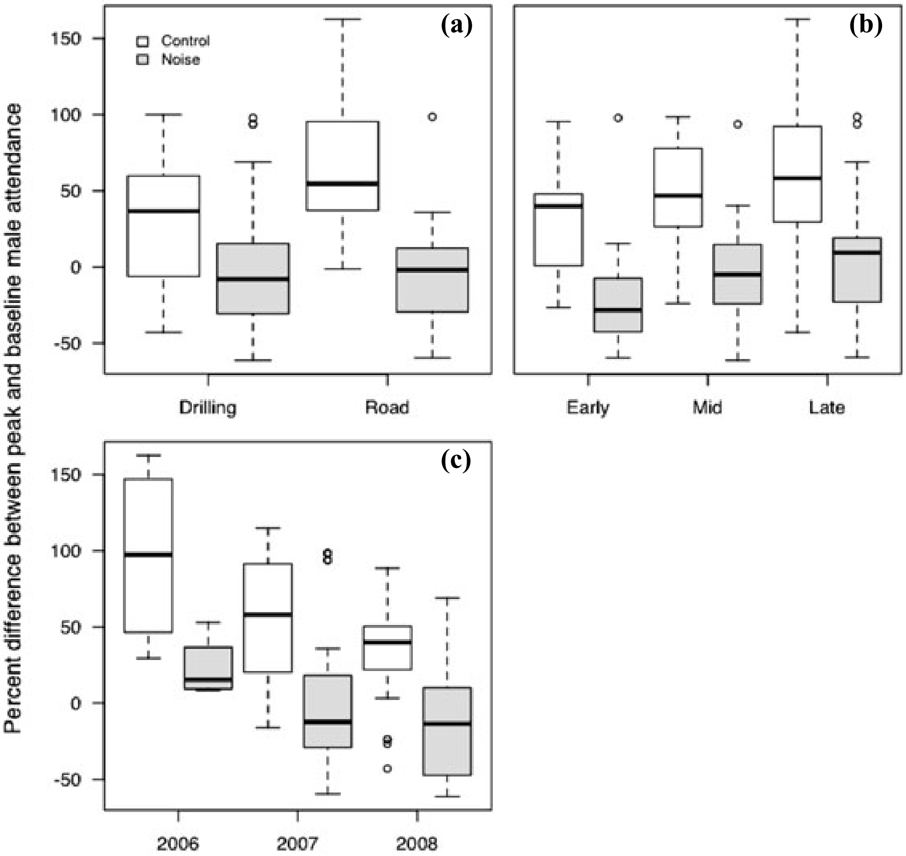

Figure 2. Percent difference between baseline attendance (i.e., abundance before experiments) of male Greater Sage-Grouse and (a) peak male attendance on control leks and leks treated with noise from natural gas drilling and road noise, (b) peak male attendance in the early (late February to 1 week prior to peak female attendance for that lek), mid (1 week before and after female peak [female peak ranged from 15 March to 6 April]), and late (starting 1 week after female peak) breeding season; on control leks and leks treated with noise, and (c) peak male attendance at control leks and leks treated with noise in experimental years 2006, 2007, and 2008 in Fremont County, Wyoming (U.S.A.) (horizontal lines, median value; box ends, upper and lower quartiles, whiskers, maximum and minimum values). Data are observed values, not model output.

immune response (Jankowski et al. 2010). Although long-term stress from noise is unlikely to be the primary cause of the rapid decreases in attendance we observed here, it may have been a contributing factor over the course of the experiment. Furthermore, in areas of dense industrial development, where noise is widespread, noise effects on mortality may be more likely.

Alternatively, noise may lower male attendance through displacement, which would occur if adult or juvenile males avoid leks with anthropogenic noise. Such behavioral shifts are consistent with the rapid decreases in attendance we observed. Adult male sage grouse typically exhibit high lek fidelity (Schroeder & Robb 2003) and visit leks regularly throughout the season, whereas juvenile males visit multiple leks and their attendance peaks late in the season (Kaiser 2006). If juveniles or adults avoid noise by visiting noisy leks less frequently or moving to quieter leks, overall attendance on noisy leks could be reduced. We could not reliably differentiate between juveniles and adults, so we do not know the relative proportion of adults and juveniles observed. Consistent with displacement due to noise avoidance, radio-collared juvenile males avoid leks near deep natural gas developments in Pinedale, Wyoming, which has resulted in decreases in attendance at leks in close proximity to development and increased attendance at nearby leks with less human activity (Kaiser 2006; Holloran et al. 2010). Reduced recruitment of juvenile males is unlikely to be the only driver of the patterns we observed because we did not observe larger decreases in lek attendance on noise-treated leks later in the season, when juvenile attendance peaks. Rather, we found immediate decreases in attendance early in the season when playback began (Fig. 2b), at which time there are few juveniles on the lek. This

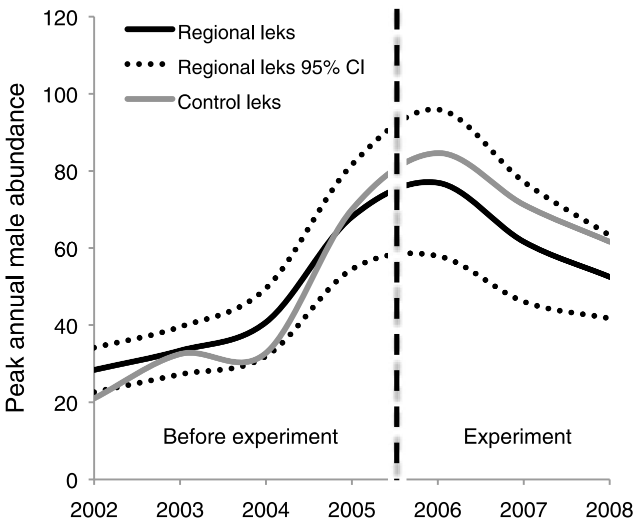

*Figure 3. Maximum abundance of male Greater Sage-Grouse from 2002 to 2008 at control leks (*n = 8*) (no anthropogenic sound played) and other leks in the region that were not part of the experiment (regional leks) (*n = 38*).*

is consistent with both adult and juvenile noise avoidance. We did not find evidence for a cumulative negative effect of noise on lek attendance, although cumulative effects may have been masked by regional population declines after 2006, a year of unusually high abundance (Fig. 3).

Female attendance at leks treated with noise was lower than that on control leks; however, the null model and the model that included noise treatment were both highly supported, providing only moderate support for the effects on noise on attendance. For this model, the overall estimated effect of noise on female attendance (−48%) was similar to that of the effect of noise on male attendance. Due to the high variability of female daily maximum attendance throughout the season and small sample size for this analysis (female attendance data available for only 4 of the 8 lek pairs), our statistical power to detect differences in female attendance was limited and effect sizes may not be representative of actual noise effects.

Our results suggest that males and possibly females avoid leks exposed to anthropogenic noise. A potential cause of avoidance is the masking of communication. Masked communication is hypothesized to cause decreases in abundance of some animal species in urban and other noisy areas. For example, bird species with low-frequency vocalizations are more likely to have low abundance or be absent from natural gas developments, roads, and urban areas than species with high-frequency vocalizations, which suggests that masking is the mechanism associated with differences in abundance (Rheindt 2003; Francis et al. 2009; Hu & Cardoso 2010). Sage-grouse may be particularly vulnerable to masked communication because their low-frequency vocalizations are likely to be masked by most sources of anthropogenic noise, including the noises we played in our experiment (Supporting Information). This may be particularly important for females if they cannot use acoustic cues to find leks or assess displaying males in noisy areas.

Alternatively, individuals may avoid noisy sites if noise is annoying or stressful, particularly if this noise is associated with danger (Wright et al. 2007). Intermittent road noise was associated with lower relative lek attendance than continuous drilling noise, in spite of the overall higher mean noise levels and greater masking potential at leks treated with drilling noise (Supporting Information). Due to the presence of roads in our study area, sage grouse may have associated road noise with potentially dangerous vehicular traffic and thus avoided traffic-noise leks more than drilling-noise leks. Alternatively, the pattern of decrease may indicate that an irregular noise is more disturbing to sage grouse than a relatively continuous noise. Regardless, our results suggest that average noise level alone is not a good predictor of the effects of noise (Slabbekoorn & Ripmeester 2008) and that species can respond differently to different types of noise.

Our results cannot be used to estimate the quantitative contribution of noise alone to observed decreases in Greater Sage-Grouse abundance at energy development sites because our experimental design may have led us to underestimate or overestimate the magnitude of these effects. Decreases in abundance due to noise could be overestimated in our study if adults and juveniles are displaced from noise leks and move to nearby control leks, which would have increased the difference in abundance between paired leks. Similar displacement occurs in areas of energy development, but over a much larger extent than is likely to have occurred in response to localized playbacks in our experiment (Holloran et al. 2010).

In contrast, we could have underestimated noise effects if there were synergistic effects of noise and other disturbances associated with energy development. For example, birds with increased stress levels due to poor forage quality may have lower tolerance for noise-induced stress, or vice versa. Noise in our experiment was localized to the immediate lek area and only played during the breeding season, so we cannot quantify the effects of noise on wintering, nesting, or foraging birds. Noise at energy development sites is less seasonal and more widespread than noise introduced in this study and may thus affect birds at all life stages and have a potentially greater effect on lek attendance. Leks do not represent discrete populations; therefore, local decreases in lek attendance do not necessarily reflect population-level decreases in abundance. However, at large energy development sites, similar displacement of Greater Sage-Grouse away from the ubiquitous noise may result in population-level declines due to spatially extensive changes in land use or increases in dispersal-related and density-dependent sources of mortality (Aldridge & Boyce 2007). Enforcement and refinement of existing seasonal restrictions on human activity could potentially reduce these effects.

We focused on the effect of noise associated with deep natural gas and coal-bed methane development on sage grouse, but our results may increase broader understanding of the effects of noise on animals. Both intermittent and constant noise from energy development affected sage grouse. Other noise sources with similar frequency range and temporal pattern, such as wind turbines, oil-drilling rigs, and mines, may have comparable effects. Similar effects may also be associated with highways, off-road vehicles, and urbanization so that the potential for noise to have an effect is large.

We believe that noise should be investigated as one potential cause of population declines in other lekking North American grouse species that are exposed to similar anthropogenic development. Populations of many bird (van der Zande et al. 1980; Rheindt 2003; Ingelfinger & Anderson 2004) and mammal (Forman & Deblinger 2000; Sawyer et al. 2009) species have been shown to decrease in abundance in response to road, urban, and energy development, and noise produced by these activities may contribute to these decreases. Our results also demonstrate that wild animals may respond differently to chronic intermittent and continuous noise, a comparison that should be expanded to other species. Additionally, we think these results highlight that experimental noise playbacks may be useful in assessing the response of wild animals to chronic noise (Blickley & Patricelli 2010).

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Supporting Information

Spectrograms and power spectrums of drilling noise, road noise and male sage-grouse vocal display (Appendix S1), map of experimental and control leks (Appendix S2), and noise playback levels on experimental leks (Appendix S3) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

Literature Cited

Aldridge, C., and M. Boyce. 2007. Linking occurrence and fitness to persistence: habitat-based approach for endangered greater sage-grouse. Ecological Applications **17:**508–526.

Barber, J. R., K. R. Crooks, and K. M. Fristrup. 2009. The costs of chronic noise exposure for terrestrial organisms. Trends in Ecology & Evolution **25:**180–189.

Bayne, E., L. Habib, and S. Boutin. 2008. Impacts of chronic anthropogenic noise from energy-sector activity on abundance of songbirds in the boreal forest. Conservation Biology **22:**1186–1193.

Blickley, J. L., and G. L. Patricelli. 2010. Impacts of anthropogenic noise on wildlife: research priorities for the development of standards and mitigation. Journal of International Wildlife Law & Policy **13:**274–292.

BLM (Bureau of Land Management). 2008. Pinedale Anticline Project area. Supplemental environmental impact statement record of decision. Appendix A. BLM, Pinedale, Wyoming.

Boyko, A. R., R. M. Gibson, and J. R. Lucas. 2004. How predation risk affects the temporal dynamics of avian leks: greater sage grouse versus golden eagles. The American Naturalist **163:**154–165.

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

Connelly, J. W., K. P. Reese, and M. A. Schroeder. 2003. Monitoring of greater sage-grouse habitats and populations. College of Natural Resources Experiment Station, University of Idaho, Moscow.

Connelly, J. W., S. T. Knick, M. A. Schroeder, and S. J. Stiver. 2004. Conservation assessment of greater sage-grouse and sagebrush habitats. Western Association of Fish and Wildlife Agencies, Cheyenne, Wyoming.

Copeland, H. E., K. E. Doherty, D. E. Naugle, A. Pocewicz, and J. M. Kiesecker. 2009. Mapping oil and gas development potential in the US intermountain west and estimating impacts to species. Public Library of Science One **4:**e7400. DOI: 10.1371.

Doherty, K., D. Naugle, B. Walker, and J. Graham. 2008. Greater sage-grouse winter habitat selection and energy development. Journal of Wildlife Management **72:**187–195.

Forman, R. T. T. 2000. Estimate of the area affected ecologically by the road system in the United States. Conservation Biology **14:** 31–35.

Forman, R. T. T., and R. D. Deblinger. 2000. The ecological road-effect zone of a Massachusetts(U. S. A.) suburban highway. Conservation Biology **14:**36–46.

Francis, C. D., C. P. Ortega, and A. Cruz. 2009. Noise pollution changes avian communities and species interactions. Current Biology **19:**415–419.

Francis, C., C. Ortega, and A. Cruz. 2011. Vocal frequency change reflects different responses to anthropogenic noise in two suboscine tyrant flycatchers. Proceedings of the Royal Society B: Biological Sciences **278:**2025–2031.

Garton, E. O., J. W. Connelly, J. S. Horne, C. A. Hagen, A. Moser, and M. A. Schroeder. 2010. Greater sage-grouse population dynamics and probablity of persistence. Pages 293–382. Studies in avian biology. University of California Press, Berkeley.

Gibson, R. M. 1989. Field playback of male display attracts females in lek breeding sage grouse. Behavioral Ecology and Sociobiology **24:**439–443.

Gibson, R. M. 1996. Female choice in sage grouse: the roles of attraction and active comparison. Behavioral Ecology and Sociobiology **39:**55–59.

Habib, L., E. M. Bayne, and S. Boutin. 2007. Chronic industrial noise affects pairing success and age structure of ovenbirds Seiurus aurocapilla. Journal of Applied Ecology **44:**176–184.

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

Wyoming. Department of Zoology and Physiology, University of Wyoming, Laramie.

Holloran, M., R. Kaiser, and W. Hubert. 2010. Yearling greater sage-grouse response to energy development in Wyoming. Journal of Wildlife Management **74:**65–72.

Hu, Y., and G. C. Cardoso. 2010. Which birds adjust the frequency of vocalizations in urban noise? Animal Behaviour **79:**863–867.

Ingelfinger, F., and S. Anderson. 2004. Passerine response to roads associated with natural gas extraction in a sagebrush steppe habitat. Western North American Naturalist **64:**385–395.

Jankowski, M. D., J. C. Franson, E. Möstl, W. P. Porter, and E. K. Hofmeister. 2010. Testing independent and interactive effects of corticosterone and synergized resmethrin on the immune response to West Nile virus in chickens. Toxicology **269:**81–88.

Kaiser, R. 2006. Recruitment by greater sage-grouse in association with natural gas development in western Wyoming. Department of Zoology and Physiology, University of Wyoming, Laramie.

Lengagne, T. 2008. Traffic noise affects communication behaviour in a breeding anuran, *Hyla arborea*. Biological Conservation **141:**2023–2031.

Leonard, M., and A. Horn. 2008. Does ambient noise affect growth and begging call structure in nestling birds? Behavioral Ecology **19:**502–507.

Naugle, D. E., et al. 2004. West Nile virus: pending crisis for greater sage-grouse. Ecology Letters **7:**704–713.

Patricelli, G., and J. Blickley. 2006. Avian communication in urban noise: causes and consequences of vocal adjustment. The Auk **123:**639–649.

Patricelli, G., and A. Krakauer. 2010. Tactical allocation of effort among multiple signals in sage grouse: an experiment with a robotic female. Behavioral Ecology **21:**97–106.

Quinn, L., J. Whittingham, J. Butler, and W. Cresswell. 2006. Noise, predation risk compensation and vigilance in the chaffinch Fringilla coelebs. Journal of Avian Biology **37:**601–608.

Rabin, L. A., R. G. Coss, and D. H. Owings. 2006. The effects of wind turbines on antipredator behavior in California ground squirrels (*Spermophilus beecheyi*). Biological Conservation **131:**410–420.

Rheindt, F. E. 2003. The impact of roads on birds: does song frequency play a role in determining susceptibility to noise pollution? Journal of Ornithology **144:**295–306.

Richardson, W. J. 1995. Marine mammals and noise. Academic Press, San Diego, California.

Sawyer, H., M. Kauffman, and R. Nielson. 2009. Influence of well pad activity on winter habitat selection patterns of mule deer. Journal of Wildlife Management **73:**1052–1061.

Schroeder, M., and L. Robb. 2003. Fidelity of greater sage-grouse *Centrocercus urophasianus* to breeding areas in a fragmented landscape. Wildlife Biology **9:**291–299.

Slabbekoorn, H., and E. A. P. Ripmeester. 2008. Birdsong and anthropogenic noise: implications and applications for conservation. Molecular Ecology **17:**72–83.

Sun, J. W. C., and P. M. Narins. 2005. Anthropogenic sounds differentially affect amphibian call rate. Biological Conservation **121:**419–427.

Tyack, P. L., et al. 2011. Beaked whales respond to simulated and actual navy sonar. Public Library of Science One **6:**e17009. DOI: 10.1371.

van der Zande, A. N., W. J. ter Keurs, and W. J. van der Weijden. 1980. The impact of roads on the densities of four bird species in an open field habitat—evidence of a long-distance effect. Biological Conservation **18:**299–321.

Vehrencamp, S., J. Bradbury, and R. Gibson. 1989. The energetic cost of display in male sage grouse. Animal Behaviour **38:**885–896.

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

Walsh, D. P., G. C. White, T. E. Remington, and D. C. Bowden. 2004. Evaluation of the lek-count index for greater sage-grouse. Wildlife Society Bulletin **32:**56–68.

Warren, P. S., M. Katti, M. Ermann, and A. Brazel. 2006. Urban bioacoustics: it's not just noise. Animal Behaviour **71:**491–502.

Weisenberger, M. E., P. R. Krausman, M. C. Wallace, D. W. D. Young, and O. E. Maughan. 1996. Effects of simulated jet aircraft noise on heart rate and behavior of desert ungulates. The Journal of Wildlife Management **60:**52–61.

Wiley, R. H. 1973. Territoriality and non-random mating in sage grouse (*Centrocercus urophasianus*). Animal Behaviour Monographs **6:**85–169.

Wright, A., et al. 2007. Anthropogenic noise as a stressor in animals: a multidisciplinary perspective. International Journal of Comparative Psychology **20:**250–273.

Experimental Chronic Noise Is Related to Elevated Fecal Corticosteroid Metabolites in Lekking Male Greater Sage-Grouse (*Centrocercus urophasianus*)

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Abstract

There is increasing evidence that individuals in many species avoid areas exposed to chronic anthropogenic noise, but the impact of noise on those who remain in these habitats is unclear. One potential impact is chronic physiological stress, which can affect disease resistance, survival and reproductive success. Previous studies have found evidence of elevated stress-related hormones (glucocorticoids) in wildlife exposed to human activities, but the impacts of noise alone are difficult to separate from confounding factors. Here we used an experimental playback study to isolate the impacts of noise from industrial activity (natural gas drilling and road noise) on glucocorticoid levels in greater sage-grouse (*Centrocercus urophasianus*), a species of conservation concern. We non-invasively measured immunoreactive corticosterone metabolites from fecal samples (FCMs) of males on both noise-treated and control leks (display grounds) in two breeding seasons. We found strong support for an impact of noise playback on stress levels, with 16.7% higher mean FCM levels in samples from noise leks compared with samples from paired control leks. Taken together with results from a previous study finding declines in male lek attendance in response to noise playbacks, these results suggest that chronic noise pollution can cause greater sage-grouse to avoid otherwise suitable habitat, and can cause elevated stress levels in the birds who remain in noisy areas.

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Introduction

Anthropogenic noise is becoming ubiquitous as natural landscapes are increasingly dominated by humans, but we still have much to learn about the impacts of chronic noise exposure on wildlife [1–3]. Recent studies have shown that some species avoid developed areas with high noise levels, reducing available habitat and potentially leading to reduced populations [4–6]. However, there is variation among species and individuals in the tendency to avoid noise [4,5,7], which raises the question of whether animals that remain suffer detrimental effects, or if these individuals are better able to habituate to noise or are less susceptible to its effects. It has been suggested that animals remaining in (or unable to leave) noisy areas may have lower survival and reproductive success [8–10]; indeed, recent studies have demonstrated complex effects of noise on community structure and on breeding and pairing success [4–6,11]. Given the ubiquity of noise in the environment, it is critical that we understand noise impacts on animals whether they remain in or avoid disturbed areas.

One possible impact of introduced noise on animals is the induction of stress, which may be defined broadly as nonspecific adverse effects in vertebrates but is most often characterized by its influence on neuroendocrine physiology. The duration of noise exposure affects the stress response of animals exposed to it [12]. Exposure to a brief but loud noise event, such as a single sonic boom, will result in an acute stress response. An acute stress response is characterized by a rapid release of epinephrine and norepinephrine (the "fight or flight" response) followed by a hypothalamic-pituitary-adrenal (HPA) cascade. The HPA cascade results in increased secretion of glucocorticoid hormones, cortisol or corticosterone, in the blood. Long-term exposure to a chronic noise stressor, such as a high-traffic freeway, can lead to chronic stress, defined as long-term overstimulation of coping mechanisms. This in turn can lead to less predictable changes in the HPA axis. Acclimation or exhaustion may result in reduced glucocorticoid release to the same or novel stressors; facilitation, conversely, can lead to elevated glucocorticoid release in response to novel stressors, and even in cases of reduced peak glucocorticoid response, deficits in negative feedback may develop that result in greater overall exposure to glucocorticoids due to prolonged elevation [12,13].

Glucocorticoid hormones and their metabolites are commonly used to measure a stress response [14–16]. Glucocorticoid hormones can be measured from blood samples or their metabolites may be measured non-invasively from fecal samples as an index of the relative physiological stress of animals [17–19]. Glucocorticoid hormones play a major role in allocating energy, and prolonged exposure due to chronic stress can affect fitness by inhibiting resource allocation to reproductive or immune activities, a condition known as allostatic overload [12,20–24].

Studies in captive animals have found that noise can increase HPA activity and glucocorticoid levels [25,26]; indeed studies of stress physiology often use noise exposure as a method to induce a stress response [27,28]. Previous observational and experimental studies on the impacts of anthropogenic noise on glucocorticoid levels in wild animals have yielded mixed results. Snowmobile and wheeled-vehicle traffic was associated with elevated fecal glucocorticoid metabolites in wolves and elk [14]. Noise is one potential mechanism of this impact, but visual and other types of disturbance may also contribute to these responses; indeed, the quieter activity of Nordic skiing also correlates with FCMs in capercaillie (*Tetrao urogallus*) [29]. Delaney et al. [30] found behavioral responses in spotted owls to loud noise from visually hidden chainsaws and helicopters, but subsequent studies found no evidence of change in FCMs with exposure to quieter chainsaw noise (below behavioral response threshold) or road proximity to nesting sites [31]. Results from chronic noise studies on humans have also been mixed [32]. Studies of children in areas with high road noise have found increased overnight glucocorticoid levels in urine, as well as impaired circadian rhythms, sleep, memory and concentration, [33] and increased heart-rate responsiveness to acute stressors [34]. However, a study in children living in communities near airports found increases in some measures of stress (blood pressure, epinephrine and norepinephrine) but no similar elevation in overnight urinary cortisol [35]. These results indicate that noise may have a significant effect on glucocorticoids and other stress-related variables in many species, but that further study is needed to determine the degree and extent of these effects and how the effects may vary with different types of noise.

In this study, we test the hypothesis that chronic noise causes an increase in stress levels of lekking greater sage-grouse. We used fecal levels of immunoreactive corticosteroid metabolites (FCMs) as an index of physiological stress and compared FCMs for breeding males on display grounds (leks) with and without experimentally introduced noise. The greater sage-grouse, an iconic species once widespread in western North America, is now declining throughout its range, leading to its listing as an endangered species in Canada and its recent designation as "warranted but precluded" for listing under the Endangered Species Act in the USA [36,37]. Over the last decade, natural gas development has expanded rapidly across much of the sage-grouse range and has been implicated in reduced lek attendance and abandonment of long-occupied (often for decades) lek sites by males [e.g. 38,39–41]. Males typically gather on lekking grounds for several hours in the early morning when conditions are quiet and still, a time when they may be particularly vulnerable to disturbance from noise pollution from natural gas development and other sources [42]. To investigate whether noise exposure may have contributed to declines in lek attendance, Blickley et al. [43] experimentally introduced noise from natural gas development activities (drilling and road noise) on leks over three breeding seasons (2006–2008). This noise playback caused immediate and sustained declines in sage-grouse lek attendance. Further, different types of noise had different degrees of impact, with drilling noise and road noise causing an average 29% and 73% decline in lek attendance, respectively, compared to their paired controls. That study provides evidence that anthropogenic noise from energy development causes some males to avoid attending leks with introduced noise, but we do not yet know whether noise also has a negative impact on the individuals that remain on noisy leks. The lekking season is a time of high metabolic demand [44] and stress [45] for males, so exposure to noise during this period may have a greater fitness cost.

Here we compare the FCM levels of male sage-grouse on control leks and leks with experimentally introduced noise in the second and third seasons of experimental noise playback (2007 and 2008) [43]. We predict that if noise exposure leads to chronic stress, male sage-grouse on experimental leks will have higher FCMs than males on control leks. Such differences in observed FCM levels may also be observed if males with low glucocorticoid levels are more likely to disperse from noise-treated leks, so we compared the variance in FCM levels on noise and control leks. We also investigated whether elevated FCM levels were associated with declines in peak male attendance on leks to determine the value of this metric as a tool for predicting lek declines.

Materials and Methods

Study Area & Experimental Design

Study sites were located on federal land relatively undisturbed by human development in Fremont County, Wyoming (42° 50′, 108° 29′30). We monitored a total of 16 leks that were divided into 8 pairs, with the leks of a pair matched according to size and location (6 pairs near the town of Hudson and 2 pairs near the town of Riverton) (Figure 1). Of the 8 lek pairs, 4 pairs were randomly assigned to each noise type, such that there were 4 "drilling pairs", each including one lek exposed to drilling noise and a similar lek as its control, and 4 "road pairs," each with one road noise and a matched control. For 3 of the pairs, one lek within a pair was randomly assigned to the treatment (noise) group and the other assigned as control. For the fourth pair, the treatment and control leks were deliberately assigned due to another study that was in progress. During sample collection periods, both leks in a pair were normally visited on the same day.

Noise and playback methods have been previously described [43] and are summarized here. Noise was played beginning in mid-February to early March and continuing through the end of April of each year. Noise was recorded from drilling and main road sites at the Pinedale Anticline natural gas fields and played back using a commercial car amplifier and 3–4 rock-shaped outdoor speakers placed along one edge of the lek. On leks with road-noise playback, recordings of semi-trailer trucks and pickup trucks were combined with 30- and 60-second files of silence at a ratio reflecting the average number of each truck type found on a main energy field access road; these files were then played using the "random shuffle" feature on an MP3 player. Most shift changes occur at 8 am, so our playback may underestimate actual traffic levels during the lekking time. On leks with drilling noise, a 14-minute recording of a drilling rig was played on continuous loop. Natural gas development activities occur 24 hours a day, so noise was broadcast continuously day and night at playback levels that approximate the noise level at 0.25 mile (402 m) from a typical drilling site (JLB and GLP unpublished data). Drilling-noise recordings were broadcast on experimental leks at an equivalent sound level (L_{eq}) of 71.4±1.7 dBF (unweighted decibels) SPL re 20 μPa (56.1±0.5 dBA [A-weighted decibels]) as measured at 16 meters; on road-noise leks, where the amplitude of the noise varied with the simulated passing of vehicles, noise was broadcast at an L_{max} (maximum RMS amplitude) of 67.6±2.0 dBF SPL (51.7±0.8 dBA) (see Blickley, et al. [43], for detailed noise-exposure measurements). Noise from playback was localized to each lek due to the small size of our speakers. To control for visual disturbance of the speaker system and researcher presence, control

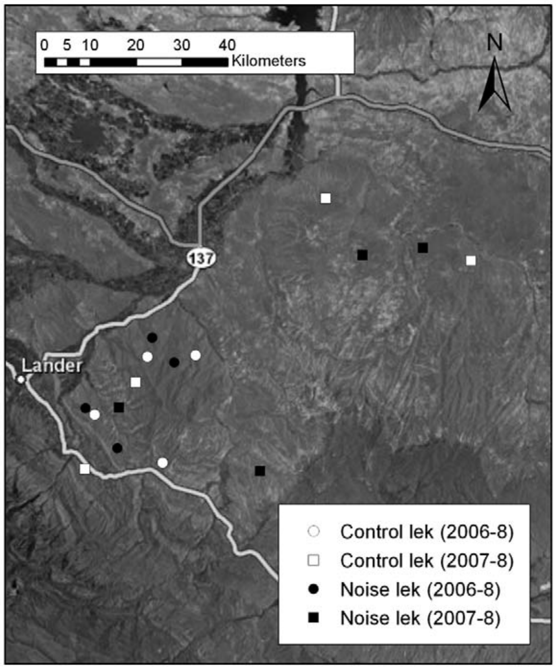

Figure 1. Noise playback study area in Fremont County, Wyoming, USA, 2006–2009. Experimental and control leks were paired on the basis of size and geographic location (the four leks in the upper right are part of the Riverton region, whereas the rest of the leks are in the Lander region).
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leks had dummy speakers placed in the same arrangement and were also visited to simulate the periodic battery changes on noise leks. This experimental protocol was reviewed and approved by the Animal Care and Use Committee at UC Davis (Protocol # 16435) and the Wyoming Game and Fish Department (Permit # 33–405).

In the first year of the experiment (2006), we played noise on only 4 of the 8 lek pairs (2 experimental leks with introduced drilling noise, 2 with introduced road noise). Therefore, some leks had been exposed to noise the breeding season prior to the first year of FCM measurement; however, we detected no significant impact of duration of noise exposure on lek attendance [43], so years of noise exposure was not included as a potential explanatory variable in candidate model sets.

Collection of Fecal Samples

Fecal samples were collected from leks soon after all sage-grouse had left the lek for the morning. Samples were collected twice per year from each lek (once during the mid season [April 4–6 in 2007, April 6–8 in 2008] and once during the late season [April 23–26 in 2007, April 22–24 in 2008]) and were collected from paired leks on the same day. Samples were collected using a sweep-search method in which the entire lek was systematically searched and fresh fecal samples were collected individually in Whirl-Pak bags and labeled with a location on the lek relative to the speakers (or dummy speakers). To minimize the chance of collecting multiple fecal samples from the same individual, we collected samples that were a minimum of 5 meters apart, roughly the minimum territory size of a male sage-grouse. Jankowski [45] found lower FCM levels in female sage-grouse than in breeding male sage-grouse. Therefore to avoid collecting samples from females, we collected samples on dates when female visitation is rare; if there were more than 1–2 females on the lek on a potential collection day, sampling for that lek pair was postponed until the next day. Time to collect samples varied among leks from 20–80 minutes. Samples were frozen at −20°C within a few hours of collection until processing. Jankowski et al. [45] found no difference in FCM levels for greater sage-grouse samples held for variable times up to 16 hours prior to freezing.

Extraction & Radioimmunoassay of Cort

We used extraction and assay procedures, with minor modifications, that were previously validated for application to greater sage-grouse by Jankowski et al. [46]. Individual fecal pellets were kept on ice while uric acid (often present in a discrete cap on the pellet) was removed and discarded. Samples were then lyophilized and returned to storage at −20°C. On the day of extraction, individual fecal pellets were weighed to the nearest 0.0001 g, then manually homogenized, vortexed, and shaken in 5 mL of 80% methanol for at least 30 minutes. Longer incubation in methanol often occurred due to the large number of tubes in each assay, but experimentation with overnight extraction produced no substantial change in detected metabolites. Samples were centrifuged at 5000 rpm for 30 minutes, then 1.5mL of supernatant was drawn off, placed in a separate tube, dried under streaming air in a 70°C water bath and reconstituted in 1.0 mL of steroid diluent provided in the RIA kit (see below). For some very large samples, it was not possible to remove 1.5 mL; in these cases, 500 μL of supernatant was drawn off and reconstitution volume was adjusted accordingly after drying. Extracts were covered with Parafilm and stored at 4°C until assayed.

A pooled sample was made by homogenizing a collection of multiple samples from one control lek (Monument lek) in a blender prior to lyophilization. From this pooled sample, 0.5 g was assayed initially to determine parallelism with the RIA standard curve, and one or more pooled samples were included in each extraction and assay.

Radioimmunoassays were conducted according to the manufacturer's instructions (catalog # 07-120103, MP Biomedicals, Costa Mesa, CA) using 1:16 dilution of reconstituted extract. This RIA kit utilizes a rabbit-produced BSA IgG polyclonal antibody against corticosterone-3-carboxymethyloxime. This antibody has been widely used for fecal assays due to its ability to bind a broad spectrum of corticosteroid metabolites [47]. Samples were randomly distributed among assays with respect to year and treatment to minimize any impacts of inter-assay variation.

FCM measures were adjusted for the mass of the fecal sample (ng ICM/g sample) to account for differences among leks in fecal pellet mass. In dividing ICM by sample mass, we effectively assume that the relationship between sample mass and fecal transit time (during which corticosteroid metabolites are secreted into the lumen of the gut) is positive and linear. To guard against faults in this assumption, we ran the same statistical analyses using "per sample" FCM data and found no difference in the main effects as reported.

Statistical Analysis

Fecal glucocorticoid metabolites levels were natural log-transformed to meet assumptions of normality and homoscedasticity prior to analysis. We used an information theoretic approach to evaluate the support for alternative candidate models using Akaike's Information Criterion for small sample sizes (AIC_c) [48]. Candidate models for the overall effect of noise (Noise effect models) were linear mixed-effect models that assessed the relationship between explanatory variables and the concentration of FCMs collected from experimental and control leks. Potential explanatory variables included pair type (NoiseType, drilling or road noise), control status (Treatment, noise or control), pellet/collection distance from speakers (SpeakerDist), maximum lek size for that year (MaxSize), location (Hudson or Riverton), season (early or late April), and relevant interactions (see Table 1 for full set of candidate models). All models contained lek pair ID, and year (2007 or 2008) as random effects.

We also evaluated a set of candidate models that assessed the relationship between the concentration of FCMs on experimental leks and the declines in peak male attendance from the previous year (attendance models). Models contained lek ID and year (2007 or 2008) as random effects. Models were ranked on the basis of differences in AICc scores (ΔAICc) and were assigned Akaike weights (w_i) corresponding to the degree of support. We calculated model-averaged coefficients and variable importance (sum of variable weights for all models in which the variable was included) for variables contained in all models that received strong support (ΔAICc <2). We also compared the variance in FCM concentrations measured on noise and control leks using a Levene's test. All statistical analyses were performed in R (version 2.12.1, R Development Team 2010).

Results

We measured baseline fecal immunoreactive corticosterone metabolites of 103.2 and 119.9 ng/g for control and treatment groups, respectively (Table 2). These values are lower than baseline measures of approximately 149 ng/g obtained previously for breeding male greater sage-grouse in Nevada, from which fecal samples were collected after capture [45].

Males on leks exposed to noise had higher (16.7% on average) FCM levels compared with controls ($w_i = 0.96$, Table 1, 2; Figure 2). While models that included the effect of Treatment (noise versus control) were highly supported by the data, there was little support for an interaction of Treatment with NoiseType variable ($w_i = 0.01$, Table 1), indicating that while noise exposure was associated with increased cort, there was little difference in FCM levels between leks with drilling versus road-noise playback. Candidate models containing other possible explanatory variables, including distance from the nearest speaker (SpeakerDist), maximum size of the lek (MaxSize), the regional location of the lek in the Hudson area or Riverton area (Location) and time of the season (Season), received little support relative to the null model (Table 1, Figure 2B), indicating that none of these factors had a strong influence on FCM levels.

To determine whether noise-playback leks with a higher stress response were associated with larger declines in lek attendance, we compared candidate models for the relationship between FCM level and change in lek attendance from the previous year. Only the null model received support (Table 3), indicating that fecal FCM level was not associated with the magnitude of changes in lek attendance on noise leks.

Finally, we examined whether there was a difference in variance among samples on noise leks and control leks. We found no significant differences in variance between treatment types in 2007 (variance on noise leks = 7729.94, control leks = 6168.28, Levene's

Table 1. Mixed-effect candidate models for the effect of noise playback on mass-dependent FCM concentrations (natural log-transformed).

Model[a,b]	K[c]	ΔAIC_c[d]	w_i[e]
Treatment[f]	5	0	0.66
Treatment + Location	6	2.4	0.20
Treatment + Location + Treatment:Location	7	4.7	0.06
Null- random effects only	4	5.5	0.04
Treatment + Season	6	6.5	0.03
Treatment + Season + Treatment:Season	7	10.0	<0.01
Treatment + NoiseType + Treatment:NoiseType	7	10.8	<0.01
Treatment + Location + NoiseType + Treatment:Location + Treatment:NoiseType	9	11.2	<0.01
Treatment + NoiseType + Season + Treatment:Season + Treatment:NoiseType	9	20.7	<0.01
Treatment + MaxSize + Treatment:MaxSize	7	25.3	<0.01
Treatment + NoiseType + Season + Treatment:NoiseType + Treatment:Season + Treatment:NoiseType:Season	11	27.3	<0.01
Treatment + SpeakerDistance + Treatment:SpeakerDistance	7	27.5	<0.01
Treatment + NoiseType + MaxSize + Treatment:NoiseType + Treatment:MaxSize	10	35.4	<0.01
Treatment + NoiseType + SpeakerDistance + Treatment:NoiseType + Treatment:SpeakerDistance	9	38.2	<0.01
Treatment + NoiseType + MaxSize + Treatment:NoiseType + Treatment:MaxSize + Treatment:NoiseType:MaxSize	12	45.1	<0.01
Treatment + NoiseType + SpeakerDistance + Treatment:NoiseType + Treatment:SpeakerDistance + Treatment:NoiseType:SpeakerDistance	11	60.4	<0.01

[a] Abbreviations of predictor variables in methods.
[b] All models contain lek pairing and year as a random effect.
[c] Number of parameters in the model.
[d] Difference in AIC_c (Akaike's Information criteria for small sample size) values from the top ranking model.
[e] Akaike weight (Probability that the model is the best fit model giving the data and model candidate set).
[f] Model with substantial support (ΔAIC_c <2).

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Table 2. Parameter estimates (± SE) and relative variable importance for variables in highly supported models ($\Delta AIC_c < 3$).

Variable	Parameter estimates[a]	Parameter estimates (back-transformed)[b]	Relative variable importance[c]
Intercept	4.63 (.06)	103.2[d]	-
Treatment:Noise	.15 (.04)	16.7[d]	0.96
Location: Hudson	0.02(.01)	2.9[d]	0.26

[a] Parameter estimates are natural-log transformed.
[b] SE not included due to back-transformation.
[c] Relative variable importance is the summed total of the model weights for models containing that variable.
[d] Intercept value was added to parameter estimates prior to back-transformation and then subtracted.
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$W = 0.6327$, $p = 0.427$). Variance on noise leks was significantly higher than on control leks in 2008 (variance on noise leks = 4462.28, control leks = 2758.69, Levene's $W = 6.6064$, $p = 0.01$).

Discussion

We found higher (16.7%) FCM levels on noise-treated leks compared to controls, supporting the hypothesis that chronic noise pollution increases stress levels in male greater sage-grouse. Combined with results from monitoring of lek attendance in the same experiment [43], these results suggest that noise from natural gas development activities can dramatically decrease male attendance on leks and cause physiological impacts on males that remain on noisy leks. The mean level of FCMs in remaining birds was not a good predictor of the degree of decline in peak male attendance on a lek compared with the previous year, indicating that the FCM level measured on a lek is not diagnostic of an effect of noise on peak male attendance (Table 3). Further, we did not find support for an effect of distance from the speakers on FCM levels. Male sage-grouse typically maintain a fixed territory on a lek throughout the season. Within a noise-treated lek, each individual's exposure to noise varied, depending on the location of their territory relative to the speakers. Since noise levels decline exponentially with distance from the speakers, the lack of a distance effect suggests that stress is not exclusively dependent on the noise exposure of individuals. Instead, noise impacted FCM levels on a lek-wide basis.

Blickley et al. [43] found a decline in lek attendance on road-noise leks more than twofold larger than the decline in lek attendance on drilling-noise leks, yet we found no difference in FCM levels between noise-playback types (Table 1, Figure 1). Both noise sources have most of their sound energy ≤ 2 kHz, but road noise is less predictable than drilling noise and more intermittent,

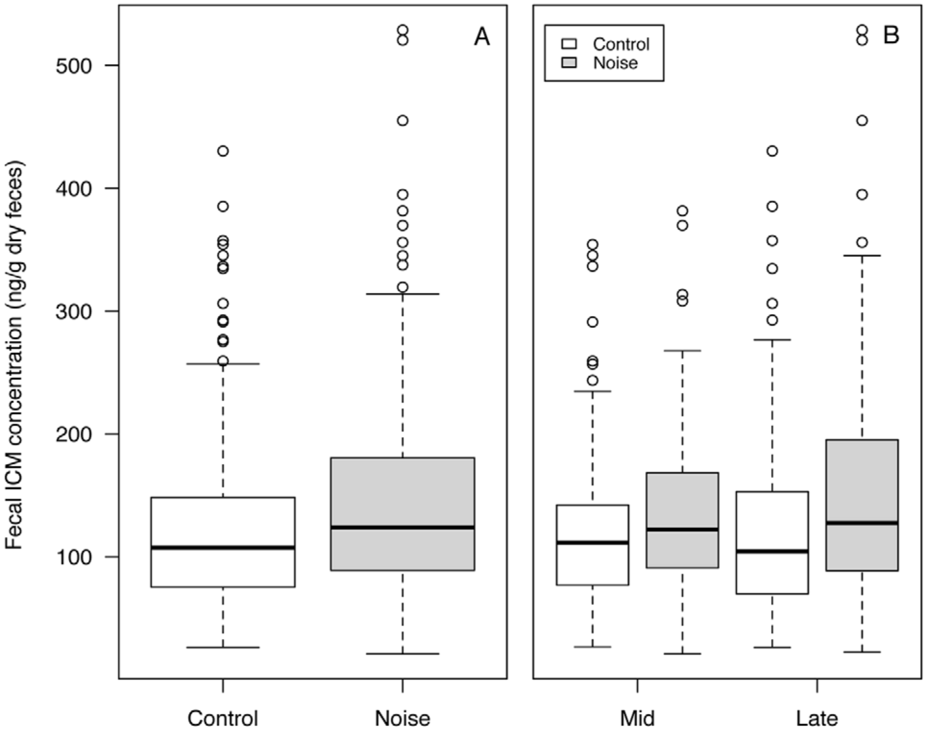

Figure 2. FCM concentrations from control and noise-treated groups. Data shown (A) pooled by season and (B) for mid and late season samples. Horizontal line represents the median value, box ends represent upper and lower quartiles, whiskers represent maximum and minimum values and open circles represent outliers. Plots present measured FCM values, not model output, which is presented in Table 2.
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Table 3. Mixed-effect candidate models assessing the relationship of FCM concentrations and changes in lek attendance from the previous year on noise-playback leks.

Model[a,b]	K[c]	ΔAIC_c [d]	w_i [e]
Null- random effects only[f]	5	0	0.90
Fecal cort	6	4.6	0.10

[a] Abbreviations of predictor variables in methods.
[b] All models contain lek pairing and year as a random effect.
[c] Number of parameters in the model.
[d] Difference in AIC_c (Akaike's Information criteria for small sample size) values from the top ranking model.
[e] Akaike weight.
[f] Model with substantial support ($\Delta AIC_c < 3$).
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leading to a lower average noise exposure across road-noise leks (43.2±0.89 dBA L_{eq}) than drilling-noise leks (56.1±0.45 dBA L_{eq}) [43]. Studies on physiological stress in rodents indicate that stressors administered at unpredictable intervals result in greater elevations in plasma corticosterone [49]. Since cort levels may also be implicated in decisions to escape from deleterious conditions [50], we cannot say with certainty that noise type has no differential impact on FCM levels, only that there was no difference observed among males that chose to remain. If road noise did result in a greater cort response in some birds, but the most susceptible birds were also the most likely to disperse, differences would not necessarily be expected among remaining birds. In this scenario, it is likely that variance would be reduced in leks with high losses, reflecting disappearance of individuals with higher FCM levels. Levene's tests did not identify any such difference in variance (indeed, there was a significant difference in one year of the study, but in the opposite direction to predictions). However, the possibility that dispersal is linked to FCM levels cannot be ruled out. Regardless of whether the stress levels of birds on noise leks increased, or whether only high-stress-level individuals remained on noisy leks, these results indicate that chronic noise at leks creates less desirable habitat for greater sage-grouse.

The unknown status of dispersed grouse – and their unknown destinations – leaves several other possible scenarios that should be considered. It is possible that the individuals most likely to disperse could have had different cort profiles at the outset compared with those more prone to remain. If noise playback caused individuals with lower integrated cort to disperse away from noisy leks, that coupled with the possible addition of those birds to control leks could cause trends similar to those observed here. Two possible sources of variation in pre-experiment cort levels among individuals are age and social status [51–53]. Reduced juvenile recruitment may have contributed to the observed declines in lek attendance on noise leks, potentially leading to a difference in age structure on noise and control leks [43]; however, this is unlikely to explain the results of this study. Studies of altricial and semi-altricial birds have found lower stress responsiveness shortly after hatching, but responses resemble those of adults by the age of fledging or first molt [54–57]. Since young male sage-grouse attending leks are likely to be at least 10 months old and after their first molt, it is unlikely that they would have lower stress response than adults. Social status can also be related to corticosteroid levels [58], therefore social upheaval caused by dispersal between noise and control leks may have contributed to observed FCM levels. Further studies are needed determine whether age-class- and social-status-dependent dispersal in response to noise contributed to the observed results.

Unlike noise sources in most energy development sites, our noise introduction in this study was localized to the immediate lek area, so birds were exposed to noise for only a few hours a day, and only during the breeding season. Therefore, we cannot quantify the effects of noise on FCMs for wintering, nesting or foraging males. Noise at energy development sites is less seasonal and more widespread and may thus affect birds at all life stages, with a potentially greater impact on stress levels. In addition, we looked only at male stress levels in this study, but males and females may respond differently to stress. For example, Jankowski et al. [45] measured FCM levels in sage-grouse in habitats with and without cattle grazing; they found no difference in male FCM levels in response to grazing regime, however, breeding females showed elevated stress response in grazed areas. This suggests that females may be more vulnerable to some types of disturbance; further studies are needed to assess whether female stress levels are influenced by noise.

Why might noise be stressful?

Increased adrenocortical activity occurs in response to circumstances perceived as threatening by an animal. Although we cannot determine from this study the extent to which noise itself is a threat to sage-grouse, noise may affect social dynamics and increase the perception of threat. Noise may have social impacts on sage-grouse by masking acoustic communication on the lekking grounds [42]. Masking occurs when the perception of a sound is decreased by the presence of background noise, which may reduce the efficacy of acoustic communication. Acoustic signals play an important role in many social interactions, including mate attraction and assessment, territorial interactions, recognition of conspecifics and alarm calling in response to environmental threats [9,10,59]. Masking of these acoustic signals may alter or interfere with social interactions and mate choice behaviors [60,61].

For prey species such as sage-grouse, noise may also increase stress levels by masking the sounds of approaching predators and increasing the perception of risk from predation [62,63]. The degree to which noise directly affects mortality through changes in predation is largely unknown, as few studies have compared predation rates or hunting success in noisy and quiet areas while controlling for other confounding factors. Francis et al. [4] did so and found that nest predation rates in some songbirds decline in noise-impacted areas, as the dominant nest predator avoided noise. This suggests that noise may cause complicated changes in predator-prey dynamics. Noise may also cause stress due to short-term disruptions in behavior, such as startling or frightening animals away from food or other resources [2,64]. Further, if individuals associate a particular type of noise, such as road noise, with a danger, such as vehicular traffic, this may provoke a stress response [43].

The impacts of chronic stress

Glucocorticoid release under challenging conditions is an adaptation to life in an unpredictable and threatening world [20]; individuals benefit from curtailing reproduction, altering behavioral patterns, and redirecting metabolic substrates to maximize glucose availability for action in response to genuine threats. Glucocorticoid levels alone are not directly or inversely correlated with fitness measures under all conditions [65], however, chronic adrenal activation has many known trade-offs that result in vulnerability to disease and death [22]. Unlike threats from predators, food shortages and inclement weather, noise typically does not directly threaten the survival of an individual or its offspring (though there may be exceptions, as discussed below). Therefore, the cost of chronic adrenal activation in response to noise pollution is unlikely to be outweighed by the benefits in most cases, and thus the net result may be adverse.

One important trade-off is the effect of corticosterone on immune response. Chickens infected with West Nile Virus (WNV) and administered corticosterone had increased oral shedding and lengthened duration of viremia compared to those without elevated cort [66]. For sage-grouse, which are highly susceptible to WNV [67,68], reduced immune response due to elevated glucocorticoid levels could have a significant effect on survival in areas where they are exposed to WNV. Therefore, despite the adaptive nature of the stress response under natural conditions, elevated glucocorticoid levels due to human disturbance may have detrimental long-term impacts on welfare and survival of sage-grouse and other wildlife.

Stress as an indicator of human impacts on sage-grouse

Measurement of FCMs may provide a non-invasive monitoring tool to assess the impact of human development (e.g. oil and gas drilling, wind farms, highways, off-road vehicle traffic) on stress levels of greater sage-grouse and other species. However comparisons between disturbed and undisturbed areas would need to account for differences in age, sex, and breeding condition of individuals sampled as well as for differences in the environmental conditions between sites in order to isolate stress as the likely cause of change [15,18,69]. We controlled for such differences by using an experimental presentation of noise that minimized effect on other habitat variables, limiting our collection to lekking birds, collecting only on days with limited female attendance and collecting samples from all leks within a short 2–3 day window. We did not find support for differences in FCM levels from samples collected in early versus late April within each season (~20 days apart in a 2–3 month breeding season), and only limited evidence for an effect of location (Hudson vs. Riverton, ~32 kilometers apart), suggesting that these temporal and spatial differences did not affect FCM levels in our study. However with a larger sample of leks or in another region or time period, it is possible that such differences might emerge.

Conclusions

Taken together, results from Blickley et al. [43] and this study suggest that noise alone can cause greater sage-grouse to avoid otherwise suitable habitat and increase the stress responses of birds that remain in noisy areas. Thus, noise mitigation may be a fruitful conservation measure for this species of concern. In this study, we focused on the effects of noise from roads and drilling rigs in natural gas development areas; other natural gas development infrastructure, including compressor stations and generators, produces noise similar to drilling rigs, with the potential for similar effects on FCM levels. Likewise, other types of energy development produce noise similar in frequency, timing, and amplitude to the noise sources used here, including shale gas, coal-bed methane, oil, and geothermal development. The noise sources used in this study also share some characteristics with other anthropogenic noise sources that are increasing across the landscape, like wind turbines, off-road vehicles, highways and urban development; this suggests that the impacts on greater sage-grouse observed here may be widespread. More generally, populations of many species of birds [4,70–74] and mammals [75–78] decline with proximity to noisy human activities, such as roads, urban and industrial developments. While further study is needed to determine whether chronic noise exposure contributes to the impacts of these human activities by activating the chronic stress response, this study adds to a growing body of evidence that such noise pollution is a threat to wildlife [1,2], significantly increasing our estimates of the footprint of human development beyond the boundaries of visible disturbance.

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Author Contributions

Conceived and designed the experiments: JLB GLP AHK SNS. Performed the experiments: JLB AHK GLP SNS KRW JLP JCW. Analyzed the data: JLB KRW GLP AHK JLP CCT JCW. Contributed reagents/materials/analysis tools: GLP JCW. Wrote the paper: JLB KRW GLP.

References

1. Kight CR, Swaddle JP (2011) How and why environmental noise impacts animals: an integrative, mechanistic review. Ecology Letters 14: 1052–1061.
2. Barber JR, Crooks KR, Fristrup KM (2009) The costs of chronic noise exposure for terrestrial organisms. Trends in Ecology & Evolution 25: 180–189.
3. Blickley JL, Patricelli GL (2010) Impacts of Anthropogenic Noise on Wildlife: Research Priorities for the Development of Standards and Mitigation. Journal of International Wildlife Law and Policy 13: 274–292.
4. Francis CD, Ortega CP, Cruz A (2009) Noise Pollution Changes Avian Communities and Species Interactions. Current Biology 19: 1415–1419.
5. Habib L, Bayne EM, Boutin S (2007) Chronic industrial noise affects pairing success and age structure of ovenbirds Seiurus aurocapilla. Journal of Applied Ecology 44: 176–184.
6. Bayne E, Habib L, Boutin S (2008) Impacts of Chronic Anthropogenic Noise from Energy-Sector Activity on Abundance of Songbirds in the Boreal Forest. Conservation Biology 22: 1186–1193.
7. Hu Y, Cardoso GC (2009) Are bird species that vocalize at higher frequencies preadapted to inhabit noisy urban areas? Behavioral Ecology 20: 1268–1273.
8. Slabbekoorn H, Ripmeester EAP (2008) Birdsong and anthropogenic noise: implications and applications for conservation. Molecular Ecology 17: 72–83.
9. Warren PS, Katti M, Ermann M, Brazel A (2006) Urban bioacoustics: it's not just noise. Animal Behaviour 71: 491–502.
10. Patricelli GL, Blickley JL (2006) Overview: Avian communication in urban noise: the causes and consequences of vocal adjustment. The Auk 123: 639–649.
11. Francis CD, Kleist NJ, Ortega CP, Cruz A (2012) Noise pollution alters ecological services: enhanced pollination and disrupted seed dispersal. Proceedings of the Royal Society B: Biological Sciences.
12. Wikelski M, Cooke SJ (2006) Conservation physiology. Trends in Ecology & Evolution 21: 38–46.
13. Romero LM (2004) Physiological stress in ecology: lessons from biomedical research. Trends in Ecology & Evolution 19: 249–255.
14. Creel S, Fox JE, Hardy A, Sands J, Garrott B, et al. (2002) Snowmobile Activity and Glucocorticoid Stress Responses in Wolves and Elk. Conservation Biology 16: 809–814.
15. Wasser SK, Bevis K, King G, Hanson E (1997) Non-Invasive Physiological Measures of Disturbance in the Northern Spotted Owl. Conservation Biology 11: 1019–1022.
16. Thiel D, Jenni-Eiermann S, Palme R (2005) Measuring corticosterone metabolites in droppings of capercaillies (*Tetrao urogallus*). Bird Hormones And Bird Migrations: Analyzing Hormones In Droppings And Egg Yolks And Assessing Adaptations In Long-Distance Migration. pp. 96–108.
17. Wasser SK, Bevis K, King G, Hanson E (1997) Noninvasive Physiological Measures of Disturbance in the Northern Spotted Owl. Conservation Biology 11: 1019–1022.
18. Millspaugh JJ, Washburn BE (2004) Use of fecal glucocorticoid metabolite measures in conservation biology research: considerations for application and interpretation. General and Comparative Endocrinology 138: 189–199.

19. Lucas JR, Freeberg TM, Egbert J, Schwabl H (2006) Fecal corticosterone, body mass, and caching rates of Carolina chickadees (*Poecile carolinensis*) from disturbed and undisturbed sites. Hormones and Behavior 49: 634–643.
20. Wingfield JC (2005) The concept of allostasis: coping with a capricious environment. Journal of Mammalogy 86: 248–254.
21. McEwen BS, Wingfield JC (2003) The concept of allostasis in biology and biomedicine. Hormones and Behavior 43: 2–15.
22. Sapolsky RM, Romero LM, Munck AU (2000) How do glucocorticoids influence stress responses? Integrating permissive, suppressive, stimulatory and preparative actions. Endocrine Reviews 21: 55–89.
23. Wingfield JC, Sapolsky RM (2003) Reproduction and resistance to stress: when and how. J Neuroendocrinol 15: 711–724.
24. Opplinger A, Clobert J, Lecomte J, Lorenzon P, Boudjemadi K, et al. (1998) Environmental stress increases the prevalence and intensity of blood parasite infection in the common lizard Lacerta vivipara. Ecology Letters 1: 129–138.
25. Alario P, Gamallo A, Beato MJ, Trancho G (1987) Body weight gain, food intake and adrenal development in chronic noise stressed rats. Physiology & Behavior 40: 29–32.
26. Barrett AM, Stockham MA (1963) The effect of housing conditions and simple experimental procedures upon the corticosterone level in the plasma of rats. Journal of Endocrinology 26: 97–105.
27. Davis M, Walker DL, Lee Y (1997) Amygdala and bed nucleus of the stria terminalis: differential roles in fear and anxiety measured with the acoustic startle reflex. Philosophical Transactions of the Royal Society of London, B 352: 1675–1687.
28. Atkinson H, Wood S, Kershaw Y, Bate E, Lightman S (2006) Diurnal Variation in the Responsiveness of the Hypothalamic-Pituitary-Adrenal Axis of the Male Rat to Noise Stress. Journal of neuroendocrinology 18: 526–533.
29. Thiel D, Jenni-Eiermann S, Palme R, Jenni L (2011) Winter tourism increases stress hormone levels in the Capercaillie *Tetrao urogallus*. Ibis 153: 122–133.
30. Delaney DK, Grubb TG, Beier P, Pater LL, Reiser MH (1999) Effects of helicopter noise on Mexican spotted owls. Journal of Wildlife Mangement 63: 60–76.
31. Tempel DJ, Gutiérrez RJ (2003) Fecal Corticosterone Levels in California Spotted Owls Exposed to Low-Intensity Chainsaw Sound. Wildlife Society Bulletin 31: 698–702.
32. Babisch W (2003) Stress hormones in the research on cardiovascular effects of noise. Noise Health 5: 1–11.
33. Ising H, Ising M (2002) Chronic cortisol increases in the first half of the night caused by road traffic noise. Noise Health 4: 13–21.
34. Evans GW, Lercher P, Meis M, Ising H, Kofler WW (2001) Community noise exposure and stress in children. Journal Of The Acoustical Society Of America 109: 1023–1027.
35. Evans GW, Bullinger M, Hygge S (1998) Chronic Noise Exposure and Physiological Response: A Prospective Study of Children Living under Environmental Stress. Psychological Science 9: 75–77.
36. Department of the Interior (2010) Endangered and Threatened Wildlife and Plants; 12-Month Findings for Petitions to List the Greater Sage-Grouse (*Centrocercus urophasianus*) as Threatened or Endangered. Federal Register 75: 13910–14014.
37. Connelly JW, Knick ST, Schroeder MA, Stiver SJ (2004) Conservation Assessment of Greater Sage-grouse and Sagebrush Habitats. Cheyenne, WY: West. Assn. Fish and Wildlife Agencies. 610 p.
38. Holloran MJ (2005) Greater Sage-Grouse (*Centrocercuc urophasianus*) Population Response to Natural Gas Field Development in Western Wyoming [Dissertation]. Laramie: University of Wyoming. 114 p.
39. Walker BL, Naugle DE, Doherty KE (2007) Greater Sage-Grouse Population Response to Energy Development and Habitat Loss. Journal of Wildlife Management 71: 2644–2654.
40. Holloran M, Kaiser R, Hubert W (2010) Yearling greater sage-grouse response to energy development in Wyoming. Journal of Wildlife Management 74: 65–72.
41. Naugle DE, Doherty KE, Walker BE, Holloran MJ, Copeland HJ (2011) Energy development and Greater Sage-Grouse. In: Knick ST, Connelly JW, editors. Greater Sage-Grouse: ecology and conservation of a landscape species and its habitats. Berkeley, CA.: University of California Press.
42. Blickley JL, Patricelli GL (2012) Potential acoustic masking of greater sage-grouse display components by chronic industrial noise. Ornithological Monographs 74: 23–35.
43. Blickley JL, Blackwood D, Patricelli GL (2012) Experimental Evidence for the Effects of Chronic Anthropogenic Noise on Abundance of Greater Sage-Grouse at Leks. Conservation Biology 26: 461–471.
44. Vehrencamp S, Bradbury J, Gibson R (1989) The energetic cost of display in male sage grouse. Animal Behaviour 38: 885–896.
45. Jankowski MD (2007) The influence of habitat disturbance and synergized resmethrin on avian immunocompetence: The University of Wisconsin, Madison.
46. Jankowski MD, Wittwer DJ, Heisey DM, Franson JC, Hofmeister EK (2009) The Adrenocortical Response of Greater Sage Grouse (*Centrocercus urophasianus*) to Capture, ACTH Injection, and Confinement, as Measured in Fecal Samples. Physiological and Biochemical Zoology 82: 190–201.
47. Wasser SK, Hunt KE, Brown JL, Cooper K, Crockett CM, et al. (2000) A Generalized Fecal Glucocorticoid Assay for Use in a Diverse Array of Nondomestic Mammalian and Avian Species. General and Comparative Endocrinology 120: 260–275.
48. Burnham KP, Anderson DR (2002) Model selection and multimodel inference: a practical information-theoretic approach: Springer Verlag.
49. Weiss JM (1970) Somatic Effects of Predictable and Unpredictable Shock. Psychosomatic Medicine 32: 397–408.
50. Wingfield JC, Maney DL, Breuner CW, Jacobs JD, Sharon L, et al. (1998) Ecological Bases of Hormone-Behavior Interactions: The "Emergency Life History Stage". American Zoologist 38: 191–206.
51. Goymann W, Wingfield JC (2004) Allostatic load, social status and stress hormones: the costs of social status matter. Animal Behaviour 67: 591–602.
52. Angelier F, Shaffer SA, Weimerskirch H, Chastel O (2006) Effect of age, breeding experience and senescence on corticosterone and prolactin levels in a long-lived seabird: The wandering albatross. General and Comparative Endocrinology 149: 1–9.
53. Angelier F, Moe B, Weimerskirch H, Chastel O (2007) Age-specific reproductive success in a long-lived bird: do older parents resist stress better? Journal of Animal Ecology 76: 1181–1191.
54. Schwabl H (1999) Developmental Changes and Among-Sibling Variation of Corticosterone Levels in an Altricial Avian Species. General and Comparative Endocrinology 116: 403–408.
55. Wada H, Hahn TP, Breuner CW (2007) Development of stress reactivity in white-crowned sparrow nestlings: Total corticosterone response increases with age, while free corticosterone response remains low. General and Comparative Endocrinology 150: 405–413.
56. Freeman BM (1982) Stress non-responsiveness in the newly-hatched fowl. Comparative Biochemistry and Physiology Part A: Physiology 72: 251–253.
57. Dickens MJ, Romero LM (2010) Stress Responsiveness Decreases With Age in Precocial, Juvenile Chukar. The Wilson Journal of Ornithology 122: 762–766.
58. Rubenstein DR (2007) Stress hormones and sociality: integrating social and environmental stressors. Proceedings of the Royal Society B: Biological Sciences 274: 967–975.
59. Brumm H, Slabbekoorn H (2005) Acoustic Communication in Noise. Advances in the Study of Behavior 35: 151–209.
60. Mockford EJ, Marshall RC (2009) Effects of urban noise on song and response behaviour in great tits. Proceedings of the Royal Society B: Biological Sciences 276: 2979–2985.
61. Swaddle JP, Page LC (2007) High levels of environmental noise erode pair preferences in zebra finches: implications for noise pollution. Animal Behaviour 74: 363–368.
62. Rabin LA, Coss RG, Owings DH (2006) The effects of wind turbines on antipredator behavior in California ground squirrels (Spermophilus beecheyi). Biological Conservation 131: 410–420.
63. Quinn L, Whittingham J, Butler J, Cresswell W (2006) Noise, predation risk compensation and vigilance in the chaffinch Fringilla coelebs. Journal of Avian Biology 37: 601–608.
64. Dooling RJ, Popper AN (2007) The Effects of Highway Noise on Birds. Sacramento, CA: The California Department of Transportation Division of Environmental Analysis. 74 p.
65. Bonier F, Martin PR, Moore IT, Wingfield JC (2009) Do baseline glucocorticoids predict fitness? Trends in Ecology & Evolution 24: 634–642.
66. Jankowski MD, Franson JC, Möstl E, Porter WP, Hofmeister EK (2010) Testing independent and interactive effects of corticosterone and synergized resmethrin on the immune response to West Nile virus in chickens. Toxicology 269: 81–88.
67. Naugle DE, Aldridge CL, Walker BL, Cornish TE, Moynahan BJ, et al. (2004) West Nile virus: Pending crisis for Greater Sage-Grouse. Ecology Letters 7: 704–713.
68. Walker BE, Naugle DE (2011) West Nile Virus ecology in sagebrush habitat and impacts on Greater Sage-Grouse populations. In: Knick ST, Connelly JW, editors. Greater Sage-Grouse: ecology and conservation of a landscape species and its habitats. Berkeley, CA.: University of California Press.
69. Sheriff MJ, Wheeler H, Donker SA, Krebs CJ, Palme R, et al. (2012) Mountain-top and valley-bottom experiences: the stress axis as an integrator of environmental variability in arctic ground squirrel populations. Journal of Zoology 287: 65–75.
70. Kuitunen M, Rossi E, Stenroos A (1998) Do Highways Influence Density of Land Birds? Environmental Management 22: 297–302.
71. van der Zande AN, ter Keurs WJ, van der Weijden WJ (1980) The impact of roads on the densities of four bird species in an open field habitat–evidence of a long-distance effect. Biological Conservation 18: 299–321.
72. Rheindt FE (2003) The impact of roads on birds: Does song frequency play a role in determining susceptibility to noise pollution? J für Ornithologie 144: 295–306.
73. Ingelfinger F, Anderson S (2004) Passerine response to roads associated with natural gas extraction in a sagebrush steppe habitat. Western North American Naturalist 64: 385–395.
74. Peris SJ, Pescador M (2004) Effects of traffic noise on paserine populations in Mediterranean wooded pastures. Applied Acoustics 65: 357–366.
75. Singer FJ (1978) Behavior of Mountain Goats in Relation to US Highway 2, Glacier National Park, Montana. The Journal of Wildlife Management 42: 591–597.
76. Rost GR, Bailey JA (1979) Distribution of Mule Deer and Elk in Relation to Roads. The Journal of Wildlife Management 43: 634–641.
77. Forman RTT, Deblinger RD (2000) The Ecological Road-Effect Zone of a Massachusetts (U. S. A.) Suburban Highway. Conservation Biology 14: 36–46.
78. Sawyer H, Kauffman M, Nielson R (2009) Influence of well pad activity on winter habitat selection patterns of mule deer. Journal of Wildlife Management 73: 1052–1061.

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Effects of Power Lines on Habitat Use and Demography of Greater Sage-Grouse (*Centrocercus urophasianus*)

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ABSTRACT Energy development and its associated infrastructure, including power lines, may influence wildlife population dynamics through effects on survival, reproduction, and movements of individuals. These infrastructure impacts may be direct or indirect, the former occurring when development acts directly as an agent of mortality (e.g., collision) and the latter when impacts occur as a by-product of other processes that are altered by infrastructure presence. Functional or numerical responses by predators to power-line corridors are indirect impacts that may suppress demographic rates for certain species, and perceived predation risk may affect animal behaviors such as habitat selection. Greater sage-grouse (*Centrocercus urophasianus*) are a species of conservation concern across western North America that may be affected by power lines. Previous studies, however, have not provided evidence for causal mechanisms influencing demographic rates. Our primary objective was to assess the influence of power lines on multiple sage-grouse vital rates, greater sage-grouse habitat selection, and ultimately greater sage-grouse population dynamics. We used demographic and behavioral data for greater sage-grouse collected from 2003 to 2012 in central Nevada, USA, accounting for sources of underlying environmental heterogeneity. We also concurrently monitored populations of common ravens (*Corvus corax*), a primary predator of sage-grouse nests and young. We focused primarily on a single 345 kV transmission line that was constructed at the beginning of our study; however, we also determined if similar patterns were associated with other nearby, preexisting power lines. We found that numerous behaviors (e.g., nest-site selection, brood-site selection) and demographic rates (e.g., nest survival, recruitment, and population growth) were affected by power lines, and that these negative effects were predominantly explained by temporal variation in the relative abundance of common ravens. Specifically, in years of high common raven abundance, avoidance of the transmission line was extended farther from the line, re-nesting propensity was reduced, and nest survival was lower near the transmission line relative to areas more distant from the transmission line. Additionally, we found that before and immediately after construction of the transmission line, habitats near the footprint of the transmission line were generally more productive (e.g., greater reproductive success and population growth) than areas farther from the transmission line. However, multiple demographic rates (i.e., pre-fledging chick survival, annual male survival, *per capita* recruitment, and population growth) for groups of individuals that used habitats near the transmission line declined to a greater extent than for individuals using habitats more distant in the years following construction of the transmission line. These decreases were correlated with an increase in common raven abundance. The geographical extent to which power lines negatively influence greater sage-grouse demographic processes was thus contingent on local raven abundance and behavior. In this system, we found that effects of power lines, depending on the behavior or demographic rate, extended 2.5–12.5 km, which exceeds current recommendations for the placement of structures in areas around sage-grouse leks. Nests located 12.5 km from the transmission line had 0.06 to 0.14 higher probabilities of hatching in years of average to high levels of raven abundance, relative to nests located within 1 km of the transmission line. Similarly, leks located 5 km from the transmission line had 0.02 to 0.16 higher rates of population growth (λ) in years of average to high levels of raven abundance, relative to leks located within 1 km of the transmission line. Our finding that negative impacts of the transmission line were associated with common raven abundance suggest that management actions that decouple this association between common raven abundance and power lines may reduce the negative indirect impacts of power lines on greater sage-grouse population dynamics. However, because the removal of common ravens or the use of perch deterrents on power lines has not been demonstrated to be consistently effective in

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reducing common raven predation rates on greater sage-grouse nests, we recommend preferential treatment to mitigation strategies that reduce the number of elevated structures placed within 10 km of critical greater sage-grouse habitat.

KEY WORDS anthropogenic disturbances, *Centrocercus urophasianus*, common ravens, *Corvus corax*, demographic rates, elevated structures, environmental heterogeneity, habitat selection, indirect anthropogenic effects, population dynamics, power lines, sage-grouse, transmission lines.

Efectos de Líneas Eléctricas en el Uso de Hábitat y la Demografía del Gallo de Salvia (*Centrocercus urophasianus*)

RESUMEN El desarrollo de energías, así como de su infraestructura asociada (incluyendo líneas eléctricas) puede afectar la dinámica poblacional de la vida silvestre debido a sus efectos en supervivencia, reproducción y movimiento. Estos efectos causados por la infraestructura pueden ser directos, o indirectos, los primeros, cuando la infraestructura actúa como un agente o causa de mortalidad (e.g., colisiones), y la segunda, cuando los efectos ocurren derivados de procesos que son alterados por la presencia de infraestructura. Respuestas funcionales o numéricas por depredadores a corredores de líneas eléctricas son considerados impactos indirectos que pueden reducir las tasas demográficas de ciertas especies. La percepción del riesgo de depredación puede afectar conductas tales como la selección de hábitat. El Gallo de Salvia (*Centrocercus urophasianus*) es una especie de preocupación para la conservación en el oeste de Norteamérica, que puede ser afectada por líneas eléctricas. Sin embargo, estudios previos no han proporcionada evidencia de los mecanismos causales que influencian las tasas demográficas. Utilizamos datos demográficos y conductuales del gallo de salvia recogidos del 2003 al 2012 en la zona centro de Nevada, USA, contemplando fuentes de heterogeneidad ambiental subyacente. Concurrentemente, monitoreamos poblaciones del cuervo común (*Corvus corax*), un depredador primario de nidos y jóvenes del gallo de salvia. Nos enfocamos principalmente en una línea de transmisión de 345kV que fue construida al inicio del estudio; sin embargo, también exploramos si patrones similares estaban asociados con otras líneas eléctricas cercanas. Encontramos que numerosas conductas (e.g., selección del sitio de anidación, y selección del sitio de crianza) y tasas demográficas (e.g., supervivencia del nido, reclutamiento, y crecimiento poblacional) fueron afectados por líneas eléctricas, y que estos efectos negativos fueron explicados predominantemente por variaciones temporales en la abundancia relativa del cuervo común. Específicamente, en años de alta abundancia del cuervo común, se incrementó la conducta de evitar las líneas eléctricas, la propensión a repetir un sitio de anidación se redujo, y la supervivencia en el nido se redujo en zonas cercanas a líneas eléctricas. Adicionalmente, encontramos que antes, e inmediatamente después de la construcción de la línea eléctrica, hábitats cercanos a la huella de la línea eléctricas fueron generalmente más productivos (e.g., mayor éxito reproductivo y crecimiento poblacional) en comparación con áreas alejadas de la línea de alta tensión. Sin embargo, múltiples tasas demográficas (e.g., supervivencia de juveniles, supervivencia anual de los machos, reclutamiento per cápita, y crecimiento poblacional) disminuyeron en mayor grado para grupos de individuos que utilizaron hábitats cercanos a las líneas de transmisión que para individuos que utilizaron hábitats más lejanos a las líneas de transmisión. Estas disminuciones estuvieron correlacionadas con un incremento en la abundancia del cuervo común. La extensión geográfica en que las líneas eléctricas tuvieron una influencia negativa en los procesos demográficos del gallo de salvia estuvo condicionada a la abundancia y conducta del cuervo común. En este sistema, encontramos que los efectos de las líneas eléctricas, dependiendo de la conducta o tasa demográfica, se extendieron 2.5–12.5 km, lo cual excede recomendaciones actuales para la colocación de estructuras en áreas alrededor de leks del gallo de salvia. Nidos encontrados a 12.5 km de la línea de transmisión tuvieron una probabilidad de eclosión en años de alta abundancia 0.06 a 0.14 mayor que nidos localizados a 1 km de la línea de transmisión. De manera similar, leks localizados a 5 km de la línea de transmisión, en años de alta abundancia de cuervos, tuvieron tasas de crecimiento poblacional (λ) 0.02 a 0.16 mayores que leks localizados a 1 km de la línea de transmisión. Nuestro descubrimiento de que los impactos negativos de las líneas de transmisión estaban asociados con la abundancia de cuervos, sugieren que las acciones de manejo que separen ésta asociación entre la abundancia del cuervo común y las líneas de transmisión pueden reducir los impactos negativos de las líneas eléctricas sobre la dinámica poblacional del gallo de salvia. Sin embargo, debido a que no se ha demostrado consistentemente la efectividad de la remoción de cuervos o el uso de disuasivos de percha de aves en las líneas de transmisión en la reducción de la depredación por cuervos en el gallo de salvia, recomendamos un tratamiento preferencial a las estrategias de mitigación que reduzcan el número de estructuras elevadas colocadas en un radio de 10 km de hábitat crítico del gallo de salvia.

Les effets des lignes électriques sur l'utilisation de l'habitat et la démographie des tétras des armoises (*Centrocercus urophasianus*)

RÉSUMÉ Le développement énergétique et les infrastructures associées, dont les lignes électriques, peuvent influencer les dynamiques de la vie sauvage par des effets sur la survie, la reproduction et les mouvements des individus. Ces impacts des infrastructures peuvent être directs ou indirects, ce premier ayant lieu quand le développement agit directement comme agent de mortalité (par exemple par collisions) et ce dernier quand les impacts sont le produit secondaire de l'altération d'autres processus par la présence d'infrastructures. Les réponses fonctionnelles et numériques des prédateurs aux couloirs de lignes électriques sont des impacts indirects qui pourraient écraser les taux démographiques pour certaines espèces. Aussi, perception d'un risque de prédation pourrait affecter certains comportements animaux comme la sélection d'habitat. Le tétras des armoises (*Centrocercus urophasianus*) est une espèce dont la conservation est préoccupante à travers l'Amérique du Nord-Ouest et qui pourrait être affectée par les lignes électriques. Cependant, les études passées n'ont pas fourni de preuves d'un mécanisme de cause à effet influençant les taux démographiques. Notre objectif premier a été d'évaluer l'influence des lignes électriques sur de multiples indices vitaux, sur la sélection d'habitat et enfin sur la dynamique de population du tétras des armoises. Nous avons utilisé des données démographiques et comportementales pour le tétras des armoises collectées de 2003 à 2012 dans le Nevada central, aux Etats-Unis, tenant compte des sources sous-jacentes d'hétérogénéité environnementale. Nous suivons aussi actuellement les populations de grands corbeaux (*Corvus corax*), le premier prédateur des nids et des petits. Nous nous sommes concentrés principalement sur une ligne de transmission à 345kV qui a été construite au début de notre étude. Cependant, nous avons déterminé si des tendances similaires étaient associées à d'autres lignes préexistantes voisines. Nous avons trouvé que nombre de comportements (par exemple la sélection du site de nidification et la sélection du site de couvée) et de taux démographiques (par exemple le succès de nidification, le recrutement et la croissance démographique) étaient affectés par les lignes électriques et que ces effets négatifs étaient principalement expliqués par la variation temporelle de l'abondance relative du grand corbeau. Plus spécifiquement, les années de forte abondance de grands corbeaux, l'évitement des lignes électriques s'étendait au-delà de la ligne et la propension de retour pour la nidification diminuait et la survie des nids était plus faible au voisinage de la ligne que dans les zones plus distantes de celle-ci. De plus, nous avons trouvé qu'avant et immédiatement après la construction de la ligne électrique, les habitats au voisinage de la trace de la ligne étaient généralement plus productifs (par exemple présentant un meilleur succès reproductif et une meilleure croissance démographique) que les zones plus loin de la ligne électrique. Cependant, de multiples taux démographiques (i.e., la survie des jeunes avant leur départ du nid, la survie annuelle des mâles, le recrutement par individu, et la croissance démographique) pour des groupes d'individus qui utilisaient les habitats proches de la ligne électrique ont diminué de façon plus importante que pour les individus utilisant des habitats plus distants dans les années qui suivirent la construction de la ligne de transmission. Ces diminutions ont été corrélées à une augmentation importante de l'abondance des grands corbeaux. L'étendue géographique sur laquelle les lignes électriques influencent négativement les processus démographiques des tétras des armoises était contingente avec l'abondance locale des grands corbeaux et leur comportement. Dans ce système, nous avons trouvé que les effets des lignes électriques, dépendant du comportement et du taux démographique, s'étendait sur 2.5 à 12.5 km, ce qui surpasse les recommandations actuelles pour le placement des structures dans des zones avoisinant des aires de parades de tétras des armoises. Des nids à 12.5 km des lignes électriques avaient une probabilité d'éclosion plus haute de 0.06 à 0.14 dans des années à haute abondance moyenne de grands corbeaux, comparé à des nids situés dans une zone de 1km autour de la ligne électrique. De façon similaire, les aires de parade situées à 5km de la ligne de transmission avaient un taux de croissance démographique (λ) plus élevé de 0.02 à 0.16 pour les années à haute abondance de corbeaux, relativement aux aires de parade situés dans une zone de 1km de la ligne électrique. Notre résultat indiquant l'effet négatif des lignes électriques était associé avec l'abondance de grands corbeaux suggère que les décisions de gestion qui dissocie cette association entre abondance de grands corbeaux et lignes électriques pourraient réduire l'impact négatifs indirect des lignes électriques sur la dynamique de populations du tétras des armoises. Cependant, comme le retrait des grands corbeaux proches des lignes, et l'utilisation de dispositifs anti-perchoir sur les lignes électriques n'ont pas montré d'efficacité constante pour la réduction du taux de prédation des nids de tétras des armoises, nous recommandons un traitement préférentiel pour des stratégies d'atténuation qui réduiraient le nombre de structures élevées placées dans les 10 km des habitats critiques du tétras des armoises.

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INTRODUCTION

Energy infrastructure has been associated with altering wildlife population dynamics by influencing survival, reproduction, and habitat use of individuals, exacerbating habitat fragmentation, and increasing spread of invasive species (Naugle et al. 2011*a*, Northrup and Wittemyer 2013). As of 2011, there were approximately 100,000 km of transmission lines in western North America (Copeland et al. 2011). Overhead power lines can negatively influence wildlife populations directly through the loss of habitat (i.e., the physical footprint of power-line towers and line rights of way; Jones et al. 2015) or increased mortality (e.g., bird collisions with guy wires, towers, or lines; Bevanger 1998; Janss 2000; Bevanger and Broseth 2001, 2004; Loss et al. 2014). Power-line towers, however, also may enhance habitat for avian predators by creating nesting (Steenhof et al. 1993, Howe et al. 2014) and perching habitat (Coates et al. 2014*b*). Although less studied, power lines are hypothesized to indirectly affect habitat use through avoidance behaviors beyond the physical footprint of the structure, potentially related to the increased presence of electromagnetic fields (Balmori and Hallberg 2007), avoidance of elevated structures, or increased harassment by predators associated with elevated structures (Pruett et al. 2009, Silva et al. 2010).

Power lines may indirectly suppress various vital rates such as nest success (DeGregorio et al. 2014) and adult survival (Hovick et al. 2014) for certain species because of increased predator abundance or changes in predator foraging behavior (Plumpton and Andersen 1997) near power-line corridors. The overall impact of power lines on wildlife populations may be influenced by surrounding environmental characteristics. For example, transmission lines may have a greater effect in open areas (e.g., shrublands or grasslands) relative to woodlands because of differences in flight behavior (Rollan et al. 2010), power-line visibility (Benitez-Lopez et al. 2010), or changes in local predator densities (Howe et al. 2014).

Placement of power lines within landscapes is typically not random because location of power lines is influenced by local topography and geology (Vajjhala and Fischbeck 2007). In the absence of conservation constraints, power-line corridors are typically placed along least-cost routes, which usually minimize variation in slope and elevation (Bagli et al. 2011). This non-random distribution of power lines across a landscape results in covariance between proximity to, or density of, power lines and other environmental features (e.g., elevation, slope, hydrology) that may influence the structure of surrounding habitat, thereby complicating assessment of impacts of power lines themselves. For example, changes in demographic rates in proximity to a power line could result from a gradient in habitat quality that occurs along an elevational gradient, rather than an impact of the line itself.

Greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse) are of conservation concern and have been negatively influenced by anthropogenic disturbances, including energy development and its supporting infrastructure (Naugle et al. 2011*b*, Hovick et al. 2014). As such, it is important to understand the anthropogenic drivers of sage-grouse population change to make informed management decisions. Sage-grouse are endemic to sagebrush (*Artemisia* spp.) ecosystems of western North America (Connelly et al. 2011), which are characterized by large expanses of woody shrubs, with trees occurring in either low densities or localized patches. In these systems, anthropogenic structures including power lines can provide novel perches or nest sites for avian predators of sage-grouse that are otherwise unavailable in the local landscape (Steenhof et al. 1993, Howe et al. 2014, Coates et al. 2014*b*). Furthermore, an analysis conducted by Knick et al. (2011) found that power lines covered a minimum of 1,089 km^2 and had an ecological influence on almost 50% of sagebrush landscapes within the range of greater sage-grouse.

Power lines have the potential to directly (e.g., collisions) and indirectly (e.g., behavior, predator-prey dynamics) affect bird species (Smith and Dwyer 2016). Although sage-grouse, like other Galliformes, are susceptible to fatal collisions with power lines (Borell 1939, Bevanger 1998, Bevanger and Broseth 2004), numerous telemetry-based studies (Connelly et al. 2000, Beck et al. 2006, Blomberg et al. 2013*a*, Dinkins et al. 2014*b*) have reported low numbers of bird strikes by radio-marked individuals, which suggests this direct source of mortality is unlikely to be important at the population level, except in unusual circumstances. Site-specific mortality due to collisions may be appreciable, however, if elevated structures are placed perpendicular to a corridor of high periodic sage-grouse use (Stevens et al. 2011). Conversely, indirect effects of elevated structures, such as avoidance of habitat near lines (Doherty et al. 2008, Dinkins et al. 2014*b*), or lower vital rates due to increased predation (Ellis 1984, Bui et al. 2010), may be important at the population level. Sage-grouse and other grouse species appear to avoid habitat near elevated structures, which are primarily other types of energy infrastructure (Doherty et al. 2008, Silva et al. 2010, Hovick et al. 2014, LeBeau et al. 2014). Authors have speculated that the perceived threat of predation associated with power lines may explain this potential avoidance of otherwise suitable habitat (Braun 1998, Holloran et al. 2015).

Common ravens (*Corvus corax*; hereafter, ravens) are important predators of sage-grouse nests and chicks throughout the western portion of the species' range (Coates et al. 2008, Hagen 2011, Lockyer et al. 2013). Raven populations have steadily increased across western North America over the last 50 years, and are associated with increases in anthropogenic subsidies (Bui et al. 2010, Webb et al. 2011). Power poles and other elevated structures have increased availability of nesting substrate for ravens in shrublands and grasslands where nest sites are otherwise not typically abundant (Steenhof et al. 1993, Howe et al. 2014). Consequently, raven and other corvid densities are higher near elevated structures compared to the surrounding landscape (Knight and Kawashima 1993, Coates et al. 2014*b*, Cunningham et al. 2015, Harju et al. 2018). Ravens can have a substantial impact on prey population dynamics even at low densities (Brussee and Coates 2018). For example, Coates and Delehanty (2010) found that an increase of 1 raven per 10-km transect was associated with a 7.4% increase in the odds of sage-grouse nest failure. Therefore, we expect that effects of power lines on sage-grouse habitat use or reproductive success could depend on raven abundance associated with power lines.

Relatively few published studies have addressed the effects of power lines on sage-grouse (e.g., Johnson et al. 2011, Dinkins et al. 2014*a*) in contrast to the widely studied impacts of oil and gas development (e.g., Walker et al. 2007, Doherty et al. 2008, Holloran et al. 2010, Naugle et al. 2011*a*, Fedy et al. 2015, Holloran et al. 2015). Effects of oil and gas development cannot be extrapolated to those of power lines because the former is often associated with substantial human activity and noise (Blickley et al. 2012) and the scope of infrastructure differs between these forms of disturbance (Copeland et al. 2011). Although some studies have reported negative effects of elevated structures on individual vital rates (e.g., adult survival, nest success, brood survival; LeBeau et al. 2014, Dinkins et al. 2014*a*) or population connectivity (Shirk et al. 2015), these studies have not provided an inclusive evaluation of the complex linkages among power lines, predator abundance and behavior, and sage-grouse ecology (Hagen et al. 2011). Additionally, most studies are based on data over a relatively short time-series (<5 yr), which reduces the power to separate actual impacts from year-to-year fluctuations (McCain et al. 2016). Furthermore, large-scale patterns in population dynamics in relation to power lines are not consistent (Johnson et al. 2011, Wisdom et al. 2011), which may be related in part to regional variation in the quantity and quality of available sage-grouse habitat.

The relative lack of evidence for negative effects of power lines on vital rates may be related to reduced statistical power owing to low numbers of individuals using habitat near power lines (Kirol et al. 2015), given that avoidance is the most consistently reported effect. Thus, the absolute cost of power lines (i.e., functional habitat lost; Aldridge and Boyce 2007) is influenced in part by the extent of avoidance by sage-grouse. Interpreting previously reported patterns in habitat use or reproductive success related to power lines is further complicated by the fact that earlier studies did not control for potential confounding habitat effects. Therefore, we cannot be certain that negative effects of power lines are not an artifact of an association between location of power lines and other characteristics that affect habitat quality.

Our primary objective was to assess the influence of power lines on sage-grouse habitat selection and demographic rates during multiple life phases, and ultimately their population dynamics, after accounting for other sources of environmental heterogeneity. Our assessment of the impacts of power lines on sage-grouse behavior and demography builds on a series of published works focused on understanding the influence of the environment on sage-grouse life-history characteristics (e.g., Atamian et al. 2010; Blomberg et al. 2012, 2013*c*, 2014, 2017; Gibson et al. 2014, 2016, 2017). We used 10 years of data on sage-grouse behavior and population dynamics associated with construction of a 345-kV transmission line in central Nevada in our assessment. Our approach to determine the impacts of power lines by revisiting these previously published works improved the inferential strength of this manuscript because each dataset and analysis was independently peer-reviewed, allowing for substantial feedback from the greater scientific community. We could use peer-reviewed models of the relationships between demographic rates and environmental covariates to control for these effects when we assessed power-line effects. As a result, we developed a more complete picture of the background ecological processes in this system with respect to sage-grouse population ecology. Equipped with this information, we could better address the influence of power lines on sage-grouse populations in this dynamic and often complex system.

Recent studies have proposed that impacts of power lines on grouse may occur through the association of avian predators with such lines (Doherty et al. 2008, LeBeau et al. 2014, Fedy et al. 2015, Holloran et al. 2015); therefore, we also evaluated the hypothesis that variation in sage-grouse behavior and demography was related to changes in raven or raptor abundance. We predicted that spatial or numerical associations between ravens and power lines would result in reduced use of adjacent habitat, lower reproductive success, and ultimately reduced population growth, in areas near power lines as the raven population increased. Similarly, we hypothesized that variation in sage-grouse survival and population growth would be negatively correlated with raptor abundance, and spatial associations between raptors and power lines would result in reduced survival and population growth in areas near power lines.

STUDY AREA

The study site was located in east-central Nevada within Eureka County (Fig. 1). The study area encompassed approximately 7,000 km^2 of sagebrush steppe and mountain ranges supporting pinyon-juniper woodlands. Within this system, sage-grouse occurred in habitat that varied in composition along an elevation gradient. At lower elevations (<2,000 m), the shrub community was dominated by Wyoming big sagebrush (*Artemisia tridentata wyomingensis*), with localized patches of black sagebrush (*A. nova*) and basin big sagebrush (*A. tridentata tridentata*). Rubber rabbitbrush (*Chrysothamnus nauseosus*), greasewood (*Sarcobatus vermiculatus*), and scattered Utah juniper (*Juniperus osteosperma*) also were relatively common. At higher elevations (>∼2,000 m), the dominant shrub community was a mixture of mountain big sagebrush (*A. tridentata vaseyana*) and low sagebrush (*A. arbuscula*), with some intermixed common snowberry (*Symphoricarpos albus*), western serviceberry (*Amelanchier alnifolia*), mountain mahogany (*Cercocarpus ledifolius*), and bitterbrush (*Purshia tridentata*). Large expanses of singleleaf pinyon (*Pinus monophylla*)-Utah juniper forest often occurred at mid-elevation sites between the low- and high-elevation sagebrush communities. Common annual and perennial forb taxa included phlox (*Phlox* spp.), lupine (*Lupinus* spp.), mustard (*Descurainia* spp.), and milkvetch (*Astragalus* spp.). Common grasses consisted of blue grass (*Poa* spp.), cheatgrass (*Bromus tectorum*), crested wheatgrass (*Agropyron cristatum*), Indian rice grass (*Achnatherum hymenoides*), and squirreltail (*Elymus elymoides*).

We define transmission lines as any overhead structure that is capable of transmitting voltages >69 kV (Hamilton and Schwann 1995), whereas overheard structures transmitting <69 kV were considered distribution lines. We use the term power line to refer to all elevated energy transmission structures (i.e., transmission and distribution lines) regardless of voltage.

In fall 2003, Sierra Pacific Power Company (now NV Energy) began construction of a 345-kV transmission line (hereafter FG transmission line) between the Falcon and Gondor substations located in White Pine and Lander Counties, respectively, in Nevada, USA. Construction of the FG transmission line was completed in spring of 2004, and the line was energized in May of that year. The completed FG transmission line was approximately 299 km long and consisted of 734 towers that varied in

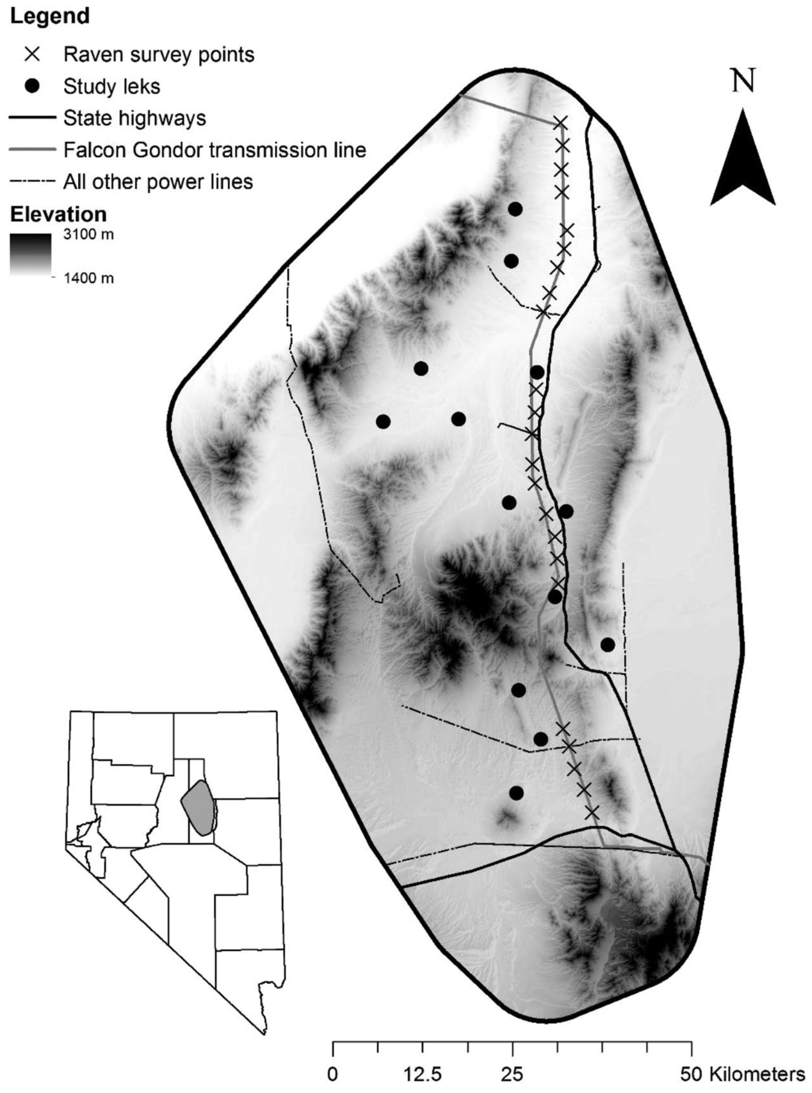

Figure 1. Map of the Falcon–Gondor (FG) transmission line (gray line), all other power lines (gray dashed lines), and state highways (black lines) occurring within the study system located primarily in Eureka County, Nevada, USA (see inset). Sage-grouse were primarily associated with one of 13 study leks (black circles). We monitored relative common raven and raptor abundance along a series of point transects (×) located along the FG transmission line corridor.

height (23–40 m), and design (2-pole H-frame or 3-pole guyed angle-transposition towers; Fig. 2), depending on topography and projection. Towers in areas of historical or active sage-grouse habitat, which included our study system, were fitted with experimental perch deterrents that were fixed on sections of towers where avian predators were most likely to perch. Deterrents consisted of 16-gauge steel in an inverted-Y design fit on horizontal tower arms, and steel plate deterrents fit on the tops of vertical tower arms and crossarms (Lammers and Collopy 2007).

We defined our study area as anything within a 10-km buffer surrounding the minimum convex-hull polygon that encompassed all female sage-grouse telemetry locations from 2003 to 2012 (Fig. 1). The study area included 134 km of the FG transmission line and focused primarily on individuals associated with 13 leks at various distances from the FG transmission line. Six study leks were within 5 km, 6 study leks were within 5–10 km, and 2 study leks were within 10–21 km of the FG transmission line. The most distant lek was 20.6 km from the FG transmission line.

The study area also included approximately 243 km of additional power lines, of which 42 km were associated with a second transmission line, and 201 km were either subtransmission or distribution lines. The other transmission line, which runs east-west through the southern portion of the study system, was substantially older (circa 1980) but of similar design and structure to the FG transmission line. Subtransmission and distribution lines were similarly older, and were typically 1- or 2-pole structures that facilitated transmission to mines, ranches, and residences. Eight study leks were within 5 km of any power line.

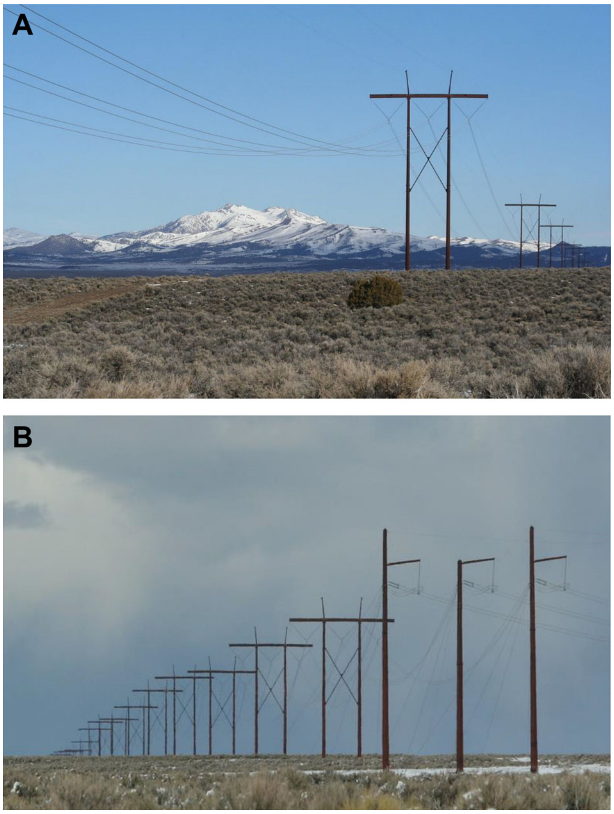

Figure 2. Representative images of towers within the Falcon–Gondor transmission line corridor depicting the A) 2-pole H-frame tower and B) 3-pole guyed angle-transposition tower design (foreground). The completed Falcon–Gondor transmission line was approximately 299 km long and consisted of 734 towers that varied in height (23–40 m), and design (2–3 pole) depending on topography and projection. Towers located in greater sage-grouse habitat in this system were fit with perch deterrents that were present but not easily visible in the figure above.

The study area included 2 major paved roads, which were both 2-lane state or federal highways that intersected in the southeast portion of the study area, and were a combined 162 km in length. Four study leks were within 5 km of a highway. There were an additional 430 km of maintained gravel or dirt roads, and 3,500 km of unmaintained single-lane dirt access roads (2-tracks). All study leks were within 5 km of a maintained or unmaintained road. In this system, each transmission line corridor ran parallel (although not always immediately adjacent to) one of the 2 previously established highways, creating spatial correlation between highways and transmission lines.

Mineral extraction (primarily gold mining) is common throughout northern Nevada. Approximately 46,000 ha (~6.6%) of the study system was currently, or had recently been, within the physical footprint of mining activities (C. B. Van Dellen, Nevada Department of Wildlife, unpublished data). The level of disturbance associated with mining is spatially heterogeneous, and ranges from complete loss of functional habitat (e.g., creation of open pit mines) to minor disturbances (e.g., increased noise; Blickley et al. 2012). We did not quantify the percentage of the study area that was composed of actual surface disturbance versus less-intrusive activities such as prospecting, or previously mined areas with no current activity. Additionally, the area associated with mining was not completely additive to other potential disturbances because the acreage associated with mining typically included roads, power lines, or recent wildfire.

Wildfires disturbed approximately 85,000 ha (~12.1%) of our study system since 1999, with 90% of this disturbance occurring before the onset of this study. Burned areas were primarily colonized by exotic grasses, predominantly cheatgrass, but were also planted with crested wheatgrass. Exotic grasslands typically suppress establishment of native vegetation (Miller et al. 2011), and are negatively associated with sage-grouse population trajectories (Blomberg et al. 2012, Coates et al. 2016).

The majority (88%; ~619,000 ha) of the study system was under the jurisdiction and management of the Bureau of Land Management (BLM). Livestock grazing (primarily cattle and to a lesser extent sheep) was prevalent on BLM-managed lands. Of the ~82,500 ha of study system under private ownership, approximately 10,500 ha (1.5% of total study area) had been converted to cropland, primarily irrigated fields planted with alfalfa or non-native grass hay. These areas were generally located in the southeastern portion of the study area. Alfalfa fields that were bordered by sagebrush were used by sage-grouse as early brood-rearing habitat, but radio-marked sage-grouse were never observed in the interior of fields (D. Gibson, Virginia Tech, unpublished data). The remaining private land holdings were primarily rangelands in a checkboard pattern intermixed with BLM land localized in the northern portion of the study system, or were associated with mesic, lower-elevation sites scattered throughout the system, often containing grazing operations and maintained through flood irrigation.

METHODS

Field Methods

We captured male and female sage-grouse at or near 10 to 13 leks during the mating season (Mar–May) from 2003 to 2012, and in seasonal high-elevation habitat during late summer and fall from 2005 to 2011. On average, we attempted to capture sage-grouse on or near each lek on 2 occasions per week throughout the mating season. Upon capture, birds were identified as male or female, classified as subadults (<1 yr) or adults (>1 yr) according to primary feather wear (Eng 1955), weighed, and measured (i.e., length of tenth primary, fifth primary, wing chord, tarsus, foot, and number of tail feathers). We banded each female with a size 14 aluminum band (National Band and Tag, Newport, KY, USA), and equipped most females with either a 22-g or 12-g radio with necklace-style attachment (A4060, A3950, Advanced Telemetry Systems, Isanti, MN, USA). Radios were equipped with a mortality sensor that doubled the signal pulse rate if the transmitter remained motionless for >8 hours. We banded each male with a size 16 aluminum band (National Band and Tag), and banded all adults and subadults that were large enough with a colored plastic tarsal band engraved with a unique 3-character alpha-numeric code for re-sighting during lek observations (described below). Individually marked male sage-grouse were re-encountered by recapture, re-sightings of tarsal bands during morning lek observations, or from images of tarsal bands recorded by trail cameras placed on leks (Gibson et al. 2013, 2014). Capture and handling of sage-grouse were approved by the University of Nevada Reno Institutional Animal Care and Use Committee (Protocol Numbers A02/03-22, A05/06-22, A07/08-22, A09/10-22).

We monitored 10 to 13 leks located within 20.6 km of the FG transmission line from 2003 to 2012. Lek activity began in late February and ceased in mid-May, with male lek attendance peaking during April, associated with high female attendance. We selected leks for study by evaluating previously collected data from the BLM and the Nevada Department of Wildlife (NDOW). Three leks were consistently monitored annually by NDOW and BLM for approximately 25 years before our study, which suggested that these populations have been declining since the early 1980s (population growth rate of 0.97; C. B. Van Dellen, Nevada Department of Wildlife, unpublished data), similar to population trends across the southern Great Basin (Garton et al. 2011, 2015).

We observed each study lek approximately once weekly during the mating season (Mar–May) from 2003 to 2012. Observers arrived on the leks a half hour before morning (nautical twilight), and remained until strutting activity ceased or birds dispersed. During these periods, observers monitored leks from trucks or mobile blinds with spotting scopes and binoculars. We occasionally included a mobile observation tower to facilitate band reading where terrain permitted and vegetation characteristics required it. Observers counted the number of males and females, marked and unmarked, on leks every 30 minutes during each observation period. Observers also recorded individual tarsal band codes (resights) and behavioral interactions with potential predators or ravens.

We located radio-marked females at least once but usually twice a week during the nesting season (end Mar–mid June) from 2003 to 2012 using a handheld receiver and Yagi antenna. Once we confirmed nesting, observers visited nests approximately twice a week until at least 1 egg hatched or the nest failed. Full nest monitoring protocols are described in Gibson et al. (2015). During 2005–2012, we continued to monitor females that successfully hatched a nest to assess brood status and habitat use. We assessed brood foraging habitat by locating brood-rearing females weekly during diurnal hours (i.e., 0700–1700), and recorded a global positioning system point near the brood's location (±10 m). We monitored each female's current brood status through weekly brood flush counts. We performed weekly flush counts until 42 days after hatch (hereafter, pre-fledging period) or after 2 weeks of consecutive counts of zero chicks, whichever occurred first. Our complete brood monitoring protocols are described in Gibson et al. (2017). After all radio-collared females had fledged young or failed, we continued to monitor survival of radio-marked females approximately once a month using aerial telemetry from fixed-wing aircraft.

We measured vegetation at each nest site and weekly diurnal brood locations. We measured nest vegetation at all monitored nest sites within 3 days of either the predicted or actual date of hatch. We sampled nest-site vegetation along 10-m intersecting transects centered at the nest bowl (Gregg et al. 1994) using the line-intercept (Canfield 1941) and Daubenmire (1959) frame methods. We used the line-intercept method to estimate total shrub cover, sagebrush shrub cover, and non-sagebrush shrub cover. We used Daubenmire frames ($n = 5$) placed along each transect to classify ground cover of grass, forbs, and total cover (grass, forb, and shrub). See Gibson et al. (2015) for detailed nest vegetation protocols. We also measured vegetation at each weekly diurnal brood location approximately 1 week after obtaining the location; these vegetation points were centered approximately (±5 m) where the brood had been located. Brood vegetation surveys followed the same protocols as nest vegetation surveys; however, from 2008 to 2012 we sampled brood vegetation surveys along 20-m intersecting transects (Gibson et al. 2017).

During March–May 2003–2012, we performed avian point counts that were spaced along 3 transects (hereafter referred to as south, central, and north) that paralleled the FG transmission line corridor (Fig. 1). The average distance between 2 points within a single transect was 3.36 km (SD = 0.70 km). The north and central transects had 9 points, and the south transect had 5 points. The nearest points in the central and north transects were 10.9 km apart, and the nearest points in the central and south transects were 20.2 km apart. Observers attempted to survey each transect once every 10 days from March to May. We alternated transect start times (between 1 hr after sunrise and at 1300), and survey start point (between northernmost and southernmost points of a transect). We did not conduct surveys if there was precipitation, fog, or if wind speeds exceeded 19 km/hr. Observers spent 10 minutes at each point, identified all observed raptor and corvid species, recorded number of individuals, and determined whether the observed individual was approximately within 400 m of the transmission line or beyond using a rangefinder to identify terrestrial landmarks.

Quantitative Methods

We estimated the following behavioral metrics or demographic rates from radio-telemetered female sage-grouse data: 1) nesting propensity; 2) re-nesting propensity; 3) nest-site selection; 4) nest survival; 5) brood-site selection; 6) pre-fledging chick survival; and 7) adult female survival. We estimated the following demographic rates from capture-mark-recapture data on male sage-grouse: 1) adult male survival; 2) male movements among leks; 3) *per capita* recruitment; and 4) lek-specific population growth rate. Lastly, we estimated whether ravens were spatially associated with the FG transmission line through occupancy models based on observed raven disturbance during lek surveys.

Approach to inference.—The underlying hypothesis for each analysis was that a particular behavior or demographic rate (e.g., nest-site selection, nest survival) was influenced by an individual's proximity to either the FG transmission line or any other power line. Environmental impact studies often employ a before-after control-impact (BACI; Green 1979) study design to account for potentially spurious correlations among various temporal or spatial variables and the potential disturbance (McNew et al. 2014, Winder et al. 2014). Although BACI study designs are ideal for disentangling variables that are spatially confounded (Green 1993), the pace at which disturbances occur, even those of anthropogenic origin, often precludes collecting sufficient data before development, thereby excluding BACI approaches. In such cases, collecting post-disturbance data sampled across sufficient spatial and temporal scales represent the only viable approach to assessing disturbance (Johnson et al. 2005). For our study, a BACI study design was not possible because the period between permitting and construction of the FG transmission line did not allow for adequate collection of pre-construction data. An additional design constraint was that other anthropogenic disturbances (e.g., highways, other transmission lines), and other natural environmental variation were associated with the location of power lines and were present before our study began. Therefore, our modeling approach had to account for potential correlations between an individual's distance from all power lines and other confounding sources of variation in behavior and demographic rates.

We developed a 2-stage approach for assessing impacts of power lines on sage-grouse habitat use and demography. First, we developed models that explained functional relationships among habitat characteristics (e.g., elevation, shrub cover), temporal processes (e.g., weather), and individual traits (e.g., age) with the response variable of interest (e.g., nest survival), which allowed us to account for variation in behavior or demography related to features of the environment that were not associated with power lines. We primarily used analysis-specific (e.g., nest survival) environmental variables based on analyses previously conducted in this study system (Blomberg et al. 2012, 2013*c*, 2017; Gibson et al. 2014, 2015, 2016, 2017; see Table SA1 in Appendix A for all covariates considered). However, we modified some analyses by considering additional variables that were not included in the original publications. We were unable to use a uniform suite of environmental variables across all analyses because of differences in levels of organization (e.g., individual- vs. lek-based analyses) and temporal resolution (e.g., daily vs. annual time-steps) for each analysis. Second, we developed a suite of explanatory variables (see below) that assessed the impact of power lines on potential demographic rates, which we added to the best-supported model (see Tables SB1–9) from the first stage. Spatial correlation between anthropogenic features and habitat variables has the potential to render our approach conservative because inclusion of confounded variables in a single model generally results in a reduction in the effect sizes or an inflation of variances for each correlated variable.

Model covariates and selection.—We were primarily interested in assessing whether sage-grouse behavior or demography varied as a function of their distance from the FG transmission line. We also were interested in whether individuals responded to a new transmission line differently from previously existing power lines; thus, we considered 2 power-line covariates for each analysis: 1) distance from the FG transmission line and 2) distance from any power line. We digitized the FG transmission line corridor from Universal Transverse Mercator coordinates of all tower locations in our study system, and created a spatial surface that represented the Euclidian distance of each pixel from the FG transmission line using the spatial analyst toolbox in ArcMap 10.0 (Environmental Systems Research Institute, Redlands, CA, USA). We used this surface to assign individuals a distance from the FG transmission line, where assignment depended on temporal resolution of each analysis (see below). Similarly, we digitized locations of all known power lines using satellite imagery, and created a spatial surface of Euclidian distances from any power line for our study system, which we assigned to each individual in each analysis.

We tested for a distance-from-power-line threshold by comparing models containing both linear and quadratic effects of distance from power lines to models allowing for threshold effects on behavior or demographic rates associated with distance to a power line (Powell et al. 2017). We suspected a behavior or demographic rate would exhibit a more ramped response, in which a specific response would exhibit a linear pattern until an unknown distance threshold, and beyond this threshold we would not observe a response. Thus, for each analysis, we considered a suite of models that individually applied a variable threshold constraint that functionally allowed for a linear relationship until the threshold point, and constrained all points that exceeded the threshold to be assigned the value of the threshold point. For female-based analyses, we considered a range of *a priori* thresholds (i.e., 2.5, 5, 7.5, 10, 12.5 km from FG or any power line) where distance from each power line was an individual-level, continuous variable. However, distance from a transmission line was specified as a lek-level covariate in the male analyses ($n = 11$ or 13), and we considered only a threshold of 5 km, which effectively tested whether a linear association between distance from the FG or any power line was supported for the leks nearest to and most likely to be affected by a transmission line ($n = 5$ or 6 leks). We used the min function in Program MARK (White and Burnham 1999) to specify the threshold point for each demographic model, and altered the covariates to create similar threshold points manually for each habitat use analysis. For both male- and female-based analyses, we also tested a pseudo-threshold model (Franklin et al. 2000, Dugger et al. 2005, McNew et al. 2014), which constrained the non-standardized explanatory variable to be modeled on the natural log scale (plus an adjustment factor to push low values off zero [i.e., $\ln(x+0.001)$]). Comparisons among the threshold models allowed for inference regarding the spatial extent, and general shape of behavioral or demographic response to the FG transmission line or any power line.

An important hypothesis underlying the influence of power lines on sage-grouse demography is that power lines benefit sage-grouse predators, and thus indirectly affect prey such as sage-grouse. To assess support for this hypothesis, we evaluated relationships between annual abundances of ravens or raptors, and power-line effects. We used the mean number of ravens and raptors observed, not corrected for probability of detection, within 400 m of each survey point during each transect in each year as an annual index of common raven and general raptor abundance (hereafter, raven index, and raptor index, respectively). Because we observed ravens as singletons, pairs, and larger flocks of loafing individuals, the raven index represents a relative estimate of general raven abundance, and not an index of the local raven breeding population. We observed individual raptor species at relatively low rates; therefore, we combined observations of all raptor species that we determined could prey on adult sage-grouse. Species included ferruginous hawk (*Buteo regalis*), rough-legged hawk (*Buteo lagopus*), red-tailed hawk (*Buteo jamaicensis*), Swainson's hawk (*Buteo swainsoni*), Cooper's hawk (*Accipiter cooperii*), northern goshawk (*Accipiter gentilis*), sharp-shinned hawk (*Accipiter striatus*), northern harrier (*Circus cyaneus*), golden eagle (*Aquila chrysaetos*), and prairie falcon (*Falco mexicanus*). We used the raven index variable in models estimating metrics of sage-grouse reproductive behavior or success (e.g., nesting propensity, nest-site selection, nest survival, population growth) as an additive effect, and as an interaction with distance from the FG transmission line. We used the raptor index in models estimating adult sage-grouse survival or population growth. Additionally, we regressed the raven and raptor indices against year of the study to determine the general trend in common raven and raptor abundance throughout the study.

For more data-rich analyses (i.e., nest-site selection, nest survival), we considered models that allowed for full annual variation in the effects of distance from the FG transmission line (i.e., year-specific slopes) to estimate year-specific effects of distance from FG transmission line. For these models, we did not use an information-theoretic approach to compare relative explanatory power because these models were only used to test a specific hypothesis. *Post hoc*, we regressed these year-specific parameter estimates against the raven and raptor indices to assess whether annual patterns in female nesting behavior or nest survival were correlated with annual raven or raptor relative abundances. For analyses in which year-specific effects of distance from the FG transmission line were not estimable because of sparse data, we allowed the effect of the FG transmission line to vary as a function of a linear year trend to determine if the effect of distance from FG transmission lines increased or decreased in magnitude throughout the duration of the study. Lastly, we considered models that allowed nest-site selection and nest survival to vary as a function of 1) distance to highway and 2) distance to any maintained road, to determine whether sage-grouse nesting ecology was more influenced by power lines or roads. The distance that sage-grouse nests were from highways was highly correlated with distance from the FG transmission line ($r=0.89$) or any power line ($r=0.91$), whereas distance from maintained roads and distance from the FG transmission line ($r=0.11$) or any power line ($r=0.08$) were substantially less correlated. We considered differential responses between roads and power lines in the nest-site selection and nest survival analyses because they were the datasets that had the highest spatial accuracy and largest sample sizes, in addition to relatively high precision on individual estimates. Furthermore, we believed that these vital rates were potentially most sensitive to road effects because of the potential role that common ravens play as a nest predator (Coates et al. 2008, 2014*a*) and their relationship with roads as a potential source of anthropogenic food subsidies (Howe et al. 2014, Dinkins et al. 2014*b*).

We used an information-theoretic approach to evaluate support for competitive models using maximum-likelihood (Burnham and Anderson 2002), which considered covariate effects to be meaningful if 85% confidence intervals of β coefficients did not overlap 0 (Arnold 2010). For models that considered interaction effects among covariates, we considered the combined interaction and covariate effects to be meaningful if the β coefficient that represented the interaction term was meaningful, and the model was more explanatory (lower Akaike's Information Criterion corrected for small sample-size [AIC_c]) than a similarly structured model that only considered additive effects of the relevant covariates. Although this approach could result in the linear components of an interaction not meeting our 85% confidence interval criteria, these components were not individually interpretable when constrained to interact with each other. We used an iterative process in model creation whereby we applied individual covariates to assess various potential sources of variation in each demographic rate. First, we added all covariates singly to the model that best accounted for temporal or spatial variation in the observation or state processes. Second, we added covariates into a more complex model 1 covariate at a time, in which we combined the covariate(s) that were most supported with the least supported covariate that had yet not been considered. We retained covariates that improved model fit in the model structure. We did not include covariates that were correlated with each other (Pearson's $r>0.50$) simultaneously in models; however, if both covariates were explanatory, we retained the more explanatory ($<\text{AIC}_c$) covariate. During the explanatory model stage, we were primarily concerned with developing a covariate model that explained the most information possible with the fewest parameters; therefore, we retained the covariate model with the lowest AIC_c for the power-line model stage. During the power-line model stage, we were interested in determining support for various hypotheses regarding the mechanism(s) by which power lines influenced sage-grouse and the spatial extent of these relationships. Because these hypotheses were not mutually exclusive, we considered models to be competitive that were more explanatory ($<\text{AIC}_c$) than the relevant covariate model (Covar) regardless of the models overall model rank (ΔAIC) relative to other hypotheses considered. All covariates in all analyses were z-standardized ($\bar{x}=0.0$, $\text{SD}=1.0$; White and Burnham 1999), unless specifically mentioned otherwise.

Specific Quantitative Analyses

Nesting and brood-rearing habitat metrics.—We used spring (1 Apr–31 May) locations from radio-marked female sage-grouse from 2003 to 2012 in a multi-state framework in Program MARK to assess the influence of power lines on probabilities of nest initiation. We formatted encounter histories and model state specifications following methods outlined in Blomberg et al. (2017), which used the recorded nesting state from each check of a radio-marked female to generate an encounter history for each female in each study year. In this analysis, we defined occasion-specific nesting states as a female not yet observed on a nest, a female observed on her first nest in that year, a female observed not on a nest following failure of a first nest, and a female observed on a second nest in that year. We were primarily interested in estimating the probabilities of transitioning (ψNest) among nesting states, which we used to derive an overall probability of nest initiation and second nest initiation conditioned on failure of a first nest. Our assessment of other environmental variables that influenced nesting and re-nesting propensity was based on previous work in this system (Blomberg et al. 2017; Table SB1 in Appendix B).

We used nest and brood location data during 2004–2012 to assess the influence of power lines on habitat selection during the nesting and brood-rearing periods using resource-selection functions as described by Boyce and McDonald (1999) and Hebblewhite and Merrill (2008). We performed resource selection function (RSF) analyses in a use versus available framework for both the nesting and brood-rearing periods, in which used points represented nest or brood locations, and available points were randomly selected from throughout the study system (Fig. 1). Thus, our approach reflects resource selection that approximates Johnson's (1980) second order for population-level selection. We randomly selected 2,200 points for each RSF analysis, which was approximately 5 times the number of available nest or brood locations. We assigned each nest, brood, and random point a value for a suite of spatial habitat characteristics. We performed each RSF analysis in a generalized linear mixed model framework (Zuur et al. 2009) using the lme4 package (Bates and Maechler 2010) in R (R Core Team 2012). For both analyses, we included year and individual as a random effect, where we randomly assigned each random point a year value that occurred during our study, and randomly paired each point with an individual female. Our assessment of other environmental variables that influenced habitat selection was based on previous work in this system (Gibson et al. 2016; Table SB2–3 in Appendix B).

We used the nest survival module in Program MARK to model the influence of power lines on daily nest survival probabilities based on nest visit and vegetation data collected from nests monitored during 2004–2012. We estimated overall nest survival rates (i.e., nest initiation to hatch) based on a 37-day exposure period that incorporated laying and exposure periods (Blomberg et al. 2015). We did not censor research-related abandonments for this analysis, which biased our estimates of overall nest survival low (~0.07; Gibson et al. 2015); however, this bias should not substantially influence estimated covariate effects on nest survival. Our assessment of other environmental variables that influenced nest survival was based on previous work in this system (Gibson et al. 2016; Table SB4 in Appendix B).

For the power-line analysis, we calculated the average distance during each spring to the closest power line or the FG transmission line for all unique locations for each female: nest, brood, or random location. We used these values as covariates for nesting propensity, re-nesting propensity, nest-site selection, nest survival, and brood-site selection parameters. For each analysis, we considered both linear and quadratic effects of distance from either the FG transmission line or any power line. We did not assess the influence of the FG transmission line on any parameter before its construction (i.e., before 2004). For each analysis, we used the raven index as an explanatory covariate, and in an interaction with distance from the FG transmission line to assess whether the impact of the transmission line varied as a function of common raven abundance. *Post hoc*, for the nest-site selection and nest-survival analyses, we allowed the distance-to-FG-transmission-line variable to be estimated for each year of the study (i.e., year-specific slopes) to assess how patterns in nest-site selection (random effect of year) and nest survival (fixed effect of year) varied over time. Additionally, for the brood-rearing habitat-selection models, we allowed the effect of distance from either power line covariate to vary as a function of weekly brood age to assess whether habitat selection varied as chicks aged.

Survival rates.—We used the Lukacs young survival of marked adults module (Lukacs-survival; Lukacs et al. 2004) in Program MARK to assess the influence of power lines on pre-fledging chick survival based on brood flush count and brood-site vegetation survey data collected from 2005 to 2012. The Lukacs young survival of marked adults model uses repeated counts of unmarked individuals (i.e., chicks) that are completely associated with a marked individual (i.e., radio-marked female), who is available for detection, to estimate apparent offspring survival (φ) while accounting for imperfect detection (p) of offspring. We did not estimate pre-fledging chick survival during 2003–2004 because broods were not monitored after hatch during those years. Our assessment of other environmental variables that influenced φ was based on previous work in this system (Gibson et al. 2017; Table SB5 in Appendix B).

We used the nest survival module in Program MARK to assess the influence of proximity to power lines on monthly female survival probabilities (S) based on year-round telemetry data collected from radio-marked females during 2003–2012. We used nest survival models as they more appropriately assign timing of mortality when telemetry data are collected at irregular intervals (Dinsmore et al. 2002, Mong and Sandercock 2007, Blomberg et al. 2014). Individual encounter histories included 12 intervals (months), beginning 1 March and terminating 28–29 February the following calendar year. We defined each year ($n_{\text{years}} = 10$) as a group; females that were monitored across multiple years had a unique 12-occasion encounter history for each year we monitored them. We acknowledge that including females monitored across multiple years may result in pseudo-replication; however, we monitored 61% of nesting females for only a single year. Thus, more sophisticated modeling approaches to account for repeated observations of individuals would not converge. We right censored encounter histories from individuals that we were unable to monitor because of radio failure or unrecorded dispersal. Our assessment of other environmental variables that influenced *S* was based on previous work in this system (Blomberg et al. 2013*c*; Table SB6 in Appendix B).

We used the multistate robust design model in Program MARK to assess the influence of proximity to power lines on annual male survival (φ_{male}) and male lek-lek movement rates (ψ_{movement}) based on mark-recapture data collected from 2003 to 2012 during trapping events on leks (captures and recaptures) and lek observations (resights). We generated encounter histories from physical recaptures and band resights, and used them in a multistate ($n_{\text{states}} = 2$) robust design framework, where we grouped males together by lek of capture ($n_{\text{leks}} = 13$). As in Gibson et al. (2014), state transition probabilities represented the annual probability of a male moving to a lek different from its lek of previous encounter. To fit criteria necessary for robust design analyses, we defined primary occasions as an annual breeding season, and subdivided each breeding season into 2 35-day secondary occasions. Our assessment of other environmental variables that influenced φ_{male} and ψ_{movement} was based on previous work in this system (Gibson et al. 2013; Table SB7 in Appendix B).

We considered linear and quadratic effects of distance from either the FG transmission line or any power line on survival of chicks, adult females, and adult males. For the pre-fledging chick survival analysis, we calculated the distance a female and her brood was located from either the nearest power line or FG transmission line at the beginning of each week, and used each of these values as a weekly time-varying covariate for the power-line analysis. For the analysis of adult female survival, we calculated the average distance a female was located from either the nearest power line or FG transmission line using all ground-based telemetry locations collected for each female during a given month (Mar–Aug), and we used each of these values as a monthly time-varying covariate for the power-line analysis. We did not assess the influence of distance from a power line or the FG transmission line from the beginning of September to the end of February because we lacked precise location data for these months. For the analysis of adult male survival and movement, we assigned each male annual time-varying covariates that represented the distance between the lek he attended in year$_t$ and the nearest power line or FG transmission line to assess the influence of power lines on either φ_{male} or ψ_{movement} from year$_t$ to year$_{t+1}$. For each analysis, we did not assign the time-varying FG transmission line covariate to individuals in 2003 because this year preceded completion of the FG transmission line.

We used the raven index as an annual covariate for the pre-fledging chick survival analysis. Additionally, we considered an interaction between distance from the FG transmission line and the raven index to assess temporal variation in the influence of distance from the FG transmission line as a function of the number of common ravens observed near the transmission line during a given year. We did not use the raven index to model female survival, male survival, or male movement because ravens are not known predators of adult sage-grouse (Hagen 2011). However, we considered an interaction between distance from the FG transmission line and the raptor index to assess the influence of distance from the FG transmission line on female and male survival as a function of the number of raptors observed near the FG transmission line. Lastly, for each analysis, we allowed the effect of the FG transmission line to vary as function of a linear year trend (FG × trend) to determine if the potential impacts of the FG transmission line on pre-fledging chick, adult female, or adult male survival increased or decreased during the study.

Recruitment and population growth.—We used robust design Pradel models in Program MARK to assess the influence of proximity to power lines on lek-specific population growth (λ) and recruitment rates (f) based on male encounters during trapping events on leks during 2003–2012. We generated encounter histories only from physical captures of males at leks that were monitored during the entire length of the study ($n_{leks} = 11$). We did not use tarsal band re-sights during lek observations in this analysis because Pradel models assume equal detection probabilities for newly marked and previously marked individuals (Sandercock 2006), and unmarked individuals are unavailable for encounter when band re-sights are used (Blomberg et al. 2013*b*). Similar to the multistate robust design analysis, we defined primary occasions as an annual breeding season, and subdivided each breeding season into 2 35-day secondary occasions. Our assessment of other environmental variables that influenced λ and f were based on previous work in this system (Blomberg et al. 2013*b*; Table SB8–9 in Appendix B).

We assigned each male annual time-varying covariates that represented the distance between the lek he attended in year t and the nearest power line or FG transmission line to assess the influence of power lines on λ or f between years t and $t + 1$. We did not assign the time-varying FG transmission line covariate to individuals in 2003 because this year preceded completion of the FG transmission line. We also used the raven and raptor indices as annual covariates. Additionally, we considered interactions between distance from the FG transmission line and the raven index to assess temporal variation of FG transmission line effects on population growth and *per capita* recruitment, as a function of the number of common ravens observed near the transmission line during a given year. Lastly, we allowed the effect of the FG transmission line to vary as function of a linear year trend (FG × trend) to determine if the potential impacts of the FG transmission line on population growth or *per capita* recruitment increased or decreased during the study.

Spatial association between common ravens and Falcon–Gondor transmission line.—We used a robust design occupancy model in Program MARK based on raven observation data collected during morning sage-grouse lek observations during 2003–2012 to estimate the following: 1) probability of a lek being visited (i.e., disturbed) by a raven (ψ_{Dis}) in year$_t$; 2) probability that a lek not visited by a raven in year$_t$ would be visited in year$_{t+1}$ (γ_{Dis}); and 3) probability of detecting a raven visit to a lek (p_{Dis}). We modeled raven visitations recorded during lek observations as a Bernoulli (presence or absence) response variable describing whether a lek was disturbed at least once by a raven during a morning lek observation. We considered each study lek to be independent ($n_{\text{leks}} = 13$), and assigned each lek observation to a 20-day secondary occasion based on the ordinal date (OD) of the survey (OD: 61–140; number of secondary occasions = 4) within each year, and a primary occasion based on year (number of primary occasions = 10). We used lengths of 20 days for secondary periods to increase the probability that at least 1 full survey per lek was completed per occasion (some scheduled observations were cancelled because of weather) and to decrease the absolute variation in length of survey observations. Although this model assumes population closure among secondary occasions, we believe this analysis is relatively insensitive to violations of this assumption because it was highly likely that each lek was available to be visited by at least 1 raven during each secondary occasion. We allowed detection probabilities to vary among secondary occasions but constrained them to be constant among years because of data limitations.

Although we were primarily interested in determining the associations between disturbance rates and the FG transmission line, we also fit linear and quadratic trends on γ_{Dis} to allow for annual variation in colonization of disturbance events. We assessed whether raven disturbance rates were spatially associated with the FG transmission line by comparing models that constrained ψ_{Dis} during 2004–2012 to vary as linear, quadratic, or natural log functions of the distance from the FG transmission line. Additionally, we tested a series of distance-threshold models (i.e., 5, 7.5, and 10 km from the FG transmission line). We also considered models that constrained γ_{Dis} to vary as a function of a linear trend across years to assess whether the rate of raven occupancy increased throughout the study. Lastly, we ran an identical suite of models that constrained ψ_{Dis} during 2003–2012 to vary as a function of distance to the nearest highway. For this analysis, we did not consider interactions between time and distance from the FG transmission line because of data sparseness.

RESULTS

We captured and radio-marked 361 (153, 192, and 16 captured as adults, subadults, or unclassified, respectively) female sage-grouse and captured and banded 988 (529, 380, and 79 captured as adults, subadults, or unclassified, respectively) male sage-grouse during the study (Table 1). Over the 10-year period, we attributed 0 mortalities of radio-marked individuals to a collision with a power line or pole. We discovered and monitored 427 nests by 249 unique females from 2003 to 2012, of which 138 nests from 116 unique females were successful. We classified 355 of the nests as first nests, 66 as second nests, and 6 as third nest attempts. Adults initiated 312 of the nests, subadults initiated 96, and 19 nests were from unknown-age females. We monitored 120 broods from 99 unique females after hatch, and observed 862 chicks at hatch, of which 163 chicks were associated with their mothers at approximately 6 weeks after hatch. We completed 875 vegetation surveys associated with breeding females, of which 423 were associated with nests, and 452 were associated with brood locations. We completed 1,067 lek observations at our 13 study leks ($\bar{x} = 8.73$ observations per lek per year). We observed a decline in the number of breeding male sage-grouse (−1.51 sage-grouse per lek per year (95% CI = −0.25 to −2.76) based on the mean maximum lek counts (Fig. 3A), whereas ravens increased by 0.09 ravens (95% CI = 0.05–0.14) per survey point per year and raptors exhibited no trend (Fig. 3B) in the years after construction of the FG transmission line.

Results from the first stage of model selection (i.e., functional relationships with environmental variables) can be found within the supporting information and previous publications from this system (Blomberg et al. 2012, 2013*c*, 2017; Gibson et al. 2014, 2015, 2016, 2017). For the remainder of the results section, we restrict comparisons of the top environmental covariate models (Tables SB1–SB9) to those containing model-supported covariates plus the explanatory variables associated with power lines (e.g., distance to FG, raven index) or roads.

Table 1. Summary of year-specific greater sage-grouse monitoring data during 2003–2012 in Eureka County, Nevada, USA.

Year	Number of radio-marked females[a]	Unique females that nested[b]	Unique females that re-nested[c]	Number of hatched nests[d]	Number of active broods at 6 weeks[e]	Number of new males captured[f]	Number of males recaptured (unique)[g]	Number of males resighted (unique)[h]
2003	15	11	1	5	NA	146	26 (20)	12 (11)
2004	21	16	3	7	NA	106	43 (36)	41 (26)
2005	35	28	8	12	9	104	55 (48)	37 (25)
2006	62	41	1	20	11	134	37 (35)	56 (35)
2007	50	25	1	10	3	113	37 (30)	34 (12)
2008	41	31	6	7	5	62	30 (26)	91 (45)
2009	54	46	17	20	9	46	50 (34)	59 (23)
2010	68	59	18	20	10	50	35 (31)	109 (33)
2011	63	48	8	18	10	63	44 (30)	107 (42)
2012	63	49	5	19	6	68	13 (12)	135 (40)
Total	472	354	68	138	63	892	370	681

[a] Number of female sage-grouse recorded alive with an active radio-collar during the spring of a given year.

[b] Number of nests assigned to a unique female in a given year.

[c] Number of nests assigned to a unique female that was known to have previously nested in a given year.

[d] Number of monitored nests that hatched in a given year.

[e] Number of broods that hatched from a monitored nest that had at least 1 chick at 6 weeks after hatch. Broods were not monitored during 2003–2004.

[f] Number of males captured for the first time on a lek during the spring on a given year. These values do not sum to the total number of males captured across the 10-year study because we also captured male sage-grouse during the fall in seasonal habitat.

[g] Total number of previously captured males recaptured during the spring lek-centric capture events; values in parentheses represent the unique number of individual's recaptured.

[h] Total number of previously captured males reencountered through visual observation of their plastic tarsal band during the spring morning lek observations; values in parentheses represent the unique number of individual's reencountered.

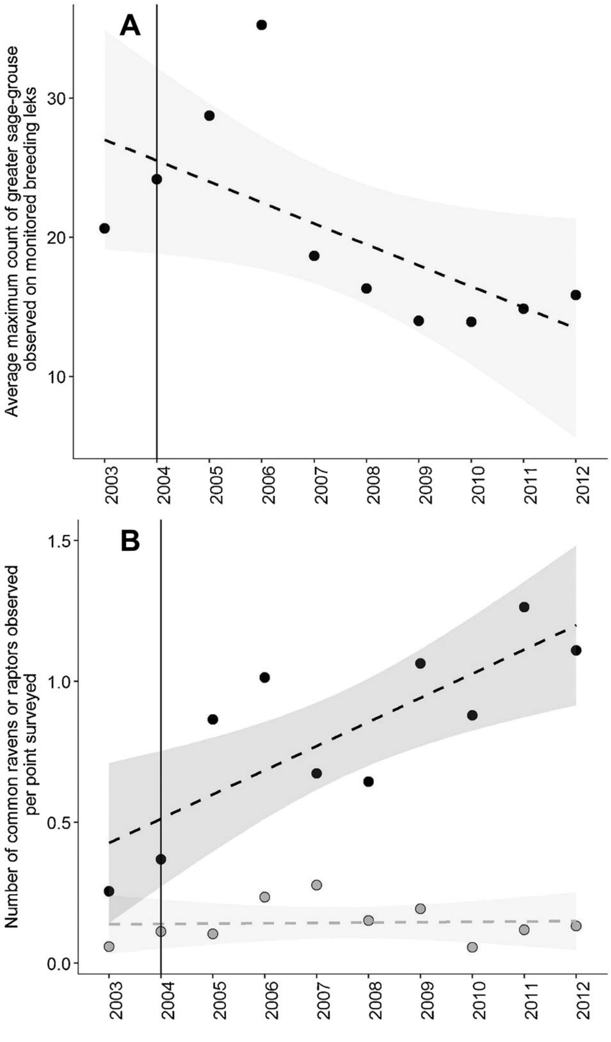

Figure 3. The average A) of the maximum male sage-grouse lek count from all monitored leks during the spring for each year, and B) the average number of common ravens (black circles) and raptor species thought to prey on adult sage-grouse (gray circles) observed within 400 m of survey points associated the Falcon–Gondor transmission line in Eureka County, Nevada from 2003–2012, regressed against year (dashed line). Construction for the Falcon-Gondor transmission line began in the fall of 2003 and was completed in spring of 2004 (solid line). Error bands represent 95% confidence intervals.

Nesting and Brood-Rearing Metrics

We did not find support for an increase in nesting propensity for individuals located farther from either the FG transmission line or any power line (Table 2). Annual relative raven abundance was negatively associated with re-nesting propensity (re-nest: $\beta_{RavenIndex} = -0.63$; 85% CI = −0.98 to −0.29; Fig. 4A) but not nesting propensity (nest: $\beta_{RavenIndex} = 0.02$; 85% CI = −0.09–0.14; Table 2). Unlike nesting propensity, we found that probabilities of re-nesting (conditioned on initial failure) were highest in areas closer to the FG transmission line ($\beta_{FG} = -0.44$; 85% CI = −0.71 to −0.17, $\beta_{FG}{}^{2} = 0.23$; 85% CI = 0.07–0.39; Fig. 4B). The negative effect of distance to the FG transmission line and re-nesting propensity was supported to a threshold of 10–12.5 km ($\beta_{FG10} = -0.66$; 85% CI = −1.12 to −0.19; $\beta_{FG12.5} = -0.53$; 85% CI = −0.91 to −0.15) from the line (Table 3). We found no model or parameter support for the hypothesis that nesting or re-nesting propensity was associated with distance from any power line at any of our thresholds.

We found support for a quadratic effect of distance from any road on nest-site selection ($\beta_{Road} = -0.47$; 85% CI = −0.61 to −0.34; $\beta_{Road^2} = 0.30$; 85% CI = 0.22–0.38; Table 4), which suggested selection of areas near maintained roads. For non-road models, we found support for an interaction ($\beta_{All \times RavenIndex} = 0.19$; 85% CI = 0.07–0.32) between the raven index ($\beta_{RavenIndex} = 0.36$; 85% CI = 0.18–0.54) and distance to any power line ($\beta_{All} = 0.18$; 85% CI = 0.07–0.29), which suggested that the magnitude of avoidance of any power line increased when raven abundance was higher (Fig. 5A). The pseudo-threshold model ($\beta_{log(FG)} = 0.17$; 85% CI = 0.07–0.26; Fig. 6; Table 5) was the best-supported description of avoidance behavior associated with the FG transmission line, which suggested high avoidance of areas within 3 km of the FG transmission line.

Annual raven abundance, by itself, did not influence nest survival; however, we found support for an interaction ($\beta_{FG^2 \times RavenIndex} = 0.21$; 85% CI = 0.08–0.33) between a quadratic effect of distance to the FG transmission line ($\beta_{FG} = 0.09$; 85% CI = −0.04–0.22; $\beta_{FG}{}^{2} = -0.10$; 85% CI = −0.16 to −0.08) and the raven index ($\beta_{RavenIndex} = 0.08$; 85% CI = −0.02–0.20), which suggested nest survival near the FG transmission line was reduced when raven abundance was higher (Table 6 and Fig. 5B). This pattern resulted in a 2-fold increase in benefits of nesting farther from any power line during years of high raven abundance as overall nest survival probability increased by approximately 0.014 per km from the FG transmission line, compared to a 0.006 per km increase during years of average raven abundance. In models lacking a raven effect, we found model support for a quadratic effect of distance from the FG transmission line on nest survival ($\beta_{FG} = 0.15$; 85% CI = 0.03–0.28, $\beta_{FG}{}^{2} = -0.08$; 85% CI = −0.15–0.02; Table 6). We found the most support for the effect of FG transmission line on nest survival extending to 12.5 km from the line ($\beta_{FG12.5} = 0.23$; 85% CI = 0.06–0.40; Table 7), which indicated the effect of the line on nest survival extended substantially farther than female avoidance behavior (Fig. 7). Although a 7.5-km threshold from any power line had more support than the full linear model (Table 7), the 85% confidence interval for the distance effect crossed zero and was not considered supported ($\beta_{All7.5} = 0.19$; 85% CI = −0.01–0.39). We did not find support for an effect of distance to road or highway on nest survival, which suggests that the observed impacts of power lines were most likely associated with elevated structures, rather than the roads with which they were partially spatially confounded.

Year-specific slopes for the effect of distance from the FG transmission line on nest-site selection covaried positively with estimated raven abundance (Fig. 6C), indicating that females were more likely to nest farther from the line in years when greater numbers of ravens were present in the study landscape. Similarly, we found that year-specific slopes for the effect of distance from the FG transmission line on nest survival positively covaried with relative raven abundance (Fig. 5C). The degree to and the distance at which nest survival was reduced at a given distance from the FG transmission line were both positively correlated with annual raven abundance. Therefore, in years of greater raven abundance, the transmission line had a stronger

Table 2. Performance of multistate models to assess the influence of power lines and common raven abundance on greater sage-grouse nesting and re-nesting propensities in Eureka County, Nevada, from 2003–2012. We considered variables in models that outperformed (lower ΔAIC) the Nesting: (NP:covar) Re-nesting: (RNP:covar) model and had 85% confidence intervals that did not overlap 0 to be explanatory.

Model[a]	ΔAIC_c[b]	w_i[c]	K[d]	Deviance
Nesting: (NP:covar) Re-nesting: (RNP:covar + raven)	0.00	0.64	28	47,414.95
Nesting: (NP:covar) Re-nesting: (RNP:covar + FG^2)	3.05	0.14	29	47,415.97
Nesting: (NP:covar) Re-nesting: (RNP:covar + FG)	4.83	0.06	28	47,419.78
Nesting: (NP:covar) Re-nesting: (RNP:covar)	5.07	0.05	27	47,422.05
Nesting: (NP:covar + FG) Re-nesting: (RNP:covar)	7.02	0.02	28	47,421.98
Nesting: (NP:covar + raven) Re-nesting: (RNP:covar)	7.02	0.02	28	47,421.98
Nesting: (NP:covar + power) Re-nesting: (RNP:covar)	7.03	0.02	28	47,421.98
Nesting: (NP:covar) Re-nesting: (RNP:covar + power)	7.06	0.02	28	47,422.02
Nesting: (NP:covar + FG^2) Re-nesting: (RNP:covar)	7.70	0.01	29	47,420.63
Nesting: (NP:covar + $power^2$) Re-nesting: (RNP:covar)	8.08	0.01	29	47,421.00
Nesting: (NP:covar) Re-nesting: (RNP:covar + $power^2$)	9.00	0.01	29	47,421.92
Nesting: (NP:covar + FG × raven) Re-nesting: (RNP:covar)	10.46	0.00	30	47,421.35

[a] All models constrained site fidelity, nest failure, and re-nest failure to be constant among and within years ($K = 3$). Detection was allowed to vary by breeding stage ($K = 3$), year ($K = 10$), and fit with a quadratic trend across occasions within years ($K = 2$). NP:covar represents the environmental characteristics ($K = 3$) that influenced nesting propensity (male population size [−]; female age [+]; female age^2 [−]; Table SB1 in Appendix B). RNP:covar represents the environmental characteristics ($K = 2$) that influenced re-nesting propensity (population size [−]; spring precipitation [+]; Table SB1 in Appendix B). Power and FG represent the average distance a female sage-grouse was from any power line or the Falcon–Gondor transmission line during a given spring (1 Apr–31 May), respectively. Raven represents the mean number of common ravens observed per point surveyed during spring point count surveys. We denote a quadratic relationship with a square notation (^{2}), and it includes the linear component. Models with interactions consider both the variables and interaction terms.

[b] The difference in Akaike's Information Criterion between the top ranked and selected model.

[c] The relative likelihood of a model (i.e., Akaike weights).

[d] The number of estimated parameters in a given model.

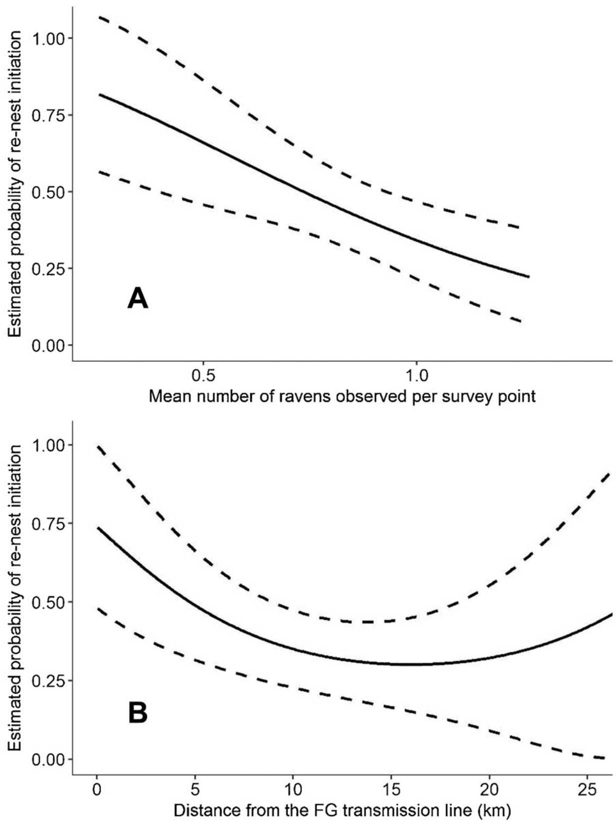

Figure 4. The influence of A) the average number of common ravens observed within 400 m of a point count survey associated the Falcon–Gondor (FG) transmission line, and B) the average distance a female greater sage-grouse was from the FG transmission line during the breeding (Apr–May) season on re-nesting propensities in Eureka County, Nevada from 2003–2012. Error lines (dashed lines) represent 95% confidence intervals.

negative effect that persisted for a greater distance away from the line itself. We found no support for a similar relationship between relative raptor abundance and year-specific slopes for the effect of distance from the FG transmission line on nest-site selection or nest survival (Fig. 5D).

We found support for a positive linear effect of distance to any power line on brood-site selection ($\beta_{All} = 0.29$; 85% CI = 0.20–0.38; Table 8), indicative of overall avoidance. *Post hoc*, we found additional support for a power-line effect on brood-site selection to 7.5 km for any power line ($\beta_{All7.5} = 0.90$; 85% CI = 0.62–1.19), and to 5 km for the FG transmission line ($\beta_{FG5} = 1.02$; 85% CI = 0.56–1.47; Table 9; Fig. 8).

Survival Rates

We found that pre-fledging chick survival was explained in part by an interaction ($\beta_{Raven \times FG} = 0.36$; 85% CI = 0.19–0.53) between the raven index ($\beta_{RavenIndex} = -0.25$; 85% CI = −0.44 to −0.07) and distance from the FG transmission line ($\beta_{FG} = -0.27$; 85% CI = −0.39 to −0.14; Fig. 9; Table 10), which suggested that chick survival near the FG transmission line decreased as raven abundance increased. During years of low and average raven abundance, pre-fledging chick survival was lower in areas farther from the FG transmission line; however, in years of high raven abundance pre-fledging chick survival was greater in areas farther from the FG transmission line. We also found support for an interaction ($\beta_{FG \times Trend} = 0.06$; 85% CI = 0.02–0.10) between distance from the FG transmission line ($\beta_{FG} = -0.37$; 85% CI = −0.59 to −0.15) and a yearly-trend variable ($\beta_{Trend} = -0.05$; 85% CI = −0.09–0.00), which suggested that pre-fledging chick survival for broods near the FG transmission line has generally declined over the course of the study (Fig. 10). We found no support for an influence of relative raptor abundance on pre-fledging chick survival, regardless of the distance a brood was found from FG. In the absence of more complex interactions, however, we found that pre-fledging chick

Table 3. Performance of multistate models assessing support of distance-threshold effects of distance from the Falcon–Gondor or any transmission line on greater sage-grouse nesting and re-nesting propensities in Eureka County, Nevada, from 2003–2012. We considered variables in models that outperformed (lower ΔAIC) the Nesting: (NP:covar) Re-nesting: (RNP:covar) model and had 85% confidence intervals that did not overlap 0 to be explanatory.

Model[a]	ΔAIC_c[b]	w_i[c]	K[d]	Deviance
Nesting: (NP:covar) Re-nesting: (RNP:covar + FG_{10})	0.00	0.13	28	47,418.05
Nesting: (NP:covar) Re-nesting: (RNP:covar + $FG_{12.5}$)	0.09	0.12	28	47,418.14
Nesting: (NP:covar) Re-nesting: (RNP:covar + $FG_{7.5}$)	0.41	0.11	28	47,418.46
Nesting: (NP:covar) Re-nesting: (RNP:covar + FG_5)	0.76	0.09	28	47,418.81
Nesting: (NP:covar) Re-nesting: (RNP:covar + FG_{log}	0.76	0.09	28	47,418.81
Nesting: (NP:covar) Re-nesting: (RNP:covar + FG)	1.73	0.05	28	47,419.78
Nesting: (NP:covar) Re-nesting: (RNP:covar)	1.97	0.05	27	47,422.05
Nesting: (NP:covar) Re-nesting: (RNP:covar + $FG_{2.5}$)	3.38	0.02	28	47,421.43
Nesting: (NP:covar + $FG_{2.5}$) Re-nesting: (RNP:covar)	3.71	0.02	28	47,421.76
Nesting: (NP:covar) Re-nesting: (RNP:covar + $power_{7.5}$)	3.76	0.02	28	47,421.82
Nesting: (NP:covar + $FG_{12.5}$) Re-nesting: (RNP:covar)	3.83	0.02	28	47,421.88
Nesting: (NP:covar + $FG_{7.5}$) Re-nesting: (RNP:covar)	3.83	0.02	28	47,421.89
Nesting: (NP:covar) Re-nesting: (RNP:covar + $power_{2.5}$)	3.85	0.02	28	47,421.91
Nesting: (NP:covar) Re-nesting: (RNP:covar + $power_{10}$)	3.91	0.02	28	47,421.96
Nesting: (NP:covar + FG) Re-nesting: (RNP:covar)	3.92	0.02	28	47,421.98
Nesting: (NP:covar + power) Re-nesting: (RNP:covar)	3.93	0.02	28	47,421.98
Nesting: (NP:covar + $power_5$) Re-nesting: (RNP:covar)	3.97	0.02	28	47,422.03
Nesting: (NP:covar + $power_{12.5}$) Re-nesting: (RNP:covar)	3.98	0.02	28	47,422.04
Nesting: (NP:covar + FG_{log} Renesting: (RNP:covar)	3.99	0.02	28	47,422.04
Nesting: (NP:covar + $power_{7.5}$) Re-nesting: (RNP:covar)	3.99	0.02	28	47,422.04
Nesting: (NP:covar + $power_{2.5}$) Re-nesting: (RNP:covar)	4.00	0.02	28	47,422.05
Nesting: (NP:covar + FG_5) Re-nesting: (RNP:covar)	4.00	0.02	28	47,422.05
Nesting: (NP:covar) Re-nesting: (RNP:covar + $power_{log}$	4.00	0.02	28	47,422.05
Nesting: (NP:covar) Re-nesting: (RNP:covar + $power_5$)	4.00	0.02	28	47,422.05
Nesting: (NP:covar + $power_{10}$) Re-nesting: (RNP:covar)	4.00	0.02	28	47,422.05
Nesting: (NP:covar) Re-nesting: (RNP:covar + $power_{12.5}$)	4.00	0.02	28	47,422.05
Nesting: (NP:covar + FG_{10}) Re-nesting: (RNP:covar)	7.81	0.00	30	47,421.80
Nesting: (NP:covar) Re-nesting: (RNP:covar + power)	8.02	0.00	30	47,422.02
Nesting: (NP:covar + $power_{log}$) Re-nesting: (RNP:covar)	10.08	0.00	31	47,422.04

[a] All models constrained site fidelity, nest failure, and re-nest failure to be constant among and within years ($K = 3$). Detection was allowed to vary by breeding stage ($K = 3$), year ($K = 10$), and fit with a quadratic trend across occasions but within years ($K = 2$). NP:covar represents the environmental characteristics ($K = 3$) that influenced nesting propensity (male population size [−]; female age [+]; female age^2 [−]; Table SB1 in Appendix B). RNP:covar represents the environmental characteristics ($K = 2$) that influenced re-nesting propensity (population size [−]; spring precipitation [+]; Table SB1 in Appendix B). Power and FG represent the average distance a female sage-grouse was from any power line or the Falcon–Gondor transmission line during a given spring (April 1st–May 31st), respectively. Raven represents the mean number of common ravens observed per point surveyed during spring point count surveys. Subscripts represent the maximum extent (in km) to which the linear distance from the FG transmission or any power line was applied to the decision to initiate a nest. The log represents a model that used the natural log of the normalized distance from FG or all transmission line covariate + 0.001, which estimates a pseudo-threshold. All models included individual and year as random effects.

[b] The difference in Akaike's Information Criterion between the top ranked and selected model.

[c] The relative likelihood of a model (i.e., Akaike weights).

[d] The number of estimated parameters in a given model.

survival was higher for broods near any power line relative to broods located farther from power lines. Benefits associated with being near power lines extended to 10 km from the FG transmission line ($\beta_{FG10} = -0.22$; 85% CI = −0.03 to −0.41) and 5 km from any power line ($\beta_{All5} = -0.59$; 85% CI = −0.19 to −0.98; Table 11; Fig. 11A).

We did not find support for effect of an interaction between a linear year trend and distance from the FG transmission line (Table 12) on adult female survival. We also did not find support that female survival was influenced by relative raptor abundance. *Post hoc*, we found support for a power-line effect on female survival to 2.5 km for any power line ($\beta_{All2.5} = 0.45$; 85% CI = 0.03–0.88), and to 7.5 km for the FG transmission line ($\beta_{FG7.5} = 0.42$; 85% CI = 0.04–0.81; Table 13; Fig. 11B), but model support and the resulting effect were weak.

Similar to results from the pre-fledging chick survival analysis, we found support for an interaction ($\beta_{FG \times Trend} = 0.06$; 85% CI = 0.01–0.11) between distance from the FG transmission line ($\beta_{FG} = -0.28$; 85% CI = −0.65 to −0.08) and an annual trend ($\beta_{YearTrend} = -0.13$; 85% CI = −0.19 to −0.08) in survival of adult males, which suggested that annual survival of males associated with leks closer to the FG transmission line declined throughout the study, whereas male survival at more distant leks was more stable (Fig. 10 and Table 14). However, this effect was not explained by relative raptor abundance. *Post hoc*, we found support for the hypothesis that male survival for individuals associated with leks within 5 km of any power line was positively associated with distance from any power line ($\beta_{All5} = 0.53$; 85% CI = 0.00–1.07; Fig. 11C). We did not include any covariates on the lek $\psi_{movement}$ parameter because the data were too sparse to reliably assess model structures more complicated than single-variable models. We did not find that the distance from a lek to the FG transmission line or any power line influenced male inter-lek movement rates (Table 14).

Lek-Specific Recruitment and Population Growth Rates

We found the most support for an interaction effect ($\beta_{FG \times Trend} = 0.05$; 85% CI = 0.04–0.06) between distance from the FG transmission line ($\beta_{FG} = -0.25$; 85% CI = −0.30 to −0.19) and an annual trend ($\beta_{YearTrend} = -0.07$; 85% CI = −0.11 to

Table 4. Performance of resource selection functions based on generalized linear mixed effects models used to assess the influence of distance from power lines on greater sage-grouse nest-site use in Eureka County, Nevada, from 2004–2012. We considered variables in models that outperformed (lower ΔAIC) the Covar model and had 85% confidence intervals that did not overlap 0 to be explanatory.

Model[a]	ΔAIC_c[b]	w_i[c]	K[d]	Deviance
Covar + road^2	0.00	0.98	13	1,695.75
Covar + power × raven	7.47	0.02	14	1,701.22
Covar + power	14.83	0.00	12	1,712.58
Covar + power^2	16.80	0.00	13	1,712.55
Covar + road	25.25	0.00	12	1,723.01
Covar + FG × raven	25.47	0.00	14	1,719.23
Covar + FG	30.04	0.00	12	1,727.79
Covar	30.54	0.00	11	1,730.29
Covar + FG^2	30.69	0.00	13	1,726.44
Covar + highway^2	31.31	0.00	13	1,727.06
Covar + highway	32.22	0.00	12	1,729.97

[a] Power and FG represent the distance a female sage-grouse nest or random point was located from any power line or the Falcon–Gondor transmission line, respectively. Highway and road represent the distance a female sage-grouse nest or random point was located from the nearest state highway or managed road, respectively. Covar represents the environmental characteristics ($K = 8$) that influenced nest-site selection at the landscape scale: (distance from lek [−]; sagebrush cover classification [+]; sagebrush cover classification × distance from lek [−]; slope [−]; elevation [+]; slope × elevation [−]; distance from water [−]; and distance from water^2 [−]; Table SB2 in Appendix B). We denote a quadratic relationship with a square notation (^{2}). Raven represents the mean number of common ravens observed per point surveyed during spring point count surveys. All models included individual and year as random effects. Models with interactions included the terms for the individual effects and interactions.

[b] The difference in Akaike's Information Criterion between the top ranked and selected model.

[c] The relative likelihood of a model (i.e., Akaike weights).

[d] The number of estimated parameters in a given model.

−0.04) in population growth rate, which suggested abundance of males at leks closer to the FG transmission line was initially greater, then declined at a greater rate than those farther from the FG line during the study (Fig. 12 and Table 15). We also found support for an interaction ($\beta_{FG \times Raven} = 0.12$; 85% CI = 0.08–0.16) between distance from the FG transmission line ($\beta_{FG} = 0.01$; 85% CI = −0.01–0.03) and relative raven abundance ($\beta_{Raven} = -0.20$; 85% CI = −0.03–0.33; Fig 13A), which suggested that population growth for leks near the FG transmission line was more reduced during years of greater relative raven abundance. Likewise, we found support for an interaction ($\beta_{FG \times Raptor} = 0.11$; 85% CI = 0.07–0.15) between distance from the FG transmission line ($\beta_{FG} = -0.03$; 85% CI = −0.01–0.05) and relative raptor abundance ($\beta_{Raptor} = -0.01$; 85% CI = −0.18–0.19; Fig. 13B), which suggested that population growth for leks near the FG transmission line was also reduced during years of higher relative raptor abundance. In the absence of more complicated interactions, however, relative raptor abundance was not supported to explain a substantial amount of variation in population growth (Table 15). *Post hoc*, we found that male population growth at leks within 5 km of the FG (Fig. 14A) transmission line was positively associated with distance from the line ($\beta_{FG5} = 0.12$; 85% CI = 0.03–0.2; Table 15).

Similar to population growth, we found support for an interaction ($\beta_{FG \times Trend} = 0.05$; 85% CI = 0.04–0.06) between distance from the FG transmission line ($\beta_{FG} = -0.25$; 85% CI = −0.30 to −0.19) and an annual trend ($\beta_{YearTrend} = -0.07$; 85% CI = −0.11 to −0.04) in *per capita* recruitment, which suggested a greater decline in *per capita* recruitment throughout the study at leks that were closer to the FG transmission line than more distant leks (Fig. 12 and Table 16). We also found support for an interaction ($\beta_{FG \times Raven} = 0.23$; 85% CI = 0.12–0.34) between effects on *per capita* recruitment of distance from the FG transmission line ($\beta_{FG} = -0.05$; 85% CI = −0.14–0.03) and relative raven abundance ($\beta_{Raven} = -0.08$; 85% CI = −0.18–0.33; Fig. 13C), but not raptor abundance (Table 16). *Post hoc*, we found support that *per capita* recruitment at leks within 5 km of any power line was positively associated with distance from the line ($\beta_{All5} = 0.12$; 85% CI = 0.00–0.25; Fig. 14B; Table 16).

Raven Occupancy Rates

We found that probability of a raven occupying a location near a monitored sage-grouse lek was higher for leks near the FG transmission line relative to leks more distant from the transmission line (Table 17; $\beta_{log(FG)} = -1.02$; 85% CI = −0.23 to −1.82). Furthermore, the pseudo-threshold model was supported over other linear or threshold models, which indicated that raven occupancy rates were greater, but decreased more rapidly with increasing distance, near the FG transmission line (within 5 km); however, occupancy rates continued to decline past this threshold (Fig. 15). A similar response was supported between distance from the nearest highway and raven occupancy ($\beta_{log(Highway)} = -1.07$; 85% CI = −0.13 to −2.02). Although this relationship was less well-supported than the top model, both models similarly described the observed spatial distribution of ravens on the landscape. We found probability of raven colonizing, or disturbing, a lek unoccupied the previous year (γ_{Dis}) increased throughout the duration of the study ($\beta_{Trend} = 2.22$; 85% CI = 0.46–3.99). These results, in conjunction with raven observations from the transect surveys, indicated that raven activity near the line generally increased throughout this study.

DISCUSSION

We found support for avoidance of power lines, for demographic suppression by those lines, and ultimately, for negative effects on sage-grouse population growth (Table 18). Additionally, we found that the magnitude of the avoidance of power lines and the extent to which vital rates were suppressed interacted with common raven abundance, which, in turn, was also positively associated with power lines. The geographical extent to which power lines could negatively influence sage-grouse demographic processes may therefore not be completely generalizable because it is likely contingent on local raven abundance and behavior. Although relationships between demographic processes or behaviors and raven abundance or other temporal processes complicated the spatial extent or magnitude of power-line effects, patterns indicative of habitat avoidance were supported up to 10 km from any power line, and we observed reductions in individual reproductive processes up to 12.5 km from the FG transmission line. Together, these resulted in a negative association between the FG transmission line and population growth, which was supported to at least 5 km from this line. Similarly, we observed a substantial increase

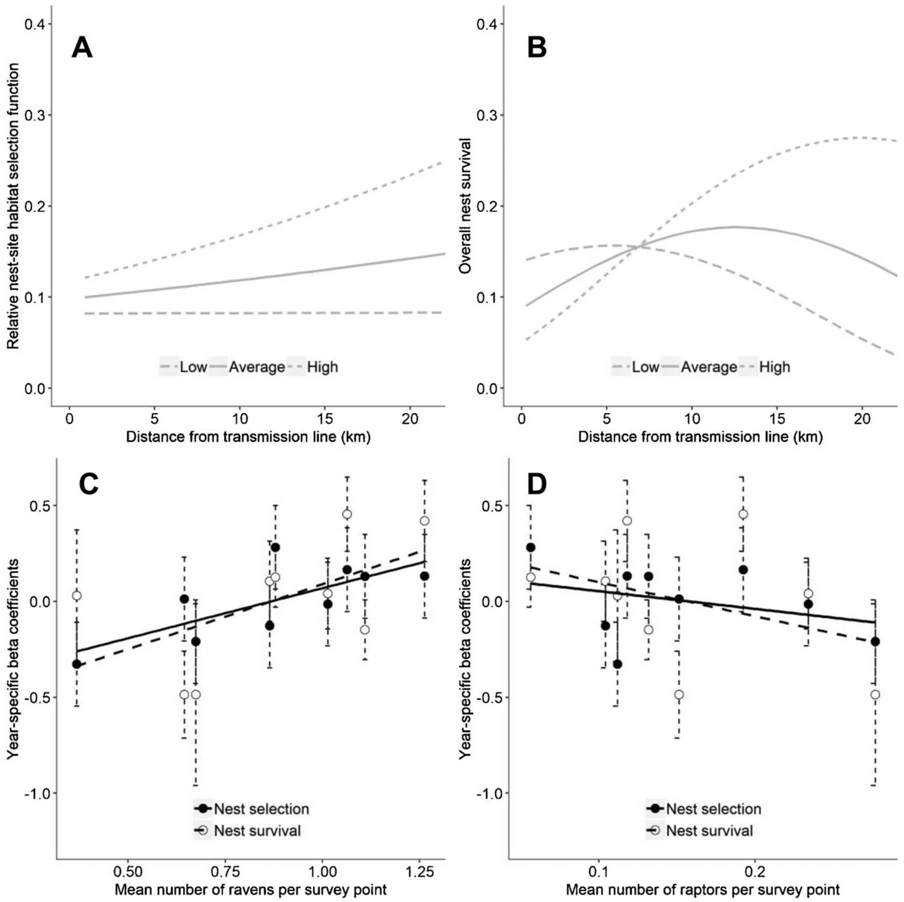

Figure 5. Associations between distance from the Falcon–Gondor transmission line and A) sage-grouse relative nest-site selection or B) overall nest survival as a function of common raven abundance (low [−1 SD from mean raven abundance, long-dash], average [solid], and high [+1 SD from mean raven abundance, short-dash]). Year-specific beta parameter estimates assessing the relationships between distance from the Falcon–Gondor transmission line and nest-site selection (filled circles, solid regression line) and nest survival (open circles, dashed regression line) were regressed on C) mean number of common ravens and D) mean number of raptors observed on the surveyed portion of the Falcon–Gondor transmission line in Eureka County, Nevada from 2004–2012. Error bars represent standard errors.

in raven populations near the FG transmission line since construction (Fig. 3), as well as higher raven occupancy rates for leks within at least 5 km from the FG transmission line (Fig. 15).

We did not attribute any sage-grouse mortalities to direct collisions with a power line, pole, or guy wire during the 10-year study period. Collisions between Galliformes and power lines have been suggested to be disproportionately high relative to those of other birds (Bevanger 1998, Bevanger and Broseth 2004); however, the observed lack of direct mortality in this system was consistent with other long-term studies that have recorded low numbers of mortalities associated with power lines, relative to other mortality, of radio-marked sage-grouse (Connelly et al. 2000, Beck et al. 2006, Dinkins et al. 2014*b*) or other North American Galliformes (Pruett et al. 2009). Thus, the effect of power lines on sage-grouse population dynamics during our study was associated with indirect mechanisms, such as avoidance of habitat near power lines or suppressed vital rates, mediated by predators that were subsidized by power lines (Boarman 2003, Kristan and Boarman 2007, Strickland and Janzen 2010). The exploitation of anthropogenic structures by predators can substantially alter the demographic processes, abundance, and ultimately, distribution of their prey (Liebezeit et al. 2009, Russell et al. 2014, Peebles and Conover, 2017, Schakner et al. 2017). Likewise, our results suggested that the effect of associations between ravens and power lines on sage-grouse behavior and demographic rates were sufficiently large to cause populations to decline, which reinforces recent calls for future studies to better consider the indirect effects of energy infrastructure (Loss 2016, Smith and Dwyer 2016).

The observed impact of power lines on certain demographic rates were small (e.g., female survival), which highlights the importance of long-term data collection on impact assessment. Determining mechanisms of population change from year-to-year variation cannot be achieved with short time-series (<5 years), especially in highly variable systems, and may lead to spurious conclusions (Gerber et al. 1999, McCain et al. 2016). Although the discussion regarding the minimum time-series required to detect population trend is ongoing (Gerber et al. 1999, Nichols and Williams 2006, White 2017), 10–20 years of continuous monitoring data may be required to have confidence in a given prediction. However, we speculate that this duration can be reduced to some extent through spatial replication and study design (e.g., independent assessment of multiple species, sexes, age classes, demographic processes).

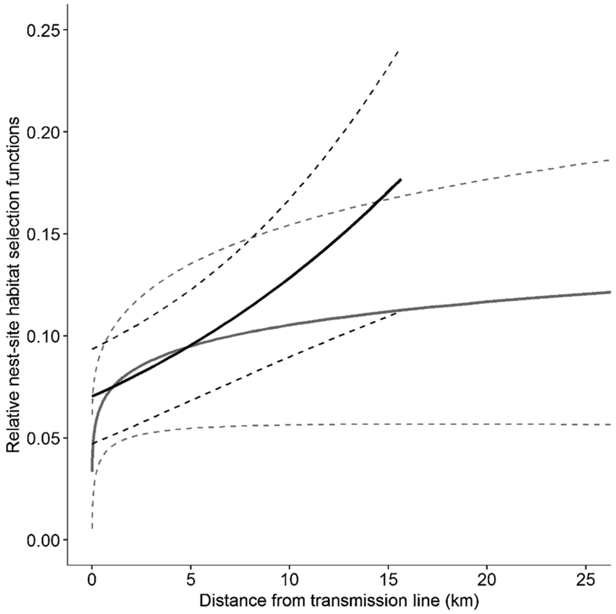

Figure 6. Relationship between distance from the Falcon–Gondor (solid gray line) or any power line (solid black line) and the relative probability of selection of a point as a sage-grouse nesting site in Eureka County, Nevada from 2004–2012. The most competitive models supported a pseudo-threshold constraint on the Falcon–Gondor effect, and a linear effect of any power line on relative nest-site selection probabilities. Error lines (dashed lines) represent 95% confidence intervals.

Table 5. Performance of resource selection functions based on generalized linear mixed effects models assessing support for distance-threshold effects of distance from the Falcon–Gondor or any transmission line on greater sage-grouse nest-site use in Eureka County, Nevada, from 2004–2012. We considered variables in models that outperformed (lower ΔAIC) the Covar model and had 85% confidence intervals that did not overlap 0 to be explanatory.

Model[a]	ΔAIC_c[b]	w_i[c]	K[d]	Deviance
Covar + power	0.00	0.32	12	1,712.58
Covar + power$_{10}$	0.31	0.28	12	1,712.89
Covar + power$_{7.5}$	1.21	0.18	12	1,713.79
Covar + power$_{12.5}$	1.74	0.14	12	1,714.32
Covar + power$_{log}$	2.97	0.07	12	1,715.55
Covar + power$_{5}$	8.18	0.01	12	1,720.76
Covar + FG$_{log}$	11.27	0.00	12	1,723.85
Covar + FG$_{10}$	12.84	0.00	12	1,725.42
Covar + FG$_{7.5}$	12.90	0.00	12	1,725.48
Covar + power$_{2.5}$	13.14	0.00	12	1,725.72
Covar + FG$_{12.5}$	14.61	0.00	12	1,727.19
Covar + FG$_{5}$	14.72	0.00	12	1,727.30
Covar + FG$_{2.5}$	15.21	0.00	12	1,727.79
Covar + FG	15.21	0.00	12	1,727.79
Covar	15.71	0.00	11	1,730.29

[a] Power and FG represent the distance a female sage-grouse nest or random point was located from any power line or the Falcon–Gondor transmission line, respectively. Covar represents the environmental characteristics ($K = 8$) that influenced nest-site selection at the landscape scale: (distance from lek [−]; sagebrush cover classification [+]; sagebrush cover classification × distance from lek [−]; slope [−]; elevation [+]; slope × elevation [−]; distance from water [−]; and distance from water^2 [−]; Table SB2 in Appendix B). Subscripts represent the maximum extent (in km) to which the linear distance from the FG transmission or any power line was applied to nest-site selection. The log represents a model that used the natural log of the normalized distance from FG or any power line covariate + 0.001, which estimates a pseudo-threshold. All models included individual and year as random effects.

[b] The difference in Akaike's Information Criterion between the top ranked and selected model.

[c] The relative likelihood of a model (i.e., Akaike weights).

[d] The number of estimated parameters in a given model.

Avoidance of Power Lines

We found consistent support for the hypothesis that female sage-grouse avoided areas near any power line. Areas proximate to either the FG transmission line or any power line, which we otherwise predicted to be appropriate habitat for either nesting or brood rearing, were less likely to be used by female sage-grouse. Most notably, we found that the degree of avoidance during the nesting period was positively associated with raven abundance (Fig. 5). This novel result suggests that changes in predator density may be one mechanism driving the avoidance of potential nesting habitat near power lines. Raven populations have been positively associated with power lines (Knight and Kawashima 1993, Knight et al. 1995, Howe et al. 2014, Coates et al. 2014*a*), and sage-grouse avoid nesting in areas with high densities of avian nest predators (Dinkins et al. 2012). However, to our knowledge, we uniquely demonstrate that sage-grouse avoid nesting near power lines when faced with increased abundance of nest predators.

We also found that females avoided power lines during the brood-rearing period, and there are at least 2 possible explanations for this result. First, it is possible the effect carried over from avoidance behavior during nesting (Fig. 6) and lower nest survival near power lines (Fig. 7). Consequently, nesting habitat and early brood habitat were causally linked and fewer broods hatching near versus farther from power lines would have resulted in fewer broods using habitats near power lines during early brood rearing. Second, it is possible that females tending broods actively avoided areas near power lines. We cannot, however, distinguish between these 2 possibilities. Regardless of the mechanism, the combined effects of avoidance during nesting, reduced reproductive success, and lower likelihood of brood use near power lines resulted in a reduction in the effective quality of brood-rearing habitat in those areas, as such habitat is only functional if it is physically accessible (i.e., near successful nests) to broods (Aldridge and Boyce 2007, Gibson et al. 2017).

Suppression of Individual Vital Rates

We found variable support for reductions of vital rates as a function of proximity to power lines. Nesting propensity was not influenced by an individual's proximity to either the FG transmission line or any power line. However, we found support for greater re-nesting rates near the FG transmission line. This relationship was not directly related to reductions in nest survival near the FG transmission line, as our estimates of re-nesting propensity were conditional on nest failure, and did not directly increase as a function of increased nest failure. However, increased levels of nest predation may result in more nests failing earlier in the nesting season, which could indirectly increase re-nesting propensity by giving unsuccessful females more time to attempt a second nest, or leaving them in better body condition for such an attempt (Gregg et al. 2008). Sage-grouse nesting propensity has been negatively influenced by other anthropogenic disturbances (e.g., oil development; Lyon and Anderson 2003); however, these estimates were reported as apparent nesting propensity and are not directly comparable to our results (Blomberg et al. 2017).

Table 6. Performance of nest survival models assessing influence of power lines and common raven abundance on greater sage-grouse nest survival in Eureka County, NV, from 2004–2012. We considered variables in models that outperformed (lower ΔAIC) the Covar model and had 85% confidence intervals that did not overlap 0 to be explanatory.

Model[a]	ΔAIC_c[b]	w_i[c]	K[d]	Deviance
Covar + FG^2 × raven	0.00	0.25	8	1,502.42
Covar + FG × raven	1.38	0.13	7	1,505.81
Covar + FG^2	2.06	0.09	6	1,508.49
Covar	2.32	0.08	4	1,512.76
Covar + $power^2$	2.46	0.07	6	1,508.89
Covar + FG_{year}	2.48	0.07	13	1,494.85
Covar + FG	3.19	0.05	5	1,511.62
Covar + highway	3.63	0.04	5	1,512.06
Covar + raven	3.64	0.04	5	1,512.07
Covar + FG^2 + raven	3.71	0.04	7	1,508.14
Covar + power	3.86	0.04	5	1,512.29
Covar + road	4.01	0.03	5	1,512.44
Covar + $highway^2$	4.30	0.03	6	1,512.72
Covar + FG + raven	4.73	0.02	6	1,511.16
Covar + $road^2$	5.62	0.02	6	1,512.05

[a] FG and power represent the distance a female greater sage-grouse nest was located from the Falcon–Gondor transmission line or any power line, respectively. Highway and road represent the distance a female sage-grouse nest was located from one of the 2 state highways or any road, respectively. The covariate FG_{year} allowed the parameter estimate for distance from Falcon–Gondor to vary (fixed effect) among years. Covar represents the environmental characteristics ($K = 3$) that influenced nest survival (non-sagebrush shrub cover [+]; forb cover [+]; and population the female was associated with (i.e., Roberts Creek Mountain [+] or Cortez Mountains [−]; Table SB4 in Appendix B). Raven represents annual average number of common ravens observed along the survey transect along the Falcon–Gondor transmission line. We denote a quadratic relationship with a square notation (^{2}). Models with interactions include both the variables and their interaction.

[b] The difference in Akaike's Information Criterion between the top ranked and selected model.

[c] The relative likelihood of a model (i.e., Akaike weights).

[d] The number of estimated parameters in a given model.

Table 7. Performance of nest survival models assessing support of distance-threshold effects of distance from the Falcon–Gondor transmission line on greater sage-grouse nest success in Eureka County, Nevada, from 2004–2012. We considered variables in models that outperformed (lower ΔAIC) the Covar model and had 85% confidence intervals that did not overlap 0 to be explanatory.

Model[a]	ΔAIC_c[b]	w_i[c]	K[d]	Deviance
Covar + $FG_{12.5}$	0.00	0.19	5	1,509.04
Covar + FG_{10}	0.85	0.13	5	1,509.90
Covar	1.71	0.08	4	1,512.76
Covar + $power_{7.5}$	1.90	0.08	5	1,510.94
Covar + $power_{10}$	1.97	0.07	5	1,511.01
Covar + $FG_{7.5}$	2.18	0.07	5	1,511.22
Covar + $power_{12.5}$	2.52	0.06	5	1,511.56
Covar + FG	2.58	0.05	5	1,511.62
Covar + FG_{log}	2.60	0.05	5	1,511.64
Covar + $power_5$	2.68	0.05	5	1,511.72
Covar + power	3.25	0.04	5	1,512.29
Covar + $power_{log}$	3.35	0.04	5	1,512.39
Covar + $power_{2.5}$	3.46	0.03	5	1,512.50
Covar + FG_5	3.58	0.03	5	1,512.62
Covar + $FG_{2.5}$	3.71	0.03	5	1,512.75

[a] Covar represents the environmental characteristics ($K = 3$) that influenced nest survival (non-sagebrush shrub cover [+]; forb cover [+]; and population the female was associated with (i.e., Roberts Creek Mountain [+] or Cortez Mountain [−]; Table SB4 in Appendix B). FG and power represent the distance a female greater sage-grouse nest was located from the Falcon–Gondor transmission line or any power line, respectively. Subscripts represent the maximum extent (in km) to which the linear distance from the FG transmission or any power line was applied to the nest survival model and log represents a model that used the natural log of the normalized distance from FG or all power line covariate + 0.001, which estimates a pseudo-threshold.

[b] The difference in Akaike's Information Criterion between the top ranked and selected model.

[c] The relative likelihood of a model (i.e., Akaike weights).

[d] The number of estimated parameters in a given model.

Reductions in re-nesting propensity and the amount of habitat avoided were correlated with greater raven abundance, which suggests that power-line effects on reproductive decision-making by female sage-grouse was associated with nest predator densities. Nest survival was similarly reduced near the FG transmission line and negatively covaried with annual raven abundance. Together these results suggest that females may perceive increased risk of nest failure near power lines as a function of raven density, and respond by avoiding those areas or reducing their reproductive investment-or both-near power lines during years of high raven abundance. Together, these results are in agreement with the general ecological literature indicating that breeding individuals reduce fitness consequences associated with predation risk through habitat selection or reproductive flexibility (Lima 2009). For example, Eurasion skylarks (*Alauda arvensis*) shifted the distribution of their nests in response to shifts in kestrel (*Falco tinnunculus*) densities, and brant (*Branta bernicla bernicla*) had lower nest initiation rates when arctic foxes (*Vulpes lagopus*), a common nest predator, were present (Suhonen et al. 1994, Spaans et al. 1998). Likewise, female sage-grouse have also exhibited avoidance of brood-rearing habitat associated with greater raven densities (Dinkins et al. 2012), which suggests behavioral mechanisms exist in sage-grouse to reduce predation risk. Given the generally low rates

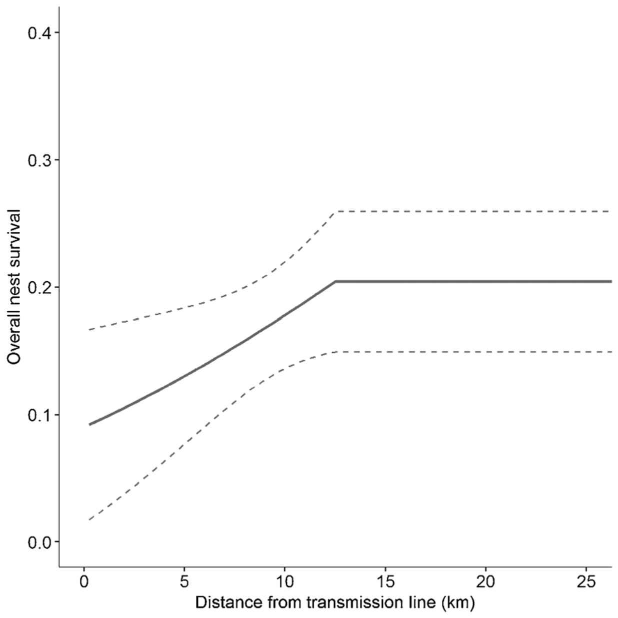

Figure 7. Relationship between the distance of a sage-grouse nest from the Falcon–Gondor (FG) line and its probability of surviving to hatch (to 37 days) in Eureka County, Nevada from 2004–2012. The threshold model that constrained the linear distance effect to end at 12.5 km (gray line) from the FG transmission line was most supported. Error lines (dashed lines) represent 95% confidence intervals.

of nest success in many sage-grouse populations (Connelly et al. 2011), lower rates of nesting combined with even lower nest survival associated with power lines is biologically significant.

We found more support for distance-threshold effects of any power line on sage-grouse behavior or demography than for simple linear models that considered the full range of observed

Table 8. Performance of resource selection functions (based on generalized linear mixed effects models) to assess the influence of a distance from power lines on greater sage-grouse brood-site use in Eureka County, Nevada, from 2005–2012. We considered variables in models that outperformed (lower ΔAIC) the Covar model and had 85% confidence intervals that did not overlap 0 to be explanatory.

Model[a]	ΔAIC_c[b]	w_i[c]	K[d]	Deviance
Covar + age + power	0.00	0.55	7	2,030.18
Covar + age × power	1.64	0.24	8	2,029.82
Covar + age	2.78	0.14	6	2,034.96
Covar + age + FG	4.78	0.05	7	2,034.96
Covar + age × FG	5.88	0.03	8	2,034.05
Covar + power	26.95	0.00	6	2,059.13
Covar + power^2	28.43	0.00	7	2,058.60
Covar	29.57	0.00	5	2,063.75
Covar + FG	31.57	0.00	6	2,063.75
Covar + FG^2	31.75	0.00	7	2,061.93

[a] FG and power represent the average distance a female sage-grouse brood or random point was located from the Falcon–Gondor transmission line or any power line, respectively. Covar represents the environmental characteristics ($K = 2$) that influenced brood-site selection (slope [−]; elevation [+]; see Table S3 in Appendix B). Age represented the age (in weeks) since the brood hatched. We denote a quadratic relationship with a square notation (^{2}). Models with interactions include both the variables and their interaction. All models included individual and year as random effects.

[b] The difference in Akaike's Information Criterion between the top ranked and selected model.

[c] The relative likelihood of a model (i.e., Akaike weights).

[d] The number of estimated parameters in a given model.

Table 9. Performance of resource selection functions based on generalized linear mixed effects models assessing support for distance-threshold effects in distance from the Falcon–Gondor transmission line on greater sage-grouse brood-site use in Eureka County, Nevada, from 2004–2012. We considered variables in models that outperformed (lower ΔAIC) the Covar model and had 85% confidence intervals that did not overlap 0 to be explanatory.

Model[a]	ΔAIC_c[b]	w_i[c]	K[d]	Deviance
Covar + power$_{7.5}$	0.00	0.99	6	2,042.12
Covar + power$_{\log}$	9.88	0.01	6	2,052.00
Covar + FG$_5$	11.65	0.00	6	2,053.77
Covar + power$_5$	15.32	0.00	6	2,057.44
Covar + FG$_{2.5}$	16.23	0.00	6	2,058.35
Covar + FG$_{7.5}$	16.68	0.00	6	2,058.80
Covar + power	17.01	0.00	6	2,059.13
Covar + power$_{10}$	17.12	0.00	6	2,059.24
Covar + FG$_{\log}$	19.10	0.00	6	2,061.22
Covar + power$_{12.5}$	19.61	0.00	6	2,061.73
Covar	19.63	0.00	5	2,063.75
Covar + power$_{2.5}$	20.49	0.00	6	2,062.62
Covar + FG$_{10}$	20.54	0.00	6	2,062.66
Covar + FG$_{12.5}$	21.62	0.00	6	2,063.74
Covar + FG	21.63	0.00	6	2,063.75

[a] Covar represents the environmental characteristics ($K = 2$) that influenced brood-site selection at the landscape scale (slope [−]; elevation [+]; see Table S3 in Appendix B). Age represented the age (in weeks) since the brood hatched. FG and power represent the average distance a female sage-grouse brood or random point was located from the Falcon–Gondor transmission line or any power line, respectively. Subscripts represent the maximum extent (in km) to which the linear distance from the FG transmission or any power line was applied to the brood-site selection function model and log represents a model that used the natural log of the normalized distance from FG or any power-line covariate + 0.001, which estimates a pseudo-threshold.

[b] The difference in Akaike's Information Criterion between the top ranked and selected model.

[c] The relative likelihood of a model (i.e., Akaike weights).

[d] The number of estimated parameters in a given model.

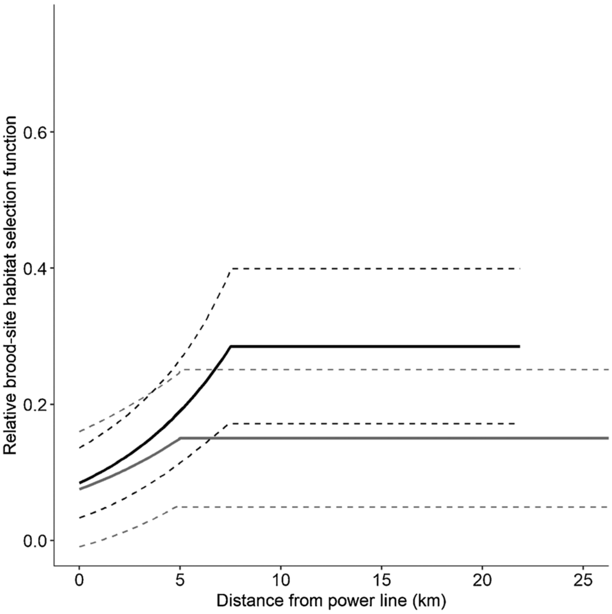

Figure 8. Relationships between distance from the Falcon–Gondor (FG; solid gray line) or any power line (solid black line) and the relative probability of selection of a point by sage-grouse as brood-rearing habitat in Eureka County, Nevada from 2005–2012. Models that applied the threshold constraint at 5 km from the FG transmission line, or 7.5 km from any power line were the most supported. Error lines (dashed lines) represent 95% confidence intervals.

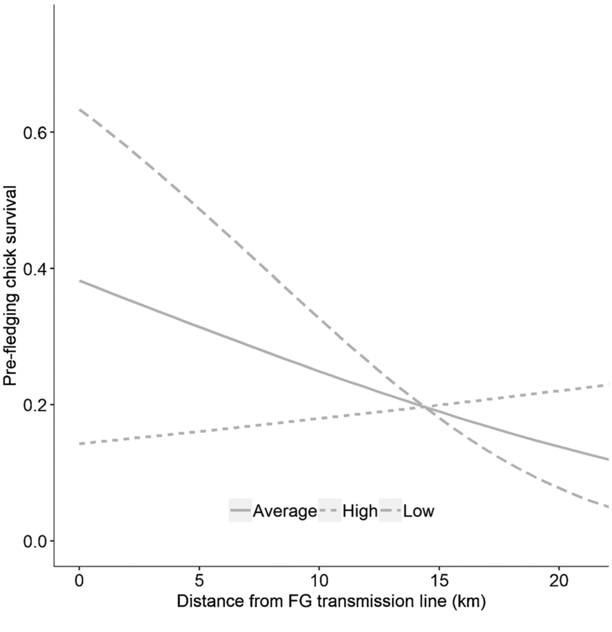

Figure 9. The association between the distance sage-grouse broods were from the Falcon–Gondor (FG) transmission line and 42-day pre-fledging chick survival varied as a function of common raven abundance (low: long-dash; average: solid; and high: short-dash) in Eureka County, Nevada from 2005–2012.

Table 10. Performance of Lukacs young of marked adults survival models assessing influence of power lines and common raven abundance on pre-fledging survival of greater sage-grouse chicks in Eureka County, Nevada, from 2005–2012. We considered variables in models that outperformed (lower ΔAIC) the Covar model and had 85% confidence intervals that did not overlap 0 to be explanatory.

Model[a]	ΔAIC_c[b]	w_i[c]	K[d]	Deviance
Covar + FG × raven	0.00	0.68	24	2,037.77
Covar + power^2	4.81	0.06	23	2,044.82
Covar + FG × trend	5.11	0.05	24	2,042.87
Covar + raptor	5.38	0.05	22	2,047.63
Covar	6.43	0.03	21	2,050.91
Covar + raven	6.46	0.03	22	2,048.71
Covar + FG + raptor	6.63	0.02	23	2,046.65
Covar + FG	7.29	0.02	22	2,049.54
Covar + FG^2	7.56	0.02	23	2,047.57
Covar + FG + raven	7.68	0.01	23	2,047.69
Covar + FG + trend	7.74	0.01	23	2,047.76
Covar + power	8.55	0.01	22	2,050.80
Covar + FG × raptor	8.80	0.01	24	2,046.56

[a] All models allowed detection probability to vary among years ($K = 8$) and weeks ($K = 4$) in an additive manner. FG and power were weekly time-varying covariates that represented the mean distance a female sage-grouse and her brood was from the Falcon–Gondor transmission line or any power line, respectively, in a given week. We denote a quadratic relationship with a square notation (^{2}). Models with interactions included both the variables and their interactions. Covar represents the environmental characteristics ($K = 8$) that influenced pre-fledging chick survival (drought severity index [+]; total vegetation cover [+]; distance brood moved in previous week [−]; average grass height [−]; distance from nearest water source [+]; nest-site quality [+]; female age [+]; female age^2 [−]; Table SB5 in Appendix B). Trend represents an annual trend. Raven represents annual average number of common ravens observed on the survey transect along the Falcon–Gondor transmission line. The final 2 weekly detection parameters were constrained to be the same, which resulted in the 6-occasion history having 4 estimated parameters for detection.

[b] The difference in Akaike's Information Criterion between the top ranked and selected model.

[c] The relative likelihood of a model (i.e., Akaike weights).

[d] The number of estimated parameters in a given model.

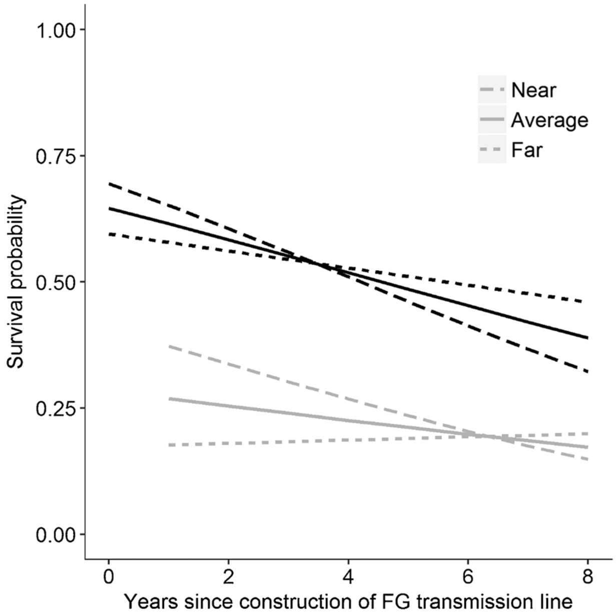

Figure 10. Sage-grouse 42-day pre-fledging chick survival (gray lines) and annual male survival (black lines) were supported to be both spatially (i.e., distance from the Falcon–Gondor [FG] transmission line [near: −1 SD from mean distance; average: mean distance; far: +1 SD from mean distance]) and temporally variable in Eureka County, Nevada from 2003–2012. Chick survival declined near and at average distance from the line over the duration of the study, whereas there was no trend far from the line. Survival of adult males declined at slower rates as distance from the line increased. Error lines represent 95% confidence intervals. Pre-fledging chick survival was not estimated prior to 2005.

distances, suggesting that the indirect effects of the FG transmission line were geographically limited to areas within 12.5 km of the FG transmission line. We found that the most spatially expansive impact of the FG transmission line was on nest survival, which occurred out to 12.5 km from the transmission line.

We observed that multiple vital rates (i.e., pre-fledging chick survival, male survival, *per capita* recruitment, and population growth) trended downwards since the construction of the FG transmission line. We also found that the strength of the effect of the FG transmission line was influenced by the number of ravens in the transmission line corridor, which exhibited an increasing trend in relative abundance during our study. Having only 1 year of pre-construction data limits our ability to draw inferences about raven responses to the presence of power lines versus a general numeric response of ravens due to other factors (e.g., general population growth). Nevertheless, the annual rate of increase of ravens along the FG line (9% increase/year) was about 3 times greater that the annual rate of increase for North America (2.7% increase/year) as a whole (BirdLife International 2017).

The mechanism(s) driving the declines in adult male survival for individuals near the FG transmission line are not completely clear. Although ravens are known to be predators of sage-grouse nests and young chicks, they are not known to kill adults (Hagen 2011). We did not have sufficient data to estimate variation in the abundances of mammalian predators of adult sage-grouse (e.g., coyotes [*Canis latrans*], American badgers [*Taxidea taxus*]) within this system; therefore, we could not design more targeted models related to adult male survival. Raptor abundances, however, were generally low and did not increase following the construction of the FG transmission line (Lammers and Collopy 2007; Fig. 3). Additionally, our index of relative raptor abundance explained little variation in adult female and male survival, or *per capita* recruitment. Nevertheless, the patterns we observed are consistent with hypothesized responses of ravens to elevated structures or other anthropogenic features (Knight et al. 1995, Kristan and Boarman 2003, Howe et al. 2014) and the effects of ravens on sage-grouse reproductive success (Coates and Delehanty 2004, Dinkins 2013) and recruitment.

We also found chick survival near the FG transmission line was reduced in years of high raven numbers. However, on average, areas near the FG transmission line were associated with the highest levels of chick survival in our system, which suggests this habitat remained the best option for brood-rearing (Kane et al. 2017) despite high mortality during years of greater predator abundance. Raven densities have been reported to be greater near sage-grouse brood-rearing areas (Bui et al. 2010), indicative of response (either numerical or functional) by ravens to increased food abundance.

Do Power Lines Lead to Population-Level Effects?

Although increased raven density has been associated with reduced nest survival across many taxa (Andren 1992, Kurki et al.

Table 11. Performance of Lukacs young of marked adults survival models assessing support of distance-threshold effects of distance from the Falcon–Gondor transmission line on pre-fledging survival of greater sage-grouse chicks in Eureka County, Nevada, from 2005–2012. We considered variables in models that outperformed (lower ΔAIC) the Covar model and had 85% confidence intervals that did not overlap 0 to be explanatory.

Model[a]	ΔAIC$_c$[b]	w_i[c]	K[d]	Deviance
Covar + power$_5$	0.00	0.22	22	2,046.08
Covar + power$_{7.5}$	0.24	0.19	22	2,046.32
Covar + FG$_{10}$	1.88	0.09	22	2,047.95
Covar + FG$_5$	1.97	0.08	22	2,048.05
Covar + FG$_{7.5}$	2.54	0.06	22	2,048.62
Covar + power$_{10}$	2.58	0.06	22	2,048.66
Covar	2.61	0.06	21	2,050.91
Covar + FG$_{\log}$	3.33	0.04	22	2,049.40
Covar + FG	3.47	0.04	22	2,049.54
Covar + FG$_{12.5}$	3.50	0.04	22	2,049.57
Covar + FG$_{2.5}$	4.01	0.03	22	2,050.09
Covar + power$_{12.5}$	4.10	0.03	22	2,050.17
Covar + power$_{\log}$	4.28	0.03	22	2,050.36
Covar + power	4.72	0.02	22	2,050.80
Covar + power$_{2.5}$	4.82	0.02	22	2,050.89

[a] Covar represents the environmental characteristics ($K = 8$) that influenced pre-fledging chick survival (drought severity index [+]; total vegetation cover [+]; distance brood moved in previous week [−]; average grass height [−]; distance from nearest water source [+]; nest-site quality [+]; female age [+]; female age^2 [−]; Table SB5 in Appendix B). FG and power were weekly time-varying covariates that represented the mean distance a female sage-grouse and her brood were from the Falcon–Gondor transmission line or any power line, respectively, in a given week. Subscripts represent the maximum extent (in km) to which the linear distance from the FG transmission or any power line was applied to pre-fledging chick survival and log represents a model that used the natural log of the normalized distance from FG, or any power-line covariate + 0.001, which estimates a pseudo-threshold.

[b] The difference in Akaike's Information Criterion between the top ranked and selected model.

[c] The relative likelihood of a model (i.e., Akaike weights).

[d] The number of estimated parameters in a given model.

1997, Klausen et al. 2010), support is lacking for population-level effects of ravens on avian populations in general (Madden et al. 2015). In our study, habitat use (e.g., nest- and brood-site selection) and reproductive success (e.g., nest survival, chick survival) were reduced for female sage-grouse near power lines, and this effect was linked to raven abundance. Most importantly, we found that 1) reductions in components of recruitment resulted in population-level effects; 2) recruitment of new males to breeding leks and rates of population growth were both reduced near the FG transmission line during years of high raven abundance; and 3) negative impacts on survival, recruitment, and population growth associated with any power line was observed at leks within 5 km of power lines regardless of raven abundance. Our observation of lowest recruitment into leks nearest the line is consistent with our finding of negative effects of proximity to the line on key components of the recruitment process: nest-site selection, nest success, and chick survival.

In summary, we found that multiple behaviors and vital rates estimated from a variety of data sources showed the same general pattern: vital rates were reduced, or individuals avoided habitat near power lines, generally when raven abundance was higher. Together, these analyses suggest power lines indirectly influenced various sage-grouse vital rates, and ultimately population growth, through the positive association of ravens with power lines. We posit that power lines created a subsidized resource for ravens resulting in increased raven densities near power lines. This increase led to habitat avoidance, lower vital rates, and population decline for sage-grouse near any power line in our study area.

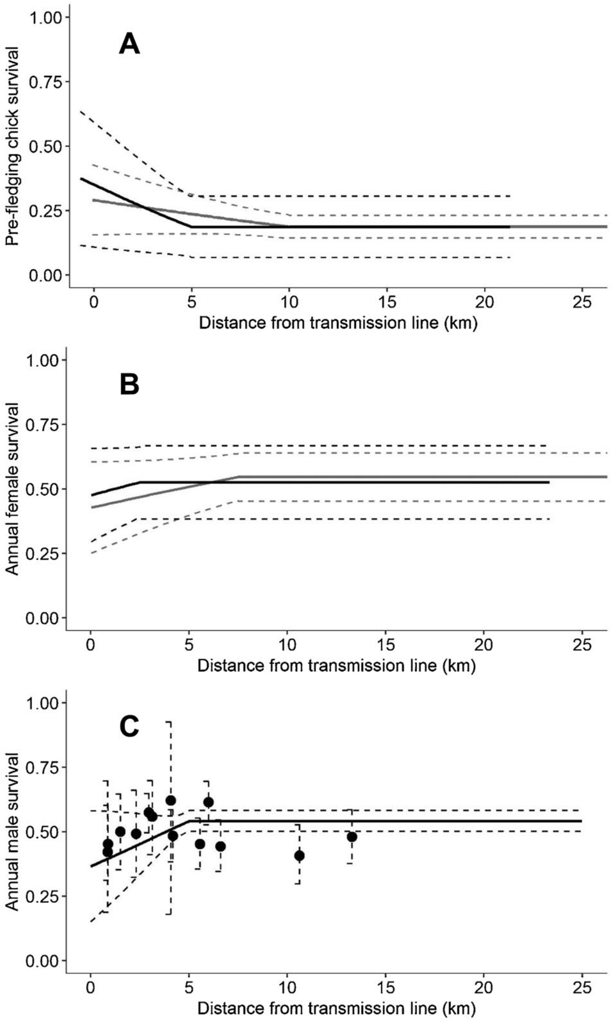

Figure 11. Sage-grouse 42-day pre-fledging chick survival (A), annual female survival (B), and annual male survival (C) were affected by an individual's association with the Falcon–Gondor (FG) transmission (gray lines) or any power line (black lines). The negative effect of distance from FG transmission line or any power line pre-fledging chick survival (A) extended out to 10 km and 5 km, respectively, which suggested that chick survival was greater near power lines relative to areas more distant. The positive effects of distance from FG transmission line or any power line on female survival (B) were weakly supported but extended out to 7.5 km and 2.5 km, respectively, which suggested female survival was slightly reduced near power lines. Lastly, for males associated with leks within 5 km of any power line, male survival (C) increased as a function of the lek's distance from any power line. Lek specific estimates of male survival are represented by circles. Error bars and lines represent 95% confidence intervals.

MANAGEMENT IMPLICATIONS

Our finding that negative impacts of the transmission line were primarily associated with raven abundance suggested that mitigation of line effects might be accomplished by reducing raven abundance near power lines. Ravens, like other corvids, have experienced a substantial increase in distribution and abundance that has been linked with increased energy

Table 12. Performance of nest survival models used to assess the influence of power lines on female greater sage-grouse survival in Eureka County, Nevada, from 2003–2012. We considered variables in models that outperformed (lower ΔAIC) the Covar model and had 85% confidence intervals that did not overlap 0 to be explanatory.

Model[a]	ΔAIC_c[b]	w_i[c]	K[d]	Deviance
Covar	0.00	0.34	8	386.46
Covar + raptor	1.45	0.17	9	386.29
Covar + power	1.87	0.13	9	386.29
Covar + FG	1.92	0.13	9	386.34
Covar + FG + raptor	3.34	0.06	10	385.77
Covar + power^2	3.83	0.05	10	386.22
Covar + FG^2	3.86	0.05	10	386.25
Covar × FG(trend)	4.75	0.03	11	385.10
Covar + FG × raptor	4.90	0.03	11	385.25

[a] FG and power were monthly time-varying covariates that represented the average distance a female sage-grouse was located from the Falcon–Gondor transmission line or any power line, respectively, in a given month. We denote a quadratic relationship with a square notation (^{2}). Covar represents the environmental characteristics ($K = 7$) that influenced female survival (minimum age [+]; nest success in given year [−]; brood success in given year [−]; seasonal differences: spring [−], summer [+], fall [−]; Table SB6 in Appendix B). Raptor represents annual average number of raptors observed along the survey transect along the Falcon–Gondor transmission line. Trend represents an annual linear trend. The covariate model was modified from Blomberg et al. (2013*a*).

[b] The difference in Akaike's Information Criterion between the top ranked and selected model.

[c] The relative likelihood of a model (i.e., Akaike weights).

[d] The number of estimated parameters in a given model.

Table 13. Performance of nest survival models used to assess support for distance-threshold effects of distance from transmission lines on adult female greater sage-grouse annual survival in Eureka County, Nevada, from 2003–2012. We considered variables in models that outperformed (lower ΔAIC) the Covar model and had 85% confidence intervals that did not overlap 0 to be explanatory.

Model[a]	ΔAIC_c[b]	w_i[c]	K[d]	Deviance
Covar + power$_{2.5}$	0.00	0.11	9	1,511.41
Covar + FG$_{7.5}$	0.14	0.10	9	1,511.55
Covar + FG$_5$	0.28	0.10	9	1,511.69
Covar + FG$_{12.5}$	0.36	0.09	9	1,511.78
Covar + FG$_{10}$	0.43	0.09	9	1,511.84
Covar	0.53	0.09	8	1,513.96
Covar + power$_{12.5}$	1.08	0.06	9	1,512.49
Covar + power$_{10}$	1.13	0.06	9	1,512.55
Covar + power$_5$	1.35	0.06	9	1,512.76
Covar + power	1.80	0.05	9	1,513.21
Covar + power$_{7.5}$	1.82	0.04	9	1,513.23
Covar + FG	1.90	0.04	9	1,513.31
Covar + power$_{\log}$	2.04	0.04	9	1,513.45
Covar + FG$_{2.5}$	2.54	0.03	9	1,513.95
Covar + FG$_{\log}$	2.54	0.03	9	1,513.95

[a] Covar represents the environmental characteristics ($K = 7$) that influenced female survival (minimum age [+]; nest success in given year [−]; brood success in given year [−]; seasonal differences: spring [−], summer [+], fall [−]; Table SB6 in Appendix B). FG and power were monthly time-varying covariates that represented the average distance a female sage-grouse was located from the Falcon–Gondor transmission line or any power line, respectively, in a given month. Subscripts represent the maximum extent (in km) to which the linear distance from the FG transmission or any power line was applied to female survival and log represents a model that used the natural log of the normalized distance from FG, or any power-line covariate + 0.001, which estimates a pseudo-threshold.

[b] The difference in Akaike's Information Criterion between the top ranked and selected model.

[c] The relative likelihood of a model (i.e., Akaike weights).

[d] The number of estimated parameters in a given model.

Table 14. Performance of multistate robust design models assessing the influence of transmission lines on male greater sage-grouse survival (φ) and among-lek movement rates (ψ) in Eureka County, Nevada, from 2003–2012. We considered variables in models that outperformed (lower ΔAIC) the φ(covar) ψ(.) model and had 85% confidence intervals that did not overlap 0 to be explanatory.

Model[a]	ΔAIC_c[b]	w_i[c]	K[d]	Deviance
φ(covar + FG × trend) ψ(.)	0.00	0.52	33	4,352.86
φ(covar + FG + trend) ψ(.)	0.75	0.36	32	4,355.70
φ(covar) ψ(.)	7.49	0.01	30	4,366.62
φ(covar + power$_5$) ψ(.)	7.80	0.01	31	4,364.85
φ(covar + FG$_5$) ψ(.)	7.84	0.01	31	4,364.88
φ(covar) ψ(FG$_{\log}$)	8.75	0.01	31	4,365.78
φ(covar) ψ(power$_5$)	8.89	0.01	31	4,365.93
φ(covar) ψ(FG$_5$)	8.96	0.01	31	4,366.01
φ(covar + power$_{\log}$) ψ(.)	9.11	0.01	31	4,366.16
φ(covar) ψ(power$_{\log}$)	9.28	0.01	31	4,366.32
φ(covar + power) ψ(.)	9.33	0.00	31	4,366.38
φ(covar + FG) ψ(.)	9.42	0.00	31	4,366.47
φ(covar + raptor) ψ(.)	9.47	0.00	31	4,366.51
φ(covar) ψ(power)	9.51	0.00	31	4,366.56
φ(covar) ψ(FG)	9.52	0.00	31	4,366.57
φ(covar + FG$_{\log}$)ψ(.)	9.54	0.00	31	4,366.59
φ(covar) ψ(FG^2)	9.80	0.00	32	4,364.75
φ(covar + FG^2) ψ(.)	10.73	0.00	32	4,365.68
φ(covar + power^2) ψ(.)	10.77	0.00	32	4,365.72
φ(covar) ψ(power^2)	11.38	0.00	32	4,366.33
φ(covar + FG + raptor) ψ(.)	11.54	0.00	32	4,366.50
φ(covar + FG × raptor) ψ(.)	13.40	0.00	33	4,366.25
φ(covar) ψ(FG × trend)	13.56	0.00	33	4,366.41

[a] All models allowed detection to vary among years (i.e., primary occasion; $K = 10$), months (i.e., secondary occasion; $K = 2$), and lek of capture ($K = 12$). Covar represents the environmental characteristics supported to influence male survival (lek elevation [+]; population the lek was associated with (Roberts [+]; Cortez [−]; the total precipitation recorded for the year prior [+]; Table SB7 in Appendix B). FG and power represent the distance from the lek with which a male was associated to Falcon–Gondor transmission line or any power line, respectively. Trend represents an annual trend. We denote a quadratic relationship with a square notation (^{2}). We modeled annual apparent survival (φ) and the annual probability of a male moving to a new breeding lek between years (ψ). Raptor represents annual average number of raptors observed on the survey transect along the Falcon–Gondor transmission line and (.) denotes the intercept-only model. Subscripts represent the maximum extent (in km) to which the linear distance from the FG transmission or any power line was applied to male survival and log represents a model that used the natural log of the normalized distance from FG, or any power-line covariate + 0.001, which estimates a pseudo-threshold.

[b] The difference in Akaike's Information Criterion between the top ranked and selected model.

[c] The relative likelihood of a model (i.e., Akaike weights).

[d] The number of estimated parameters in a given model.

infrastructure in some areas (Cunningham et al. 2015). Active removal of ravens in the area affected by power lines is one potential approach to mitigation. Across all avian taxa, predator control regimes, on average, have successfully improved individual reproductive parameters (Smith et al. 2010), and tend to be more effective if all predator taxa are removed because reductions in predation risk from the removed species may be compensated by increased risk from another predator (Ellis-Felege et al. 2012). Meta-analyses on the effectiveness of predator control, however, have not found that predator removal leads to observable growth in prey populations (Côté and Sutherland 1997, Smith et al. 2010), which may suggest that 1) predator removal was not effective in reducing predation by the target species; 2) reduced predation by the removed predator was

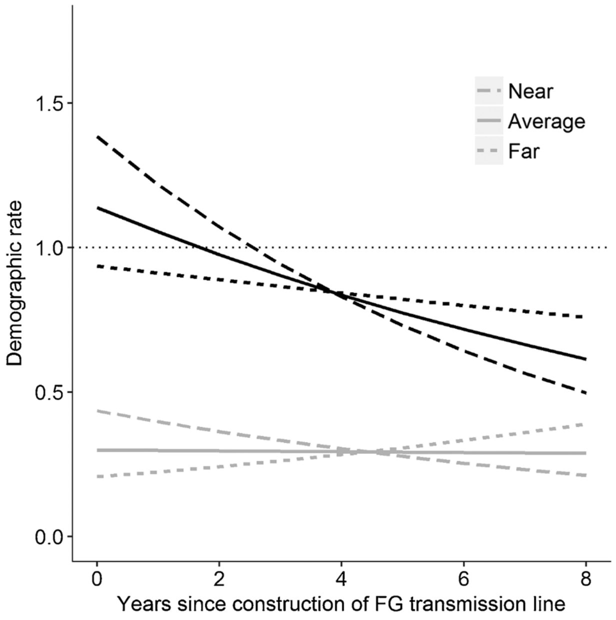

Figure 12. Sage-grouse *per capita* recruitment (gray lines) and population growth (λ, black lines) were both spatially (i.e., distance a lek was from the Falcon–Gondor [FG] transmission line [near: −1 SD from mean distance; average: mean distance; far: +1 SD from mean distance]) and temporally variable in Eureka County, Nevada from 2003–2012. Recruitment declined near the line, was stable at average distances, and slightly increased far from the line as the study progressed. Population growth declined at all distances from the line during the study; λ was >1 near and at average distances from the line early in the study, indicating a stable or increasing population in these areas, but declined to <1, indicating a declining population, by the second year of the study. Population growth was never >1 in habitats far from the line. Trend lines were generated from models that constrained each demographic parameter to vary as function of an interaction between a lek's distance from the transmission line and a yearly trend. Dotted line represents a λ value of 1.0, or stable population growth.

Table 15. Performance of robust design Pradel models used to assess the influence of distance from power lines and annual common raven abundance on lek-specific population growth of greater sage-grouse in Eureka County, Nevada, from 2003–2012. We considered variables in models that outperformed (lower ΔAIC) the Covar model and had 85% confidence intervals that did not overlap 0 to be explanatory.

Model[a,b]	ΔAIC_c[c]	w_i[d]	K[e]	Deviance
Covar + FG × trend	0.00	1.00	36	6,419.53
Covar + FG × raven	20.65	0.00	36	6,440.19
Covar + FG × raptor	26.04	0.00	36	6,445.57
Covar + FG + trend	34.27	0.00	35	6,455.95
Covar + FG_5	34.34	0.00	34	6,458.16
Covar + raven	34.92	0.00	34	6,458.74
Covar	36.00	0.00	33	6,461.96
Covar + $\text{power}_{\text{log}}$	36.68	0.00	34	6,460.50
Covar + FG + raven	36.81	0.00	35	6,458.49
Covar + power + raven	36.83	0.00	35	6,458.51
Covar + power_5	37.16	0.00	34	6,460.98
Covar + FG_{log}	37.40	0.00	34	6,561.22
Covar + FG^2	37.63	0.00	35	6,459.31
Covar + power^2	37.64	0.00	35	6,459.32
Covar + power	37.80	0.00	34	6,461.63
Covar + FG	37.96	0.00	34	6,461.78
Covar + raptor	38.12	0.00	34	6,461.94
Covar + FG + raptor	40.08	0.00	35	6,461.76

[a] Apparent survival was allowed to vary among years ($K = 9$), as was detection probability ($K = 10$) and lek ($K = 11$). Covar represents the suite of explanatory variables supported to influence lek-specific population growth rates (i.e., lek elevation [+]; annual precipitation [+]; Table SB9 in Appendix B). The suite of explanatory variables considered for this analysis was modified from Blomberg et al. (2013*b*). FG and power represent the distance from the lek with which a male was associated to Falcon–Gondor transmission line or any power line, respectively. Raven represents annual average number of common ravens observed on the survey transect along the Falcon–Gondor transmission line. Raptor represents annual average number of raptors observed on the survey transect along the Falcon–Gondor transmission line. Trend represents a year trend. We denote a quadratic relationship with a square notation (^{2}). Models with interactions consider both the variables and interaction terms. Subscripts represent the maximum extent (in km) to which the linear distance from the FG transmission or any power line was applied to lek-specific male population growth and log represents a model that used the natural log of the normalized distance from FG, or any power-line covariate + 0.001, which estimates a pseudo-threshold.

[b] See supplemental material (Table SB9 in Appendix B) for full model results.

[c] The difference in Akaike's Information Criterion between the top ranked and selected model.

[d] The relative likelihood of a model (i.e., Akaike weights).

[e] The number of estimated parameters in a given model.

compensated by increased predation by other predators; or 3) reductions in reproductive success and survival due to predation were compensated through density-dependent mechanisms that regulate population growth, or latent individual heterogeneity (Pettorelli et al. 2011, Lindberg et al. 2013).

The effectiveness of raven removal, primarily achieved through deployment of poisoned eggs or meat, for improving sage-grouse demographic rates is inconclusive (Hagen 2011). Control measures (i.e., poison baits) can effectively reduce raven populations; however, numbers of ravens removed may be overestimated (Coates et al. 2007). Also, it is not clear whether territorial ravens, which may disproportionately contribute to both population growth of ravens and reproductive failure in sage-grouse, are as susceptible to control measures as migratory or subadult ravens (Bui et al. 2010, Dinkins 2013, Harju et al. 2018). Additionally, support for a positive impact of raven removal on individual sage-grouse reproductive rates has been inconsistent (Coates and Delehanty 2004, Dinkins 2013, Orning 2013). Peebles et al. (2017) reported an increase in counts of male sage-grouse attending leks associated with a decline in local raven abundance; however, the demographic mechanism(s) that accounted for these changes in breeding male abundance could not be determined (e.g., shifts in reproductive success, lek attendance, or lek fidelity). Thus, more studies are needed to understand the effect of raven removal on population growth (Hagen 2011). Additionally, the extent that roads, and more importantly roadkill, influence raven foraging behavior, raven fitness, and the attractiveness of power lines as nesting territories for ravens remains unclear (Kristan et al. 2004). Thus, efficacy of raven management or removal measures requires well-designed studies to assess impacts of such mangement actions on raven populations and sage-grouse (Hagen 2011).

Installation of deterrents to perching and nesting offers another approach to reducing raven populations associated with power lines. Perch deterrents have been used extensively to reduce damage caused by perching birds on power-line towers or surrounding structures, to reduce electrocutions for species of conservation concern, and to reduce perching by avian predators on elevated structures (Lammers and Collopy 2007, Seamans et al. 2007, Lopez-Lopez et al. 2011, Dwyer and Leiker 2012). Typically, perch deterrents only inhibit the

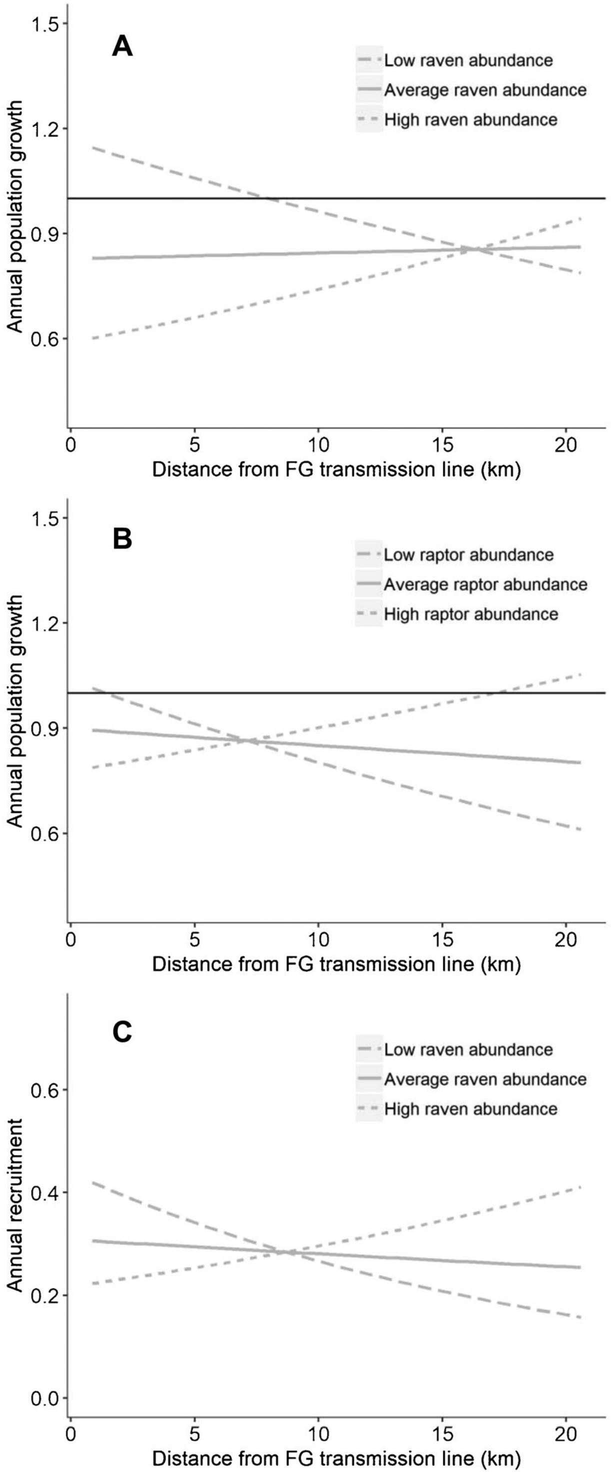

Figure 13. The relationships of sage-grouse population growth (A, B) and annual recruitment (C) as a function of the distance a lek was from the Falcon–Gondor (FG) transmission line were associated with relative common raven abundance (A, C) or relative raptor abundance (B) in Eureka County, Nevada from 2004–2012 (low: −1 SD from mean abundance; average: mean abundance; high: +1 SD from mean abundance). Population growth declined farther from the transmission line under both low raven and raptor abundance (long dashes) but increased with distance from the line under high raven and raptor abundance (short dashed). Recruitment also declined with increasing distance from the line under low raven abundance but increased with increasing distance from the line under high raven abundance. Under average weather conditions, only leks near the Falcon–Gondor line in years of low common raven abundance (i.e., before and shortly after construction) experienced positive population growth. Solid black line represents stable population growth.

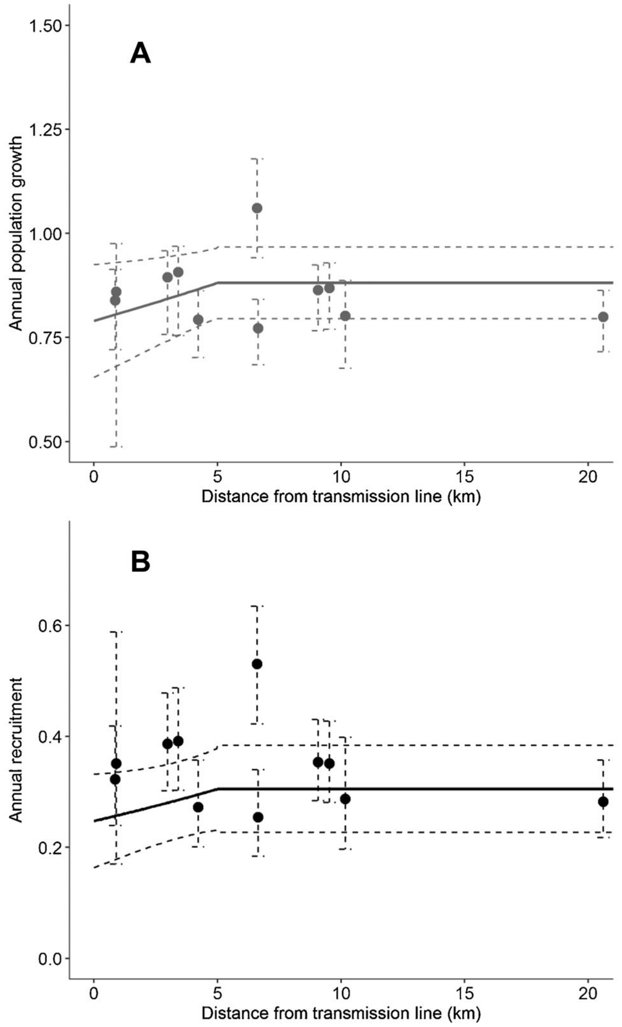

Figure 14. Greater sage-grouse population growth (A) for leks within 5 km of the Falcon–Gondor transmission line and greater sage-grouse annual recruitment (B) for leks within 5 km of any power line were negatively affected by the lek's proximity to a power line in Eureka County, Nevada from 2004–2012.

duration of perching bouts, meaning they are not perch inhibitors (Lammers and Collopy 2007). The overall effectiveness of perch deterrents on raven habitat use or foraging efficiency is questionable as some studies have reported short-term reductions in perching or habitat use related to perch deterrents (e.g., Slater and Smith 2010, Dwyer and Leiker 2012), whereas others failed to detect reductions in perching or nesting behavior (e.g., Lammers and Collopy 2007, Prather and Messmer 2010). Furthermore, we observed reductions in vital rates of sage-grouse that were associated with a transmission line (i.e., FG transmission line) although it was outfitted with perch deterrents within suitable sage-grouse habitat. We conclude that the use of currently available perch deterrents as a mitigation strategy for power-line impacts to sage-grouse is not singularly effective.

Alternative mitigation strategies could involve burying existing power lines within sage-grouse habitat (Fedy et al. 2015, Kirol et al. 2015) or routing new lines through non-habitat or areas less critical to local populations (Bagli et al. 2011). The effectiveness of these 2 approaches is conditioned on accurate delineations of

Table 16. Performance of robust design Pradel models used to assess the influence of distance from power lines and common ravens on lek-specific *per capita* recruitment rates of greater sage-grouse in Eureka County, Nevada, from 2003–2012. We considered variables in models that outperformed (lower ΔAIC) the Covar model and had 85% confidence intervals that did not overlap 0 to be explanatory.

Model[a,b]	$\Delta\mathrm{AIC}_c$[c]	w_i[d]	K[e]	Deviance
Covar + FG × trend	0.00	0.93	39	6,388.40
Covar + FG^2	6.76	0.03	38	6,397.33
Covar + FG × raven	7.45	0.02	39	6,395.85
Covar + power^2	8.55	0.01	38	6,399.11
Covar + power_5	12.70	0.00	37	6,405.41
Covar	12.70	0.00	36	6,407.56
Covar + $\mathrm{power}_{\log}$	13.46	0.00	37	6,406.17
Covar + FG_5	13.64	0.00	37	6,406.35
Covar + raptor	13.82	0.00	37	6,406.54
Covar + power	14.11	0.00	37	6,406.83
Covar + FG	14.13	0.00	37	6,406.85
Covar + raven	14.63	0.00	37	6,407.34
Covar + $\mathrm{FG}_{\log}$	14.67	0.00	37	6,407.39
Covar + FG + raptor	15.21	0.00	38	6,405.76
Covar + power + raven	16.02	0.00	38	6,406.58
Covar + FG + raven	16.16	0.00	38	6,406.73
Covar + FG + trend	16.18	0.00	38	6,406.74
Covar + FG × raptor	17.34	0.00	39	6,405.74

[a] Apparent survival was allowed to vary by year ($K = 10$). Detection was allowed to vary by year ($K = 10$) and lek ($K = 10$). Covar represents the suite of explanatory variables supported to influence lek-specific *per capita* recruitment (i.e., lek elevation [+]; annual precipitation [+]; total vegetation cover [+]; habitat converted to exotic grassland [−]; annual precipitation × habitat converted to exotic grassland [−]; Table SB8 in Appendix B). The suite of explanatory variables considered for this analysis was modified from Blomberg et al. (2013*b*). FG and power represent the distance from the lek with which a male was associated to Falcon–Gondor transmission line or any power line, respectively. Raptor represents annual average number of raptors observed on the survey transect along the Falcon–Gondor transmission line. Raven represents annual average number of common ravens observed along the survey transect along the Falcon–Gondor transmission line. Trend represents a year trend. We denote a quadratic relationship with a square notation (^{2}). Models with interactions include both the variables and interaction Subscripts represent the maximum extent (in km) to which the linear distance from the FG transmission or any power line was applied to lek-specific male recruitment and log represents a model that used the natural log of the normalized distance from FG, or any power-line covariate + 0.001, which estimates a pseudo-threshold.

[b] See supplemental material (Table SB8 in Appendix B) for model results.

[c] The difference in Akaike's Information Criterion between the top ranked and selected model.

[d] The relative likelihood of a model (i.e., Akaike weights).

[e] The number of estimated parameters in a given model.

Table 17. Performance of robust design occupancy models used to assess the influence of proximity to the Falcon-transmission line or nearest highway on common raven disturbance rates at greater sage-grouse leks in Eureka County, Nevada, from 2003–2012.

Model[a]	$\Delta\mathrm{AIC}_c$[b]	w_i[c]	K[d]	Deviance
$\psi(\mathrm{FG}_{\log})\ \gamma(\mathrm{trend})\ p(\mathrm{s})$	0.00	0.74	8	441.15
$\psi(\mathrm{FG}_{\log})\ \gamma(\mathrm{trend} + \mathrm{FG}_{\log})\ p(\mathrm{s})$	2.33	0.23	9	441.12
$\psi(\mathrm{FG}_{\log})\ \gamma(.)\ p(\mathrm{s})$	8.26	0.01	7	451.72
$\psi(\mathrm{FG}_{10})\ \gamma(.)\ p(\mathrm{s})$	10.49	0.00	7	453.95
$\psi(\mathrm{highway}_{\log})\ \gamma(.)\ p(\mathrm{s})$	11.27	0.00	7	454.73
$\psi(\mathrm{FG}_{7.5})\ \gamma(.)\ p(\mathrm{s})$	11.62	0.00	7	455.08
$\psi(\mathrm{highway}_{10})\ \gamma(.)\ p(\mathrm{s})$	11.82	0.00	7	455.28
$\psi(\mathrm{highway})\ \gamma(.)\ p(\mathrm{s})$	12.13	0.00	7	455.59
$\psi(\mathrm{FG})\ \gamma(.)\ p(\mathrm{s})$	12.49	0.00	7	455.95
$\psi(\mathrm{highway}_5)\ \gamma(.)\ p(\mathrm{s})$	12.55	0.00	7	456.01
$\psi(\mathrm{FG}^2)\ \gamma(.)\ p(\mathrm{s})$	12.57	0.00	8	453.73
$\psi(\mathrm{highway}_{7.5})\ \gamma(.)\ p(\mathrm{s})$	12.72	0.00	7	456.18
$\psi(.)\ \gamma(.)\ p(\mathrm{s})$	12.80	0.00	6	458.53
$\psi(\mathrm{highway}^2)\ \gamma(.)\ p(\mathrm{s})$	13.52	0.00	8	454.67
$\psi(\mathrm{FG}_5)\ \gamma(.)\ p(\mathrm{s})$	14.86	0.00	7	458.32

[a] Annual occupancy denoted by (ψ). Local colonization denoted by (γ). Detection (p) was allowed to vary by secondary occasion ($n = 4$). Highway and FG represent each lek's distance from any state highway or the Falcon–Gondor transmission line, respectively. Trend represents a year trend. Subscripts represent the maximum extent (in km) to which the linear distance from the FG transmission or any highway was applied to raven occupancy of sage-grouse leks and log represents a model that used the natural log of the normalized distance from FG transmission line or any highway covariate + 0.001, which estimates a pseudo-threshold.

[b] The difference in Akaike's Information Criterion between the top ranked and selected model.

[c] The relative likelihood of a model (i.e., Akaike weights).

[d] The number of estimated parameters in a given model.

critical habitat, defined in the United States as the "geographic area occupied by the species" (U.S. Department of the Interior 2014: 27069), which is widespread for sage-grouse (Aldridge and Boyce 2007, Doherty et al. 2008, Kaczor et al. 2011, Fedy et al. 2014). Both of these measures result in increased cost to developers (Fenrick and Getachew 2012). However, some of these costs may be recouped because underground lines are often more reliable, less susceptible to environmental damage, and require less maintenance (Hall 2009). Furthermore, cost-benefit analyses suggest that realized cost differentials, after accounting for other costs (e.g., aesthetics, wildlife interactions, maintenance) between underground and overhead transmission lines, may be less than previously thought (Navrud et al. 2008), and many countries in Europe have adopted this strategy (Lehman et al. 2007). Sage-grouse have positively responded (e.g., reduced avoidance behavior, increased nest survival rates) to mitigation treatments, which included burying power lines and other reductions in surface disturbance (Fedy et al. 2015, Kirol et al. 2015). However, the response of individual vital rates to removal of transmission towers is unclear, and these studies could not

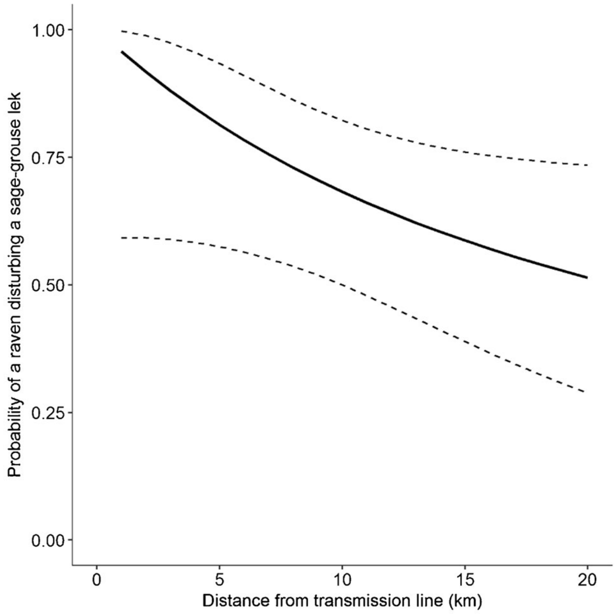

Figure 15. The association between the probability of common raven occupancy of an area surrounding a greater sage-grouse lek and the lek's distance from the Falcon–Gondor transmission line in Eureka County, Nevada from 2004–2012.

Table 18. Summary of the overall impacts of the Falcon–Gondor transmission line (FG) and all power lines on greater sage-grouse demography or behavior. The spatial extent, direction, and associations with nest predators, such as common ravens were variable among analyses.

Demographic rate or behavior	Linear power-line effect[a]	Trend since FG construction	FG threshold	Any power-line threshold	Negatively associated with common raven abundance
Nesting propensity	No	Not determined	No	No	No
Re-nesting propensity	(+)	Not determined	10–12.5 km (+)	No	Yes
Nest-site selection	(−)	Not determined	<3 km (−)	>10 km (−)	Yes
Nest survival	(−)	Not determined	10–12.5 km (−)	No	Yes
Brood-rearing habitat selection	(−)	Not determined	5 km (−)	7.5 km (−)	Not determined
Pre-fledging chick survival	(+)	Negative	10 km (+)	5 km (+)	Yes
Adult female survival	No	No	No	No	Not determined
Adult male survival	(−)	Negative	No	5 km (−)	Not determined
Male population growth	(−)	Negative	5 km (−)	5 km (−)	Yes
Per capita recruitment	(−)	Negative	No	5 km (−)	Yes
Ravenoccupancy or abundance	(+)	Positive	5 km (−)	Not determined	Not determined

[a] (+) power-line effect means that the demographic rate was greater closer to the line relative to more distant, whereas a (−) effect indicates that demographic rates were greater farther from the line relative to closer.

quantify the overall impact of mitigation efforts on population growth. Additionally, surface disturbance associated with a buried line may still result in landscape-level changes, such as introduction of exotic grasses or reduction of shrub cover, which elicit a response by ravens through the creation of edge habitat (Howe et al. 2014). Additional research is required to determine if burying power lines is an effective strategy for reducing local raven abundance or their effectiveness as predators, and results in improved probabilities of sage-grouse population persistence.

Other possible mitigation strategies include constructing new transmission lines in currently existing power-line rights-of-way (i.e., co-locating). Although we doubt this approach, singularly, would reduce the influence of existing corridors on sage-grouse demographic rates, it would reduce the cumulative impact of power lines on sage-grouse through time by reducing the cumulative development footprint relative to plans that proposed multiple spatially independent power-line corridors (Hansen et al. 2016). Future work, however, is needed to assess whether avian predator use of these super-corridors scales linearly with total number of perching sites, or if other mechanisms influence their attractiveness as habitat. Mitigation plans also should consider alternative designs of power lines or poles. Although the design of power lines can influence electrocution rates of large-bodied birds (Janss 2000), studies are lacking that demonstrate power lines with reduced surface area of potential nesting substrate (e.g., no horizontal crossbeams) are used less by avian predators relative to standard power-pole line designs.

Gaps remain in our knowledge of the efficacy of various power-line mitigation strategies for management of sage-grouse populations. Until the necessary research has been completed, we recommend that management agencies throughout the sage-grouse range assume at least a 10-km radius of disturbance when planning the placement of new power-line corridors, and provide preferential treatment to mitigation strategies that reduce the number of elevated structures placed within 10 km of critical sage-grouse habitat.

SUMMARY

1. Power lines can alter wildlife population dynamics by influencing survival, reproduction, habitat selection, and movements of individuals through increased presence of electromagnetic fields, avoidance of elevated structures, or increased harassment by predators associated with elevated structures.
2. In 2004, a 345-kV transmission line (i.e., Falcon–Gondor transmission line) was completed in central Nevada, USA. The completed transmission line was approximately 299-km long and located partially in habitats of greater sage-grouse.
3. Relative abundance of common ravens near the Falcon–Gondor transmission line increased throughout the 9 years of post-construction monitoring more rapidly than ravens in the Great Basin as a whole, suggesting a numerical response by ravens to the Falcon–Gondor line.
4. Nest-site selection and nest survival of greater sage-grouse were lower in areas closer to the Falcon–Gondor transmission line. Additionally, the magnitude of the effect of the transmission line on nest-site selection and nest survival interacted with an abundance index of common ravens. Together, these results suggest that changes in predator distribution across the landscape may be influencing the avoidance behavior of individuals nesting in suitable habitat near power lines.
5. Relative abundance of ravens or the association between raven abundance and an individual's distance from the Falcon–Gondor transmission also was associated with reductions in greater sage-grouse re-nesting propensity, pre-fledging chick survival, *per capita* recruitment, and population growth. Thus, shifts in individual reproductive potentials related to changes in predator communities resulted in population-level impacts.
6. We found that habitats near the footprint of the FG transmission line were more productive (e.g., greater reproductive success and population growth) than areas farther from the transmission line before and immediately after construction. However, demographic rates in habitats near the transmission line have generally declined in the years following construction, associated with the increase in common ravens.
7. We found that leks located within 5 km of power lines were negatively influenced by their proximity to power lines. Males associated with close leks had lower survival than males associated with leks more distant from power lines. *Per capita* recruitment and population growth at these leks were similarly affected.

8. The geographical extent to which power lines negatively influence greater sage-grouse demographic processes is not completely generalizable because it was contingent on local raven abundance or behavior. In this system, we found that effects of power lines exceeded current maximum recommendations for placement of tall structures relative to active sage-grouse leks (8 km; Manier et al. 2014), and extended to at least 10 km from transmission lines and up to 7.5 km from any power line.

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LITERATURE CITED

Aldridge, C. L., and M. S. Boyce. 2007. Linking occurrence and fitness to persistence: habitat-based approach for endangered greater sage-grouse. Ecological Applications 17:508–526.

Andren, H. 1992. Corvid density and nest predation in relation to forest fragmentation—a landscape perspective. Ecology 73:794–804.

Arnold, T. W. 2010. Uninformative parameters and model selection using Akaike's Information Criterion. Journal of Wildlife Management 74:1175–1178.

Atamian, M. T., J. S. Sedinger, J. S. Heaton, and E. J. Blomberg. 2010. Landscape-level assessment of brood rearing habitat for greater sage-grouse in Nevada. Journal of Wildlife Management 74:1533–1543.

Bagli, S., D. Geneletti, and F. Orsi. 2011. Routeing of power lines through least-cost path analysis and multicriteria evaluation to minimise environmental impacts. Environmental Impact Assessment Review 31:234–239.

Balmori, A., and O. Hallberg. 2007. The urban decline of the house sparrow (*Passer domesticus*): a possible link with electromagnetic radiation. Electromagnetic Biology and Medicine 26:141–151.

Bates, D. M., and M. Maechler. 2010. lme4: linear mixed-effects models using S4 classes. R package version 0.999375-36/r1083. http://R-Forge.R-project.org/projects/lme4/. Accessed 19 May 2013.

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.

Benitez-Lopez, A., R. Alkemade, and P. A. Verweij. 2010. The impacts of roads and other infrastructure on mammal and bird populations: a meta-analysis. Biological Conservation 143:1307–1316.

Bevanger, K. 1998. Biological and conservation aspects of bird mortality caused by electricity power lines: a review. Biological Conservation 86:67–76.

Bevanger, K., and H. Broseth. 2001. Bird collisions with power lines—an experiment with ptarmigan (*Lagopus* spp.). Biological Conservation 99:341–346.

Bevanger, K., and H. Broseth. 2004. Impact of power lines on bird mortality in a subalpine area. Animal Biodiversity and Conservation 27:67–77.

BirdLife International. 2017. Species factsheet: *Corvus corax*. http://www.birdlife.org. Accessed 10 Dec 2017.

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

Blomberg, E. J., D. Gibson, and J. S. Sedinger. 2015. Biases in nest survival associated with choice of exposure period; a case study for North American upland game birds. Condor: Ornithological Applications 117:577–588.

Blomberg, E. J., D. Gibson, and J. S. Sedinger. 2017. Variable drivers of primary versus secondary nesting; density-dependence and drought effects on greater sage-grouse. Journal of Avian Biology 48:827–836.

Blomberg, E. J., D. Gibson, J. S. Sedinger, M. L. Casazza, and P. S. Coates. 2013*a*. Intraseasonal variation in survival and probable causes of mortality in greater sage-grouse *Centrocercus urophasianus*. Wildlife Biology 19:347–357.

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 3:55.

Blomberg, E. J., J. S. Sedinger, D. Gibson, P. S. Coates, and M. L. Casazza. 2014. Carryover effects and climatic conditions influence the postfledging survival of greater sage-grouse. Ecology and Evolution 4:4488–4499.

Blomberg, E. J., J. S. Sedinger, D. V. Nonne, and M. T. Atamian. 2013*b*. Annual male lek attendance influences count-based population indices of greater sage-grouse. Journal of Wildlife Management 77:1583–1592.

Blomberg, E. J., J. S. Sedinger, D. V. Nonne, and M. T. Atamian. 2013*c*. Seasonal reproductive costs contribute to reduced survival of female greater sage-grouse. Journal of Avian Biology 44:149–158.

Boarman, W. I. 2003. Managing a subsidized predator population: reducing common raven predation on desert tortoises. Environmental Management 32:205–217.

Borell, A. E. 1939. Telephone wires fatal to sage grouse. Condor 41:85–86.

Boyce, M. S., and L. L. McDonald. 1999. Relating populations to habitats using resource selection functions. Trends in Ecology & Evolution 14:268–272.

Braun, C. E. 1998. Sage-grouse declines in western North America: what are the problems? Proceedings of the Western Association of State Fish and Wildlife Agencies 78:139–156.

Brussee, B. E., and P. S. Coates. 2018. Reproductive success of common ravens influences nest predation rates of their prey: implications for egg-oiling techniques. Avian Conservation and Ecology 13:17.

Bui, T.-V. D., J. M. Marzluff, and B. Bedrosian. 2010. Common raven activity in relation to land use in western Wyoming: implications for greater sage-grouse reproductive success. Condor 112:65–78.

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

Canfield, R. H. 1941. Application of the line interception method in sampling range vegetation. Journal of Forestry 39:388–394.

Coates, P. S., J. W. Connelly, and D. J. Delehanty. 2008. Predators of greater sage-grouse nests identified by video monitoring. Journal of Field Ornithology 79:421–428.

Coates, P. S., and D. J. Delehanty. 2004. The effects of raven removal on sage grouse nest success. Proceedings of the Vertebrate Pest Conference 21:17–20.

Coates, P. S., and D. J. Delehanty. 2010. Nest predation of greater sage-grouse in relation to microhabitat factors and predators. Journal of Wildlife Management 74:240–248.

Coates, P. S., K. B. Howe, M. L. Casazza, and D. J. Delehanty. 2014*a*. Common raven occurrence in relation to energy transmission line corridors transiting human-altered sagebrush steppe. Journal of Arid Environments 111:68–78.

Coates, P. S., K. B. Howe, M. L. Casazza, and D. J. Delehanty. 2014*b*. Landscape alterations influence differential habitat use of nesting buteos and ravens within sagebrush ecosystem: implications for transmission line development. Condor 116:341–356.

Coates, P. S., M. A. Ricca, B. G. Prochazka, M. L. Brooks, K. E. Doherty, T. Kroger, E. J. Blomberg, C. A. Hagen, and M. L. Casazza. 2016. Wildfire, climate, and invasive grass interactions negatively impact an indicator species by reshaping sagebrush ecosystems. PNAS 113:12745–12750.

Coates, P. S., J. O. Spencer, Jr., and D. J. Delehanty. 2007. Efficacy of CPTH-treated egg baits for removing ravens. Human-Wildlife Conflicts 1:224–234

Connelly, J. W., A. D. Apa, R. B. Smith, and K. P. Reese. 2000. Effects of predation and hunting on adult sage-grouse *Centrocercus urophasianus* in Idaho. Wildlife Biology 6:227–232.

Connelly, J. W., C. A. Hagen, and M. A. Schroeder. 2011. Characteristics and dynamics of greater sage-grouse populations. Studies in Avian Biology 38:53–68.

Copeland, H. E., A. Pocewicz, and J. M. Kiesecker. 2011. Geography of energy development in western North America: potential impacts on terrestrial ecosystems. Pages 7–22 *in* D. Naugle, editor. Energy development and wildlife conservation in western North America. Island Press, Washington, D.C., USA.

Côté, I. M., and W. J. Sutherland. 1997. The effectiveness of removing predators to protect bird populations. Conservation Biology 11:395–405.

Cunningham, S. J., C. F. Madden, P. Bamard, and A. Amar. 2015. Electric crows: powerlines, climate change and the emergence of a native invader. Diversity and Distributions 22:17–29.

Daubenmire, R. F. 1959. Canopy coverage method of vegetation analysis. Northwest Science 33:43–64.

DeGregorio, B. A., P. J. Weatherhead, and J. H. Sperry. 2014. Power lines, roads, and avian nest survival: effects on predator identity and predation intensity. Ecology and Evolution 4:1589–1600.

Dinkins, J. B. 2013. Common raven density and greater sage-grouse nesting success in southern Wyoming: potential conservation and management implications. Dissertation, Utah State University, Logan, USA.

Dinkins, J. B., M. R. Conover, C. P. Kirol, and J. L. Beck. 2012. Greater sage-grouse (*Centrocercus urophasianus*) select nest sites and brood sites away from avian predators. Auk 129:600–610.

Dinkins, J. B., M. R. Conover, C. P. Kirol, J. L. Beck, and S. N. Frey. 2014*a*. Greater sage-grouse (*Centrocercus urophasianus*) hen survival: effects of raptors, anthropogenic and landscape features, and hen behavior. Canadian Journal of Zoology 92:319–330.

Dinkins, J. B., M. R. Conover, C. P. Kirol, J. L. Beck, and S. N. Frey. 2014*b*. Greater sage-grouse (*Centrocercus urophasianus*) select habitat based on avian predators, landscape composition, and anthropogenic features. Condor 116:629–642.

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

Doherty, K. E., D. E. Naugle, B. L. Walker, and J. M. Graham. 2008. Greater sage-grouse winter habitat selection and energy development. Journal of Wildlife Management 72:187–195.

Dugger, K. M., F. Wagner, R. G. Anthony, and G. S. Olson. 2005. The relationship between habitat characteristics and demographic performance of northern spotted owls in southern Oregon. Condor 107:863–878.

Dwyer, J. F., and D. L. Leiker. 2012. Managing nesting by Chihuahuan ravens on H-frame electric transmission structures. Wildlife Society Bulletin 36:336–341.

Ellis, K. L. 1984. Behavior of lekking sage-grouse in response to a perched golden eagle. Western Birds 15:37–38.

Ellis-Felege, S. N., M. J. Conroy, W. E. Palmer, and J. P. Carroll. 2012. Predator reduction results in compensatory shifts in losses of avian ground nests. Journal of Applied Ecology 49:661–669.

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

Fedy, B. C., K. E. Doherty, C. L. Aldridge, M. O'Donnell, J. L. Beck, B. Bedrosian, D. Gummer, M. J. Holloran, G. D. Johnson, N. W. Kaczor, C. P. Kirol, C. A. Mandich, D. Marshall, G. McKee, C. Olson, A. C. Pratt, C. C. Swanson, and B. L. Walker. 2014. Habitat prioritization across large landscapes, multiple seasons, and novel areas: an example using greater sage-grouse in Wyoming. Wildlife Monographs 190:1–39.

Fedy, B. C., C. P. Kirol, A. L. Sutphin, and T. L. Maechtle. 2015. The influence of mitigation on sage-grouse habitat selection within an energy development field. PLoS ONE 10:e0121603. doi:0121610.0121371/journal.pone.0121603

Fenrick, S. A., and L. Getachew. 2012. Cost and reliability comparisons of underground and overhead power lines. Utilities Policy 20:31–37.

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

Garton, E. O., J. W. Connelly, J. S. Horne, C. A. Hagen, A. Moser, and M. A. Schroeder. 2011. Greater sage-grouse population dynamics and probability of persistence. Studies in Avian Biology 38:293–381.

Garton, E. O., A. G. Wells, J. A. Baumgardt, and J. W. Connelly. 2015. Greater sage-grouse population dynamics and probability of persistence. Pew Charitable Trusts, Philadelphia, Pennsylvania, USA.

Gerber, L. R., D. P. DeMaster, and P. M. Kareiva. 1999. Gray whales and the value of monitering data in implementing the U.S. endangered species act. Conservation Biology 13:1215–1219

Gibson, D., E. J. Blomberg, M. T. Atamian, and J. S. Sedinger. 2014. Lek fidelity and movement among leks by male greater sage-grouse *Centrocercus urophasianus*: a capture-mark-recapture approach. Ibis 156:729–740.

Gibson, D., E. J. Blomberg, M. T. Atamian, and J. S. Sedinger. 2015. Observer effects strongly influence estimates of daily nest survival probability but do not substantially increase rates of nest failure in greater sage-grouse Auk 132:397–407.

Gibson, D., E. J. Blomberg, M. T. Atamian, and J. S. Sedinger. 2016. Nesting habitat selection influences nest and early offspring survival in greater sage-grouse. Condor 18:689–702.

Gibson, D., E. J. Blomberg, M. T. Atamian, and J. S. Sedinger. 2017. Weather, habitat composition, and female behavior interact to determine offspring survival in greater sage-grouse. Ecological Applications 27:168–181.

Gibson, D., E. J. Blomberg, G. L. Patricelli, A. H. Krakauer, M. T. Atamian, and J. S. Sedinger. 2013. Effects of radio collars on survival and lekking behavior of male greater sage-grouse. Condor 115:769–776.

Green, R. H. 1979. Sampling design and statistical methods for environmental biologists. Wiley, Chichester, United Kingdom.

Green, R. H. 1993. Application of repeated-measures designs in environmental-impact and monitoring studies. Australian Journal of Ecology 18:81–98.

Gregg, M. A., J. K. Barnett, and J. A. Crawford. 2008. Temporal variation in diet and nutrition of preincubating greater sage-grouse. Rangeland Ecology & Management 61:535–542.

Gregg, M. A., J. A. Crawford, M. S. Drut, and A. K. Delong. 1994. Vegetational cover and predation of sage grouse nests in Oregon. Journal of Wildlife Management 58:162–166.

Hagen, C. A. 2011. Predation on greater sage-grouse: facts, process, and effects. Studies in Avian Biology 38:95–100.

Hall, K. L. 2009. Out of sight, out of mind revisited: an updated study on undergrounding of overhead power lines. Edison Electric Institute Web 16.10. 11.

Hamilton, S. W., and G. M. Schwann. 1995. Do high-voltage electric transmission-lines affect property value. Land Economics 71:436–444.

Hansen, E. P., A. C. Stewert, 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.

Harju, S. M., C. V. Olson, J. E. Hess, and B. Bedrosian. 2018. Common raven movement and space use: influence of anthropogenic subsidies within greater sage-grouse nesting habitat. Ecosphere 9:e02348

Hebblewhite, M., and E. Merrill. 2008. Modelling wildlife-human relationships for social species with mixed-effects resource selection models. Journal of Applied Ecology 45:834–844.

Holloran, M. J., B. C. Fedy, and J. Dahlke. 2015. Winter habitat use of greater sage-grouse relative to activity levels at natural gas well pads. Journal of Wildlife Management 79:630–640.

Holloran, M. J., R. C. Kaiser, and W. A. Hubert. 2010. Yearling greater sage-grouse response to energy development in Wyoming. Journal of Wildlife Management 74:65–72.

Hovick, T. J., R. D. Elmore, D. K. Dahlgren, S. D. Fuhlendorf, and D. M. Engle. 2014. Evidence of negative effects of anthropogenic structures on wildlife: a review of grouse survival and behaviour. Journal of Applied Ecology 51:1680–1689.

Howe, K. B., P. S. Coates, and D. J. Delehanty. 2014. Selection of anthropogenic features and vegetation characteristics by nesting common ravens in the sagebrush ecosystem. Condor 116:35–49.

Jahner, J. P., D. Gibson, C. L. Weitzman, E. J. Blomberg, J. S. Sedinger, and T. L. Parchman. 2016. Lek breeding and geography drive fine-scale genetic structure of sage-grouse. BMC Evolutionary Biology 16:127. doi: 10.1186/s12862-016- 0702-4

Janss, G. F. E. 2000. Avian mortality from power lines: a morphologic approach of a species-specific mortality. Biological Conservation 95:353–359.

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. Studies in Avian Biology 38:407–450.

Johnson, M. J., P. S. Giller, J. O'Halloran, K. O'Gorman, and M. B. Gallaher. 2005. A novel approach to assess the impact of landuse activity on chemical and biological parameters in river catchments. Freshwater Biology 50: 1273–1289.

Jones, N. F., L. Pejchar, and J. M. Kiesecker. 2015. The energy footprint: how oil, natural gas, and wind energy affect land for biodiversity and the flow of ecosystem services. Bioscience 65:290–301.

Kaczor, N. W., K. C. Jensen, R. W. Klaver, M. A. Rumble, K. M. Herman-Brunson, and C. C. Swanson. 2011. Nesting success and resource selection of greater sage-grouse. Ecology, Conservation, and Management of Grouse 39:107–118.

Kane, K., J. S. Sedinger, D. Gibson, E. J. Blomberg, and M. T. Atamian. 2017. Fitness landscapes and life table response experiments predict the importance of local areas to population dynamics. Ecosphere 8:e01869

Kirol, C. P., A. L. Sutphin, L. Bond, M. R. Fuller, and T. L. Maechtle. 2015. Mitigation effectiveness for improving nesting success of greater sage-grouse influenced by energy development. Wildlife Biology 21:98–109.

Klausen, K. B., A. O. Pedersen, N. G. Yoccoz, and R. A. Ims. 2010. Prevalence of nest predators in a sub-Arctic ecosystem. European Journal of Wildlife Research 56:221–232.

Knight, R. L., and J. Y. Kawashima. 1993. Responses of raven and red-tailed hawk populations to linear right-of-ways. Journal of Wildlife Management 57:266–271.

Knight, R. L., H. A. L. Knight, and R. J. Camp. 1995. Common ravens and number and type of linear rights-of-way. Biological Conservation 74:65–67.

Kristan, W. B. III, and W. I. Boarman. 2003. Spatial pattern of risk of common raven predation on desert tortoises. Ecology 84:2432–2443.

Kristan, W. B. III, and W. I. Boarman. 2007. Effects of anthropogenic developments on common raven nesting biology in the west Mojave Desert. Ecological Applications 17:1703–1713.

Kristan, W. B. III, W. I. Boarman, and J. J. Crayon. 2004. Diet composition of common ravens across the urban-wildland interface of the West Mojave Desert. Wildlife Society Bulletin 32:244–253.

Kurki, S., A. Nikula, P. Helle, and H. Linden. 1997. Landscape-dependent breeding success of forest grouse in Fennoscandia. Wildlife Biology 3:295.

Lammers, W. M., and M. W. Collopy. 2007. Effectiveness of avian predator perch deterrents on electric transmission lines. Journal of Wildlife Management 71:2752–2758.

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

Lehman, R. N., P. L. Kennedy, and J. A. Savidge. 2007. The state of the art in raptor electrocution research: a global review. Biological Conservation 136:159–174.

Liebezeit, J. R., S. 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.

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

Lindberg, M. S., J. S. Sedinger, and J.-D. Lebreton. 2013. Individual heterogeneity in black brant survival and recruitment with implications for harvest dynamics. Ecology and Evolution 3:4045–4056.

Lockyer, Z. B., P. S. Coates, M. L. Casazza, S. Espinosa, and D. J. Delehanty. 2013. Greater sage-grouse nest predators in the Virginia Mountains of northwestern Nevada. Journal of Fish and Wildlife Management 4:242–254.

Lopez-Lopez, P., M. Ferrer, A. Madero, E. Casado, and M. McGrady. 2011. Solving man-induced large-scale conservation problems: the Spanish Imperial Eagle and power lines. PLoS ONE 6(3):e17196.

Loss, S. R. 2016. Avian interactions with energy infrastructure in the context of other anthropogenic threats. Condor 118:424–432.

Loss, S. R., T. Will, and P. P. Marra. 2014. Refining estimates of bird collision and electrocution mortality at power lines in the United States. PLoS ONE 9(7):e101565.

Lukacs, P. M., V. J. Dreitz, F. L. Knopf, and K. P. Burnham. 2004. Estimating survival probabilities of unmarked dependent young when detection is imperfect. Condor 106:926–931.

Lyon, A. G., and S. H. Anderson. 2003. Potential gas development impacts on sage-grouse nest initiation and movement. Wildlife Society Bulletin 31:486–491.

Knick, S. T., S. E. Hanser, R. F. Miller, D. A. Pyke, M. J. Wisdom, S. P. Finn, E. T. Rinkes, and C. J. Henny. 2011. Ecological influence and pathways of land use in sagebrush. Studies in Avian Biology 38:203–251.

Madden, C. F., B. Arroyo, and A. Amar. 2015. A review of the impacts of corvids on bird productivity and abundance. Ibis 157:1–16.

Manier, D. J., Z. H. Bowen, M. L. Brooks, M. L. Casazza, P. S. Coates, P. A. Deibert, S. E. Hanser, and D. H. Johnson. 2014. Conservation buffer distance estimates for greater sage-grouse—a review: U.S. Geological Survey Open-File Report 2014-1239, Fort Collins, Colorado, USA. https://dx.doi.org/10.3133/ofr20141239

McCain, C., T. Szewczik, and B. K. Knight. 2016. Population variability complicates the accurate detection of climate change responses. Global Change Biology 22:2081–2093.

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

Miller, R. F., S. T. Knick, D. A. Pyke, C. W. Meinke, S. E. Hanser, M. J. Wisdom, and A. L. Hild. 2011. Characteristics of sagebrush habitats and limitations to long-term conservation. Studies in Avian Biology 38: 145–184.

Mong, T. W., and B. K. Sandercock. 2007. Optimizing radio retention and minimizing radio impacts in a field study of upland sandpipers. Journal of Wildlife Management 71:971–980.

Naugle, D. E., K. Doherty, B. L. Walker, H. E. Copeland, and J. D. Tack. 2011*a*. Sage-grouse and cumulative impacts of energy development. Page 274 *in* P. R. Krausman and L. K. Harris, editors. Cumulative effects in wildlife management. CRC Press, Boca Raton, Florida, USA.

Naugle, D. E., K. E. Doherty, B. L. Walker, M. J. Holloran, and H. E. Copeland. 2011*b*. Energy development and greater sage-grouse. Studies in Avian Biology 38:489–503.

Navrud, S., R. C. Ready, K. Magnussen, and O. Bergland. 2008. Valuing the social benefits of avoiding landscape degradation from overhead power transmission lines: do underground cables pass the benefit-cost test? Landscape Research 33:281–296.

Nichols, J. D., and B. K. Williams. 2006. Monitoring for conservation. Trends in Ecology and Evolution 21:668–73.

Northrup, J. M., and G. Wittemyer. 2013. Characterising the impacts of emerging energy development on wildlife, with an eye towards mitigation. Ecology Letters 16:112–125.

Orning, E. K. 2013. Effect of predator removal on greater sage-grouse (*Centrocercus urophasianus*) ecology in the Bighorn Basin Conservation Area of Wyoming. Thesis, Utah State University, Logan, USA.

Peebles, L. W., and M. R. Conover. 2017. Winter ecology and spring dispersal of common ravens in Wyoming. Western North American Naturalist. 77:293–308.

Peebles, L. W., M. R. Conover, and J. B. Dinkins. 2017. Adult sage-grouse numbers rise following raven removal or an increase in precipitation. Wildlife Society Bulletin 41:471–478.

Pettorelli, N., T. Coulson, S. M. Durant, and J.-M. Gaillard. 2011. Predation, individual variability and vertebrate population dynamics. Oecologia 167:305–314.

Plumpton, D. L., and D. E. Andersen. 1997. Habitat use and time budgeting by wintering Ferruginous Hawks. Condor 99:888–893.

Powell, L. A., M. Bomberger Brown, J. A. Smith, J. Olney Harrison, and C. Whalen. 2017. Modeling the spatial effects of disturbance: a constructive critique to provide evidence of ecological thresholds. Wildlife Biology 17: wlb.00245.

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

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

R Core Team. 2012. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Rollan, A., J. Real, R. Bosch, A. Tinto, and A. Hernandez-Matias. 2010. Modelling the risk of collision with power lines in Bonelli's Eagle *Hieraaetus fasciatus* and its conservation implications. Bird Conservation International 20:279–294.

Russell, D. J. F., S. M. J. M. Brasseur, D. Thompson, G. D. Hastie, V. M. Janik, G. Aarts, B. T. McClintock, J. Matthiopoulos, S. E. W. Moss, and B. McConnell. 2014. Marine mammals trace anthropogenic structures at sea. Current Biology 24:638–639.

Sandercock, B. K. 2006. Estimation of demographic parameters from live-encounter data: a summary review. Journal of Wildlife Management 70:1504–1520.

Schakner, Z. A., M. B. Petelle, M. J. Tennis, B. K. Van der Leeuw, R. T. Stansell, and D. T. Blumstein. 2017. Social associations between California sea lions influence the use of a novel foraging ground. Roysl Society Open Science 4:160820

Seamans, T. W., S. C. Barras, and G. E. Bernhardt. 2007. Evaluation of two perch deterrents for starlings, blackbirds and pigeons. International Journal of Pest Management 53:45–51.

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.

Silva, J. P., M. Santos, L. Queiros, D. Leitao, F. Moreira, M. Pinto, M. Leqoc, and J. A. Cabral. 2010. Estimating the influence of overhead transmission power lines and landscape context on the density of Little Bustard *Tetrax tetrax* breeding populations. Ecological Modelling 221:1954–1963.

Slater, S. J., and J. P. Smith. 2010. Effectiveness of raptor perch deterrents on an electrical transmission line in southwestern Wyoming. Journal of Wildlife Management 74:1080–1088.

Smith, J. A., and J. F. Dwyer. 2016. Avian interactions with renewable energy infrastructure: an update. Condor 118:411–423.

Smith, R. K., A. S. Pullin, G. B. Stewart, and W. J. Sutherland. 2010. Effectiveness of predator removal for enhancing bird populations. Conservation Biology 24:820–829.

Spaans, B., H. J. Blijleven, I. U. Popov, M. E. Rykhlikova and B. S. Ebbinge. 1998. Dark-bellied brent geese *Branta bernicla bernicla* forego breeding when arctic foxes *Alopex lagopus* are present during nest initiation. Ardea 86:11–20.

Steenhof, K., M. N. Kochert, and J. A. Roppe. 1993. Nesting by raptors and common ravens on electrical transmission-line towers. Journal of Wildlife Management 57:271–281.

Stevens, B. S., K. P. Reese, and J. W. Connelly. 2011. Survival and detectability bias of avian fence collision surveys in sagebrush steppe. Journal of Wildlife Management 75:437–449.

Suhonen, J., K. Norrdahl, and E. Korpimäki. 1994. Avian predation risk modifies breeding bird community on a farmland area. Ecology 75: 1626–1634.

U.S. Department of the Interior. 2014. Listing endangered and threatened species and designating critical habitat; implementing changes to the regulations for designating critical habitat. Federal Register 79: 27066–27078.

Vajjhala, S. P., and P. S. Fischbeck. 2007. Quantifying siting difficulty: a case study of US transmission line siting. Energy Policy 35:650–671.

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

Webb, W. C., J. M. Marzluff, and J. Hepinstall-Cymerman. 2011. Linking resource use with demography in a synanthropic population of common ravens. Biological Conservation 144:2264–2273.

White, G. C., and K. P. Burnham. 1999. Program MARK: survival estimation from populations of marked animals. Bird Study 46:120–139.

White, E. R. 2017. Minimum time required to detect population trends: the need for long-term monitoring programs. PeerJ Preprints 5:e3168v2.

Winder, V. L., L. B. McNew, A. J. Gregory, L. M. Hunt, S. M. Wisely, and B. K. Sandercock. 2014. Effects of wind energy development on the survival of greater prairie-chickens. Journal of Applied Ecology 51:395–405.

Wisdom, M. J., C. W. Meinke, S. T. Knick, and M. A. Schroeder. 2011. Factors associated with extirpation of sage-grouse. Studies in Avian Biology 38:451–472.

Zuur, A. F., E. N. Ieno, N. J. Walker, A. A. Saveliew, and G. M. Smith. 2009. Mixed effects models and extensions in ecology with R. Springer, New York, New York, USA.

APPENDIX A. EXPLANATORY COVARIATES

Table SA1. List of all covariates considered to account for background environmental variation (Tables SB1–SB9), how the data were collected, and a publication that describes data collection for each analysis that estimated a particular demographic rate or behavior of greater sage-grouse in Eureka County, Nevada, USA, from 2003–2012.

Variable	Data type	Additional information	Nesting (and re-nesting) propensity	Nest-site selection	Nest survival	Brood-site selection	Pre-fledging chick survival	Adult female survival	Adult male survival	Recruitment	Population growth
Percent non-sagebrush shrub cover	Line intercept surveys	Gibson et al. (2016)			x		x			x	x
Percent forb cover	Daubenmire frame surveys	Gibson et al. (2016)			x		x			x	x
Percent total shrub cover	Line intercept surveys	Gibson et al. (2016)			x		x			x	x
Average shrub height	Daubenmire frame surveys	Gibson et al. (2016)			x		x			x	x
Total percent vegetation cover	Daubenmire frame surveys	Gibson et al. (2016)			x		x			x	x
Percent grass cover	Daubenmire frame surveys	Gibson et al. (2016)			x		x			x	x
Percent sagebrush shrub cover	Line intercept surveys	Gibson et al. (2016)			x		x			x	x
Forb taxa richness	Daubenmire frame surveys	Gibson et al. (2016)			x		x			x	x
Average live grass height	Daubenmire frame surveys	Gibson et al. (2016)			x		x			x	x
Average residual grass height	Daubenmire frame surveys	Gibson et al. (2016)			x		x			x	x
Average forb height	Daubenmire frame surveys	Gibson et al. (2016)			x		x			x	x
Proportion of surrounding area classified as exotic grasslands	Bureau Of Land Management wildfire data layer For Nevada (NV Fire History; BLM)	Gibson et al. (2016)		x	x	x	x	x		x	x
Distance from nearest road	Roads data layer For Eureka County, NV	Gibson et al. (2016)		x	x	x	x	x	x	x	x
Proportion of surrounding area classified as Pinyon-Juniper woodlands	Southwest Regional Gap (SWREGAP; USGS National Gap Analysis Program 2004)	Gibson et al. (2016)		x	x	x	x	x			
Proportion of surrounding area classified as sagebrush	Southwest Regional Gap (SWREGAP; USGS National Gap Analysis Program 2004)	Gibson et al. (2016)		x	x	x	x	x			
Elevation	National Elevation Dataset Digital Elevation Model (Ned Dem; USGS)	Gibson et al. (2016)		x	x	x	x	x	x	x	x
Distance to nearest active lek	Nevada Department Of Wildlife (NDOW) lek data layer	Gibson et al. (2016)		x	x	x	x				
Distance to nearest spring or water source	Water source data layer	Gibson et al. (2016)		x	x	x	x		x	x	x

(*Continued*)

Table SA1. (*Continued*)

Variable	Data type	Additional information	Nesting (and re-nesting) propensity	Nest-site selection	Nest survival	Brood-site selection	Pre-fledging chick survival	Adult female survival	Adult male survival	Recruitment	Population growth
Slope	National Elevation Dataset Digital Elevation Model (Ned Dem; USGS)	Gibson et al. (2016)		x	x	x	x				
Northness: cosine(aspect)	National Elevation Dataset Digital Elevation Model (Ned Dem; USGS)	Gibson et al. (2016)		x	x	x	x				
Eastness: sine(aspect)	National Elevation Dataset Digital Elevation Model (Ned Dem; USGS)	Gibson et al. (2016)		x	x	x	x				
Minimum age	Monitoring	Blomberg et al. (2013)	x				x	x			
Estimated male population size	Model estimate	Gibson et al. (2014)	x								
Precipitation/ Drought severity	Model estimate	Gibson et al. (2017)	x				x		x	x	x
Summer temperature	PRISM climate data explorer http://www.prism.oregonstate.edu/	Gibson et al. (2017)	x				x		x		
Nest hatch date	Monitoring	Gibson et al. (2015)			x		x				
Nesting success	Monitoring	Blomberg et al. (2013)						x			
Fledging success	Monitoring	Blomberg et al. (2013)						x			
Nest quality	Model estimate	Gibson et al. (2016)					x				
Distance brood moved	Monitoring	Gibson et al. (2017)					x				
Population (Roberts versus Cortez)	Monitoring ormodel estimate	Jahner et al. (2016)	x		x		x	x	x	x	x

APPENDIX B. ENVIRONMENTAL ANALYSES

Table SB1. Performance of all multistate models used to assess the influence of environmental conditions on female greater sage-grouse nesting and re-nesting propensity Eureka County, Nevada, 2003–2012. Model design, structure, and results are based on analyses previously published in Blomberg et al. (2017).

Model[a]	ΔAIC$_c$[b]	w_i[c]	K[d]	Deviance
φ(.) p(stage + year + quad) Nesting(N + age^2 + quad) Fail(.) ReNesting(N + prec)	0.00	0.74	27	47,422.05
φ(.) p(stage + year + quad) Nesting(N + age^2 + quad) Fail(.) ReNesting(N + prec + age^2)	2.35	0.23	29	47,420.34
φ(.) p(stage + year + quad) Nesting(N + quad) Fail(.) ReNesting(year)	8.32	0.01	32	47,420.22
φ(.) p(stage + year + quad) Nesting(N + quad) Fail(.) ReNesting(N + prec)	9.77	0.01	25	47,435.88
φ(.) p(stage + year + quad) Nesting(N + quad) Fail(.) ReNesting(N)	9.88	0.01	24	47,438.02
φ(.) p(stage + year + quad) Nesting(N + prec + quad) Fail(.) ReNesting(year)	10.23	0.00	33	47,420.10
φ(.) p(stage + year + quad) Nesting(N × prec + quad) Fail(.) ReNesting(year)	11.39	0.00	34	47,419.22
φ(.) p(stage + year + quad) Nesting(N + season + quad) Fail(.) ReNesting(N + prec + season)	12.58	0.00	27	47,434.63
φ(.) p(stage + year + quad) Nesting(year + quad) Fail(.) ReNesting(year)	16.72	0.00	40	47,412.32
φ(.) p(stage + year + quad) Nesting(year + quad) Fail(.) ReNesting(N + prec)	18.10	0.00	33	47,427.96
φ(.) p(stage + year + quad) Nesting(year + quad) Fail(.) ReNesting(N)	18.19	0.00	32	47,430.09
φ(.) p(stage + year + quad) Nesting(year + quad) Fail(.) ReNesting(N × prec)	19.69	0.00	34	47,427.52
φ(.) p(stage + year + quad) Nesting(year + quad) Fail(.) ReNesting(.)	20.06	0.00	31	47,434.00
φ(.) p(stage + year + quad) Nesting(quad) Fail(.) ReNesting(year)	49.03	0.00	31	47,462.96
φ(.) p(stage + year + quad) Nesting(year) Fail(.) ReNesting(year)	187.47	0.00	38	47,587.15
φ(.) p(stage + year + quad) Nesting(age^2) Fail(.) ReNesting(N + prec)	197.99	0.00	24	47,626.12
φ(.) p(stage + year + quad) Nesting(.) Fail(.) ReNesting(.)	206.29	0.00	20	47,642.51

[a] Parameters estimated are apparent survival (φ), detection (p), and transition probabilities (ψ) from not nesting to nesting (Nesting), from not nesting to a second nest (ReNesting), and from nesting to not nesting (Fail). We denote the intercept-only model as (.). Year = full annual variation. Quad = quadratic constraint applied across within-year interval transition probabilities. N = estimated male population size (Gibson et al. 2014). Age^2 = quadratic relationship of minimum hen age. Prec = sum of total monthly precipitation recorded for the year prior (Aug–July). Season = season of capture (spring or fall). All covariates were z-standardized prior to analysis. See Blomberg et al. (2017) for analytical procedures. We retained the highest ranked model (lowest ΔAIC) and considered it as the baseline covariate model for the power-line impact analysis.

[b] The difference in Akaike's Information Criterion between the top ranked and selected model.

[c] The relative likelihood of a model (i.e., Akaike weights).

[d] The number of estimated parameters in a given model.

Table SB2. Performance of all landscape-scale nest-site selection species distribution models (GLMM) used to assess the influence of habitat features on nest-site selection in Eureka County, Nevada, 2004–2012. Models based on analyses previously published in Gibson et al. (2016).

Model[a]	ΔAIC$_c$[b]	w_i[c]	K[d]	Deviance
Topography				
DLek + elevation + DSpring^2	0.00	0.42	7	2,037.24
DLek + elevation × slope + DSpring^2	0.55	0.32	9	2,033.79
DLek + elevation	2.69	0.11	5	2,043.92
DLek + elevation + slope	2.88	0.10	6	2,042.12
DLek + elevation × slope	4.32	0.05	7	2,041.55
DLek + DSpring^2	57.42	0.00	6	2,096.66
DLek	63.72	0.00	4	2,106.95
DSpring^2	183.05	0.00	5	2,224.29
Slope + elevation	190.04	0.00	5	2,231.27
Slope × elevation	190.72	0.00	6	2,229.96
Elevation	191.86	0.00	4	2,235.10
Intercepts-only	200.83	0.00	3	2,246.07
Northing	201.94	0.00	4	2,245.17
DSpring	202.42	0.00	4	2,245.66
Easting	202.61	0.00	4	2,245.85
Slope	202.64	0.00	4	2,245.88
Vegetation classifications				
Sagebrush$_{1000}$	0.00	0.69	4	2,011.45
Sagebrush$_{1000}{}^2$	1.66	0.30	5	2,011.11
Sagebrush$_{2000}{}^2$	11.56	0.00	5	2,021.01
Sagebrush$_{2000}$	14.35	0.00	4	2,025.80
Sagebrush$_{500}$	17.45	0.00	4	2,028.90
Sagebrush$_{500}{}^2$	18.85	0.00	5	2,028.30
PJ$_{500}{}^2$	185.88	0.00	5	2,195.32
PJ$_{1000}{}^2$	186.09	0.00	5	2,195.54
PJ$_{500}$	190.92	0.00	4	2,202.37
PJ$_{1000}$	194.48	0.00	4	2,205.92
PJ$_{2000}{}^2$	199.46	0.00	5	2,208.91
PJ$_{2000}$	213.05	0.00	4	2,224.49
Intercepts-only	232.62	0.00	3	2,246.07

(Continued)

Table SB2. (*Continued*)

Model[a]	$\Delta\mathrm{AIC}_c$[b]	w_i[c]	K[d]	Deviance
Environmental disturbance				
WF$_{500}$ + DRoad	0.00	0.98	5	2,217.62
WF$_{500}$	8.34	0.02	4	2,227.96
WF$_{1000}$	10.69	0.00	4	2,230.31
DRoad	12.08	0.00	4	2,231.70
WF$_{2000}$	19.55	0.00	4	2,239.18
Intercepts-only	24.45	0.00	3	2,246.07
Overall model				
DLek × sagebrush$_{1000}$ + elevation × slope + DSpring^2	0.00	1.00	11	1,730.29
DLek + elevation × slope + DSpring^2 + sagebrush$_{1000}$	37.24	0.00	10	1,769.54
DLek + elevation × slope + DSpring^2 + sagebrush$_{1000}$ + WF$_{500}$	37.43	0.00	11	1,767.72
DLek + elevation × slope + DSpring^2 + sagebrush$_{1000}$ + WF$_{500}$ + DRoad	37.54	0.00	12	1,765.84
DLek + elevation + slope + DSpring^2 + sagebrush$_{1000}$	57.44	0.00	9	1,791.74
DLek + elevation + DSpring^2 + sagebrush$_{1000}$	59.59	0.00	8	1,795.89
DLek + elevation × slope + DSpring^2 + PJ$_{500}$^{2} + WF$_{500}$ + DRoad	223.26	0.00	13	1,949.55

[a] Subscripts denote the scale of the variable (i.e., within a radius of 500 m, 1,000 m, or 2,000 m of a point). DLek, DRoad, and DSpring represent distance (in m) from nearest active lek, nearest road, and nearest spring or water source, respectively. Sagebrush represent the proportion of habitat classified as sagebrush at a specified scale; WF represented the proportion of habitat converted to exotic grasslands by wildfire at a specified scale; PJ represented the proportion of habitat classified as pinyon-juniper woodlands at a specified scale. Elevation represented the elevation (in m) of a point; slope represented the slope (in degrees) of a point. North is the cosine of aspect; east is the sin of aspect. Intercepts-only denotes intercept-only model. We denote a quadratic relationship with a square notation (^{2}). Models with interactions contain the linear parameter components. Model weights (w_i) and differences in corrected Akaike's Information Criterion ($\Delta\mathrm{AIC}_c$) are relative only to the subset of models within each group. All covariates were z-standardized prior to analysis. See Gibson et al. (2016) for analytical procedures. We retained the highest ranked model (lowest ΔAIC) in the overall model category and considered it as the baseline covariate model for the power-line impact analysis.

[b] The difference in Akaike's Information Criterion between the top ranked and selected model.

[c] The relative likelihood of a model (i.e., Akaike weights).

[d] The number of estimated parameters in a given model.

Table SB3. Performance of all landscape-scale brood-site selection species distribution models (GLMM) used to assess the influence of habitat features on greater sage-grouse brood-site selection in Eureka County, Nevada, 2005–2012.

Model[a]	$\Delta\mathrm{AIC}_c$[b]	w_i[c]	K[d]	Deviance
Elevation + slope	0.00	0.37	5	2,063.75
Elevation × slope	0.21	0.34	6	2,061.96
Elevation^2 + slope	0.50	0.29	6	2,062.25
Elevation^2	21.00	0.00	5	2,084.75
Elevation	21.99	0.00	4	2,087.74
Sagebrush$_{500}$	73.83	0.00	4	2,139.58
Sagebrush$_{1000}$	75.42	0.00	4	2,141.17
PJ$_{500}$	78.89	0.00	4	2,144.64
Sagebrush$_{2000}$	88.29	0.00	4	2,154.04
PJ$_{1000}$	93.19	0.00	4	2,158.94
PJ$_{2000}$	136.71	0.00	4	2,202.46
Slope	163.51	0.00	4	2,229.26
WF$_{1000}$	179.60	0.00	4	2,245.35
WF$_{500}$	179.95	0.00	4	2,245.70
Intercepts-only	180.08	0.00	3	2,247.83
WF$_{2000}$	180.50	0.00	4	2,246.25
DSpring^2	180.77	0.00	5	2,244.52
DSpring	181.88	0.00	4	2,247.63

[a] All models include random intercepts for year and individual. Subscripts denote the scale of the variable (i.e., radius of 500 m, 1,000 m, or 2,000 m from a point), superscripts denote quadratic relationships. DLek, DRoad, and DSpring represent distance (in m) from nearest active lek, nearest road, and nearest spring or water source, respectively. All sagebrush represented the proportion of area classified as sagebrush at a specified scale; WF represented the proportion of area converted to exotic grasslands by wildfire at a specified scale; PJ represented the proportion of area classified as pinyon-juniper woodlands at a specified scale. Elevation represented the elevation (in m) of a point; slope represented the slope (in degrees) of a point. Intercepts-only denotes intercept-only model. All variables were z-standardized prior to analysis. Analytical framework based on nest-site selection analyses presented in Gibson et al. (2016). We retained the highest ranked model (lowest ΔAIC) and considered it as the baseline covariate model for the power-line impact analysis.

[b] The difference in Akaike's Information Criterion between the top ranked and selected model.

[c] The relative likelihood of a model (i.e., Akaike weights).

[d] The number of estimated parameters in a given model.

Table SB4. Performance of all nest survival models used to assess the influence of nest-site features greater sage-grouse nest survival in Eureka County, Nevada, 2004–2012. Tables are organized by individual heterogeneity, disturbance, landscape-scale habitat features, temporal characteristics, local-scale vegetation features, and multivariable models. Models based on analyses previously published in Gibson et al. (2016).

Model[a]	ΔAIC_c[b]	w_i[c]	K[d]	Deviance
Individual heterogeneity models				
Base + pop	0.00	0.84	5	1,268.21
Base	6.19	0.04	4	1,276.40
Base + ID^2	6.71	0.03	6	1,272.91
Base + season	6.88	0.03	5	1,275.08
Base + age class	7.46	0.02	5	1,275.67
Base + min age	8.09	0.01	5	1,276.30
Base + ID	8.11	0.01	5	1,276.32
Base + nest attempt	8.18	0.01	5	1,276.39
Disturbance models				
Base + WF_{2000}	0.00	0.31	5	1,274.06
Base	0.33	0.26	4	1,276.40
Base + WF_{1000}	1.26	0.17	5	1,275.32
Base + WF_{500}	1.68	0.14	5	1,275.75
Base + DRoad	2.01	0.12	5	1,276.07
Spatial models				
Base + PJ_{2000}	0.00	0.71	5	1,265.60
Base + elev	4.20	0.09	5	1,269.80
Base + PJ_{1000}	4.22	0.09	5	1,269.81
Base + Dlek	5.62	0.04	5	1,271.21
Base + DLek^2	7.51	0.02	6	1,271.11
Base + all_{2000}	8.11	0.01	5	1,273.71
Base + PJ_{500}	8.13	0.01	5	1,273.72
Base	8.80	0.01	4	1,276.40
Base + DSpring	8.82	0.01	5	1,274.42
Base + north	8.83	0.01	5	1,274.43
Base + slope	8.96	0.01	5	1,274.56
Base + sagebrush_{1000}	9.76	0.01	5	1,275.36
Base + sagebrush_{500}	10.56	0.00	5	1,276.16
Base + east	10.61	0.00	5	1,276.20
Base + DSpring^2	10.82	0.00	6	1,274.42
Base + north × east	11.78	0.00	7	1,273.37
Temporal models				
Stage + incubation trend (base)	0.00	0.23	4	1,276.40
(.)	0.64	0.17	1	1,283.04
Stage	0.64	0.16	3	1,279.05
Snowpack	1.54	0.11	2	1,281.95
Weekly trend	2.50	0.07	2	1,282.90
Daily trend	2.60	0.06	2	1,283.00
Precipitation	2.60	0.06	2	1,283.00
Week quadratic trend	4.50	0.02	3	1,282.90
Day quadratic trend	4.56	0.02	3	1,282.96
Week	5.65	0.01	6	1,278.04
Year + stage + incubation trend	9.18	0.00	12	1,269.53
Year	10.24	0.00	9	1,276.61
Local vegetation models				
Base + NSC_5	0.00	0.79	5	1,264.68
Base + FC_5	4.88	0.07	5	1,269.56
Base + $\text{TC}_{0.5}$	6.54	0.03	5	1,271.22
Base + TSC_5	6.64	0.03	5	1,271.32
Base + SH_5	6.95	0.02	5	1,271.63
Base + TC_5	8.39	0.01	5	1,273.07
Base + FH_5	8.67	0.01	5	1,273.34
Base + $\text{SH}_{0.5}$	9.53	0.01	5	1,274.21
Base	9.72	0.01	4	1,276.40
Base + $\text{GH}_{0.5}$	10.87	0.00	5	1,275.55
Base + GH_5	11.24	0.00	5	1,275.92
Base + GC_5	11.32	0.00	5	1,276.00
Base + SC_5	11.57	0.00	5	1,276.24
Base + FRich_5	11.71	0.00	5	1,276.39
Base + RGH_5	11.72	0.00	5	1,276.39
Base + $\text{FH}_{0.5}$	11.72	0.00	5	1,276.40
Multivariable models				
Base + NSC_5 + FC_5 + pop	0.00	0.29	7	1,253.92
Base + NSC_5 + FC_5 + pop + PJ_{2000}	0.56	0.22	8	1,252.47
+ NSC_5 + FC_5 + PJ_{2000}	1.29	0.15	7	1,255.20
Base + NSC_5 + FC_5	3.29	0.06	6	1,259.21
Base + NSC_5 + FC_5 + SH_5	3.96	0.04	7	1,257.88
Base + NSC_5 + PJ_{2000}	4.19	0.04	6	1,260.12
Base + NSC_5 + FC_5 + Dlek	4.29	0.03	7	1,258.21
Base + NSC_5 + FC_5 + elev	4.88	0.03	7	1,258.80
Base + NSC_5 + FC_5 + $\text{TC}_{0.5}$	4.93	0.02	7	1,258.85
Base + NSC_5 + pop	5.13	0.02	6	1,261.05
Base + NSC_5 + $\text{TC}_{0.5}$	6.50	0.01	6	1,262.42
Base + NSC_5 + Dlek	6.50	0.01	6	1,262.42
Base + NSC_5 + SH_5	6.58	0.01	6	1,262.50
Base + NSC_5 + elev	6.63	0.01	6	1,262.56
Base + NSC_5	6.75	0.01	5	1,264.68
Base + NSC_5 + DSpring	7.05	0.01	6	1,262.97
Base + NSC_5 + TC_5	7.13	0.01	6	1,263.05
Base + NSC_5 + WF_{2000}	7.66	0.01	6	1,263.59
Base + PJ_{2000}	7.67	0.01	5	1,265.60
Base + NSC_5 + TSC	8.08	0.01	6	1,264.00
Base + NSC_5 + $\text{SH}_{0.5}$	8.46	0.00	6	1,264.38
Base + NSC_5 + $\text{FH}_{0.5}$	8.72	0.00	6	1,264.65
Base + pop	10.28	0.00	5	1,268.21
Base + FC_5	11.63	0.00	5	1,269.56
Base + elev	11.87	0.00	5	1,269.80
Base + Dlek	13.28	0.00	5	1,271.21
Base + $\text{TC}_{0.5}$	13.29	0.00	5	1,271.22
Base + TSC_5	13.39	0.00	5	1,271.32
Base + SH_5	13.70	0.00	5	1,271.63
Base + TC_5	15.14	0.00	5	1,273.07
Base + WF_{2000}	16.13	0.00	5	1,274.06
Base + $\text{SH}_{0.5}$	16.28	0.00	5	1,274.21
Base + DSpring	16.49	0.00	5	1,274.42
Base + $\text{FH}_{0.5}$	18.47	0.00	5	1,276.40

[a] Base represents a competitive 4 parameter design to account for variation in nest survival related to nest age; we allowed the laying period for the average nest (occasions 1–10), early incubation/late laying period (occasions 11–15), and the primary incubation period (occasions 16–44) to estimate independently from each other, with the linear trend (daily) on the primary incubation period. Subscripts denote the scale of the variable (i.e., within 0.5 m, 5 m or within a radius of 500 m, 1,000 m, or 2,000 m of a point). Horizontal cover variables included non-sagebrush shrub cover of all size classes (NSC), sagebrush shrub cover at all size classes (SC), total shrub cover (TSC), forb cover (FC), grass cover (GC), and total vegetation cover (TC). Vertical cover variables included average shrub height (SH), average forb height (FH), average live grass height (GH), and average residual grass height (RGH). FRich represented forb taxa richness within a given plot. DLek, DRoad, and DSpring represent distance (in m) from nearest active lek, nearest road, and nearest spring or water source, respectively. Sagebrush represent the proportion of habitat classified as sagebrush at a specified scale; WF represented the proportion of habitat converted to exotic grasslands by wildfire at a specified scale; PJ represented the proportion of habitat classified as pinyon-juniper woodlands at a specified scale. Elev represented the elevation (in m) of a point; slope represented the slope (in degrees) of a point. North is the cosine of aspect; east is the sin of aspect. Pop was a binomial covariate delineating nests from females associated from the Cortez Mountains from females associated with Roberts Creek Mountain. Age class was a binomial covariate, which delineated second year females from after second year females; min age was a continuous covariate, which represented the females minimum age. Season was a binomial covariate which delineated females captured in the spring from females captured in the fall; ID represented estimate nest initiation date; (.) denotes intercept-only model. Year denotes full annual variation. We also considered annual constraints related to annual precipitation (precipitation), and winter snowpack (snowpack). Week allowed for variation among 7-day fixed periods. Stage allowed for the laying, early incubation, and primary incubation phases to estimate separately. Model weights (w_i) and difference in corrected Akaike's Information Criterion (ΔAIC_c) are relative only to the subset of models within each group. Linear and quadratic daily and weekly trends are clearly denoted. All covariates were z-standardized prior to analysis. We retained the highest ranked model (lowest ΔAIC) in the multivariable model section and considered it as the baseline covariate model for the power-line impact analysis.

[b] The difference in Akaike's Information Criterion between the top ranked and selected model.

[c] The relative likelihood of a model (i.e., Akaike weights).

[d] The number of estimated parameters in a given model.

Table SB5. Performance of all models used to assess the influence of environmental variables on greater sage-grouse pre-fledging chick survival in Eureka County, Nevada, 2005–2012. Models based on analyses previously published in Gibson et al. (2017).

Model[a]	$\Delta\mathrm{AIC}_c$[b]	w_i[c]	K[d]	Deviance
φ(week + DSI + TPC + DMove + GH + DSpring + NSI) p(week + year)	0.00	0.98	24	1,999.89
φ(week + DSI + POP + TPC + DMove + GH + DSpring) p(week + year)	9.23	0.01	24	2,009.11
φ(week + DSI + TPC + DMove + GH + DSpring) p(week + year)	10.70	0.00	23	2,012.83
φ(week + DSI + TPC + DMove + GH + POP + SC) p(week + year)	19.19	0.00	24	2,019.08
φ(week + DSI + elev + TPC + DMove + GH + DSpring) p(week + year)	19.49	0.00	24	2,019.38
φ(week + DSI + TPC + DMove + GH + POP + MAge) p(week + year)	20.38	0.00	24	2,020.27
φ(week + DSI + TPC + DMove + GH + POP + MT) p(week + year)	21.78	0.00	24	2,021.67
φ(year + week + DMove) p(week + year)	28.93	0.00	26	2,024.29
φ(week + DSI + TPC + DMove + GH) p(week + year)	29.34	0.00	22	2,033.71
φ(week + DSI + DMove + TPC) p(week + year)	30.72	0.00	21	2,037.31
φ(year + week + TPC) p(week + year)	33.40	0.00	26	2,028.76
φ(year + week + NSI) p(week + year)	41.50	0.00	26	2,036.85
φ(year + week + elev) p(week + year)	44.44	0.00	26	2,039.79
φ(year + week + spring) p(week + year)	45.81	0.00	26	2,041.17
φ(week + DMove + TPC) p(week + year)	49.08	0.00	20	2,057.89
φ(year + week + MAge) p(week + year)	49.82	0.00	26	2,045.17
φ(year + week + GH) p(week + year)	50.47	0.00	26	2,045.83
φ(year + week + SC) p(week + year)	50.62	0.00	26	2,045.98
φ(year + week + pop) p(week + year)	50.91	0.00	26	2,046.27
φ(year + week + TR) p(week + year)	51.00	0.00	26	2,046.36
φ(year + week + TSC) p(week + year)	52.97	0.00	26	2,048.33
φ(year + week + FR) p(week + year)	55.30	0.00	26	2,050.65
φ(year + week + FC) p(week + year)	55.70	0.00	26	2,051.06
φ(year + week) p(week + year)	56.80	0.00	25	2,054.42
φ(year + week + SH) p(week + year)	57.39	0.00	25	2,055.02
φ(year + week + HD) p(week + year)	57.72	0.00	26	2,053.08
φ(year + week + GC) p(week + year)	57.91	0.00	26	2,053.27
φ(year + week + FH) p(week + year)	58.64	0.00	26	2,054.00
φ(year + week + all)) p(week + year)	58.85	0.00	26	2,054.21
φ(year + week + all) p(week + year)	58.85	0.00	26	2,054.21
φ(year + week + RGH) p(week + year)	59.03	0.00	26	2,054.39
φ(year + week + NSC) p(week + year)	59.03	0.00	26	2,054.39
φ(week + DSI) p(week + year)	61.76	0.00	19	2,072.78
φ(week) p(week + year)	79.55	0.00	18	2,092.75
φ(year) p(year)	223.05	0.00	16	2,240.61
φ(.) p(.)	365.73	0.00	2	2,412.59

[a] We modeled probability of apparent survival (φ) and detection probabilities (p); (.) denotes intercept-only model. Week denotes that each week was allowed to estimate independently from other weeks. The drought severity index (DSI) constrained annual chick survival with the first principle component axis from a principle components analysis that included many weather metrics (mean maximum monthly summer temperature, mean minimum monthly summer temperature, spring precipitation, summer precipitation, breeding season precipitation, water year precipitation, and mean monthly winter snowpack) thought to influence primary productivity (see Gibson et al. 2017). We also modeled NSI as an index of selected nest-site characteristics for each brood based on the nest-site vegetation composition (see Gibson et al. 2016, 2017). We modeled weekly time-varying covariates that represent the total (TPC) percent cover of shrubs, forbs (FC), and grasses (GC) within 400 m^2 at each weekly brood location. We modeled weekly time-varying covariates that represent total (TSC), sagebrush (SC), and other (NSC) shrub cover within 400 m^2 at each weekly brood location. We modeled time-varying covariates that represented average dead grass (RGH), average live grass (GH), forb (FH), and shrub (SH) heights within 400 m^2 at each weekly brood location. HD represents the broods hatch date (in Julian days). DMove is a weekly time-varying covariate that represents the average daily distance a brood moved based on the Euclidian distance between 2 subsequent weekly brood locations. Spring is a time-varying covariate that represents the distance between weekly brood locations and the nearest water spring. Elev is a time-varying covariate that represents elevation of the brood survey location. MAge represents a current minimum age of the mother. Models that considered interactions (denoted by ×) between covariates included the additive parameters within the model. All variables were z-standardized prior to analysis. See Gibson et al. (2017) for analytical procedures. We retained the highest ranked model (lowest ΔAIC) in the multivariable model section and considered it as the baseline covariate model for the power-line impact analysis.

[b] The difference in Akaike's Information Criterion between the top ranked and selected model.

[c] The relative likelihood of a model (i.e., Akaike weights).

[d] The number of estimated parameters in a given model.

FEMALE SURVIVAL

Model Modifications

We modified the analyses reported in Blomberg et al. (2013) by the following: 1) inclusion of an additional year of data (i.e., 2012); 2) inclusion of additional predictor variables; and 3) transitioning the modeling framework from a known-fate analysis to that of a nest survival model.

Table SB6. Performance of all nest survival models used to assess the influence of environmental characteristics on monthly survival of adult female greater sage-grouse in Eureka County, Nevada, 2003–2012. Models based on analyses previously published in Blomberg et al. (2013*c*).

Model[a]	**$\Delta\mathrm{AIC}_c$**[b]	**w_i**[c]	**K**[d]	**Deviance**
Elev + seasons + pre-breeding + age_{min} + hatch_{summer} + fledge_{fall}	0.00	0.26	9	1,511.44
Seasons + pre-breeding + age_{min} + hatch_{summer} + fledge_{fall}	0.51	0.20	8	1,513.96
PJ + seasons + pre-breeding + age_{min} + hatch_{summer} + fledge_{fall}	1.01	0.16	9	1,512.45
Road + seasons + pre-breeding + age_{min} + hatch_{summer} + fledge_{fall}	1.40	0.13	9	1,512.84
Month + winter + pre-breeding + age_{min} + hatch_{summer} + fledge_{fall}	5.50	0.02	13	1,508.90
Month + winter + pre-breeding + age_{min}	10.36	0.00	11	1,517.77
Seasons	11.77	0.00	4	1,533.25
Month + winter + hatch_{summer} + fledge_{fall}	13.62	0.00	11	1,521.04
Month + winter + elev	14.55	0.00	10	1,523.98
Month + winter + fledge_{fall}	14.60	0.00	10	1,524.03
Month + winter + hatch_{summer}	15.48	0.00	10	1,524.91
Month + winter + pre-breeding + age_{min}^{2}	15.74	0.00	12	1,521.14
Month + winter + pre-breeding	16.01	0.00	10	1,525.44
Month + winter + PJ	16.75	0.00	10	1,526.17
Month + winter + age_{min}	16.76	0.00	10	1,526.19
Month + winter	17.15	0.00	9	1,528.59
Month + winter + fire	17.71	0.00	10	1,527.14
Year + month + winter	25.69	0.00	18	1,519.00
(.)	62.91	0.00	1	1,590.40
Year	73.17	0.00	10	1,582.60

[a] Month + winter ($K = 9$) allows survival during March–October to estimate independently but constrained to estimate together from November–February. Seasons ($K = 4$) constrains monthly survival into seasonal blocks (i.e., Mar–May, Jun–Jul, Aug–Oct, and Nov–Feb) that estimate independently from each other. Year ($K = 10$) allows survival each year (2003–2012) to estimate independently from another. Elev is a monthly (Mar–Oct) time-varying covariate that represents the average elevation from all locations of a radio-marked female during that month. PJ is a monthly (Mar–Oct) time-varying covariate that represents the average proportion of area classified as Pinyon-Juniper within 5 km from all locations of a radio-marked female during that month. Fire is a monthly (Mar–Oct) time-varying covariate that represents the average proportion of area classified as exotic grasslands within 5 km from all locations of a radio-marked female during that month. Road is a monthly (Mar–Oct) time-varying covariate that represents the average distance between each location of a radio-marked female and the nearest road. Pre-breeding is a binomial (yes/no) variable modeled on post-breeding months (Aug–Feb) that delineates young-of-year individuals from females that have survived at least one breeding season. Age_{min} represents the minimum age for each female each year. Hatch_{summer} is a binomial (yes/no) variable modeled on the season immediately following hatching (Jun–Jul) that delineates females that successfully hatched a nest from those that did not. Fledge_{fall} is a binomial (yes/no) variable modeled on the season immediately following fledging (Aug–Oct) that delineates females that successfully fledged at least one chick from those that did not. We retained the highest ranked model (lowest ΔAIC) in the multivariable model section and considered it as the baseline covariate model for the power-line impact analysis.

[b] The difference in Akaike's Information Criterion between the top ranked and selected model.

[c] The relative likelihood of a model (i.e., Akaike weights).

[d] The number of estimated parameters in a given model.

Table SB7. Performance of all multistate robust design models used to assess the influence of environmental characteristics on annual survival and lek movement rates of male greater sage-grouse in Eureka County, Nevada, 2003–2012. Models based on analyses in Gibson et al. (2014).

Model[a]	**$\Delta\mathrm{AIC}_c$**[b]	**w_i**[c]	**K**[d]	**Deviance**
φ(prec + pop) ψAB(.) ψBA(.) $p{\sim}c$(year + month + lek)	0.00	0.19	29	4,368.59
φ(elev + prec + pop) ψAB(.) ψBA(.) $p{\sim}c$(year + month + lek)	0.12	0.17	30	4,366.62
φ(prec + pop) ψAB(pop) ψBA(.) $p{\sim}c$(year + month + lek)	1.10	0.11	30	4,367.60
φ(prec + pop) ψAB(age) ψBA(.) $p{\sim}c$(year + month + lek)	1.77	0.08	30	4,368.27
φ(prec × temp + pop) ψAB(.) ψBA(.) $p{\sim}c$(year + month + lek)	1.87	0.07	31	4,366.28
φ(prec + temp + pop) ψAB(.) ψBA(.) $p{\sim}c$(year + month + lek)	1.99	0.07	30	4,368.49
φ(WF + prec + pop) ψAB(.) ψBA(.) $p{\sim}c$(year + month + lek)	2.03	0.07	30	4,368.53
φ(elev + prec) ψAB(.) ψBA(.) $p{\sim}c$(year + month + lek)	2.09	0.07	29	4,370.68
φ(elev + year) ψAB(.) ψBA(.) $p{\sim}c$(year + month + lek)	2.45	0.05	36	4,356.36
φ(prec + pop) ψAB(age^2) ψBA(.) $p{\sim}c$(year + month + lek)	3.51	0.03	31	4,367.92
φ(WF + prec) ψAB(.) ψBA(.) $p{\sim}c$(year + month + lek)	3.61	0.03	29	4,372.20
φ(elev × WF + prec) ψAB(.) ψBA(.) $p{\sim}c$(year + month + lek)	4.28	0.02	31	4,368.69
φ(prec) ψAB(.) ψBA(.) $p{\sim}c$(year + month+ + lek)	5.08	0.01	28	4,375.75
φ(prec × temp) ψAB(.) ψBA(.) $p{\sim}c$(year + month + lek)	6.53	0.01	30	4,373.03
φ(prec + temp) ψAB(.) ψBA(.) $p{\sim}c$(year + month + lek)	6.69	0.01	29	4,375.28
φ(WF + year) ψAB(.) ψBA(.) $p{\sim}c$(year + month + lek)	7.76	0.00	36	4,361.67
φ(temp + +pop) ψAB(.) ψBA(.) $p{\sim}c$(year + month + lek)	11.60	0.00	29	4,380.18

(*Continued*)

Table SB7. (*Continued*)

Model[a]	ΔAIC$_c$[b]	w_i[c]	K[d]	Deviance
φ(pop) ψAB(.) ψBA(.) $p{\sim}c$(year + month + lek)	11.82	0.00	28	4,382.49
φ(pop) ψAB(.) ψBA(.) $p{\sim}c$(year + month + lek)	11.82	0.00	28	4,382.49
φ(WF) ψAB(.) ψBA(.) $p{\sim}c$(year + month + lek)	14.15	0.00	28	4,384.82
φ(.) ψAB(.) ψBA(.) $p{\sim}c$(year + month + lek)	16.70	0.00	27	4,389.45

[a] Annual variation in apparent survival (φ) or lek movement rates (ψ) was constrained by an index of average maximum summer temperature (temp), annual precipitation from August to July (prec), the elevation of the lek (elev), and the population (pop) a male was associated with (Cortez Mountains or Roberts Creek Mountain). Our base detection model constrained detection (p) and recapture (c) to a common intercept with additive variation between the parameters, which allowed for p and c to vary temporally among primary (year) and secondary (month) occasions by a constant amount, as well as spatially by lek. Age denotes minimum age of male during each encounter, and (.) denotes constancy over time. Main effects are included in models in which an interaction is specified. All variables were z-standardized prior to analysis. See Gibson et al. (2014) for parameter estimates, model results, and analytical procedures. We retained the highest ranked model (lowest ΔAIC) in the multivariable model section and considered it as the baseline covariate model for the power-line impact analysis.

[b] The difference in Akaike's Information Criterion between the top ranked and selected model.

[c] The relative likelihood of a model (i.e., Akaike weights).

[d] The number of estimated parameters in a given model.

RECRUITMENT AND POPULATION GROWTH

Model Modifications

We modified the analyses reported in Blomberg et al. (2012) by the following: 1) inclusion of 2 additional years of data (i.e., 2011–2012); 2) inclusion of additional predictor variables; and 3) including increased model parameterization that allowed for lek specific estimates of *per capita* recruitment and lambda. Additional predictor variables included average values for various metrics of vegetation composition (e.g., total percent vegetation cover, percent sagebrush cover) that were derived from vegetation surveys conducted at random locations within 5 km from each lek (mean number of surveys per lek = 26.85).

Table SB8. Performance of all Pradel models used to assess the influence of environmental characteristics on *per capita* recruitment (f) of male greater sage-grouse in Eureka County, Nevada, 2003–2012. Model design, structure, and results based on analyses previously published in Blomberg et al. (2012).

Model[a]	ΔAIC$_c$[b]	w_i[c]	K[d]	Deviance
f(prec × WF$_{1000}$ + TC + elev)	0.00	1.00	35	6,414.16
f(prec + TC + elev + WF$_{1000}$)	26.67	0.00	34	6,442.98
f(prec + PC + elev)	27.38	0.00	33	6,445.82
f(prec + TC + RD + FRich + WF + FC)	28.65	0.00	36	6,440.67
f(year + TC + FRich)	29.65	0.00	37	6,439.52
f(prec + TC + FRich)	30.21	0.00	33	6,448.66
f(year + TC + WF$_{1000}$)	32.06	0.00	36	6,444.08
f(year + lek)	32.40	0.00	43	6,429.29
f(year + TC + FC)	32.54	0.00	37	6,442.41
f(year + TC)	33.06	0.00	36	6,445.08
f(prec + TC + WF$_{1000}$)	34.21	0.00	33	6,452.65
f(year + TC + SH)	34.85	0.00	37	6,444.72
f(year + elev)	42.08	0.00	36	6,454.10
f(prec + elev + WF$_{1000}$)	45.49	0.00	33	6,463.94
f(year + WF$_{1000}$)	46.39	0.00	36	6,458.41
f(year + RD)	49.07	0.00	36	6,461.09
f(year + FC)	49.54	0.00	36	6,461.56
f(year + SH)	50.47	0.00	35	6,464.63
f(lek)	55.80	0.00	39	6,461.35
f(year + FRich)	60.34	0.00	36	6,472.36
f(year)	61.76	0.00	34	6,478.06
f(year + DSpring)	61.93	0.00	36	6,473.95
f(year + FH)	62.24	0.00	36	6,474.26
f(prec)	62.47	0.00	31	6,485.18
f(year + RGH)	62.50	0.00	36	6,474.52
f(year + pop)	63.04	0.00	36	6,475.06
f(year + GC)	64.40	0.00	36	6,476.42
f(year + TSC)	64.93	0.00	36	6,476.95
f(year + SC)	65.00	0.00	36	6,477.02
f(year + NSC)	65.10	0.00	36	6,477.12
f(year + GH)	65.22	0.00	36	6,477.24

(*Continued*)

Table SB8. (*Continued*)

Model[a]	ΔAIC_c[b]	w_i[c]	K[d]	Deviance
f(elev)	72.35	0.00	31	6,495.05
f(.)	84.10	0.00	30	6,508.93

[a] All models had identical constraints on survival and detection that allowed survival to vary by year ($K = 9$) and detection to vary by year ($K = 10$) and lek ($K = 11$). Elev and slope represents lek elevation and slope, respectively. Year and lek allowed *per capita* recruitment to vary independently by year and lek, respectively. Prec constrained *per capita* recruitment to vary as a function of total precipitation recorded during the year prior. RDist and DSpring represent distance from lek to nearest road and spring or water source, respectively. Horizontal cover variables included average non-sagebrush shrub cover (NSC), average sagebrush shrub cover (SC), average total shrub cover (TSC), average forb cover (FC), average grass cover (GC), and average total vegetation cover (TC). Vertical cover variables included average shrub height (SH), average forb height (FH), average live grass height (GH), and average residual grass height (RGH). FRich represents average forb taxa richness across all vegetation surveys associated with each lek. WF represents the amount of habitat surrounding each lek within 5 km that was converted to exotic grasslands by wildfire; (.) denotes intercept-only model. Main effects are included in models in which an interaction is specified. All variables were z-standardized prior to analysis. See Blomberg et al. (2012) for parameter estimates, model results, and analytical procedures. We retained the highest ranked model (lowest ΔAIC) in the multivariable model section and considered it as the baseline covariate model for the power-line impact analysis.

[b] The difference in Akaike's Information Criterion between the top ranked and selected model.

[c] The relative likelihood of a model (i.e., Akaike weights).

[d] The number of estimated parameters in a given model.

Table SB9. Performance of all Pradel models used to assess the influence of environmental characteristics on population growth (λ) of male greater sage-grouse in Eureka County, Nevada, 2003–2012. Model design, structure, and results based on analyses in Blomberg et al. (2012).

Model[a]	ΔAIC_c[b]	w_i[c]	K[d]	Deviance
λ(TC + prec × WF + elev)	0.00	0.37	35	6,404.81
λ(TC + RDist + prec × WF + elev)	0.69	0.26	36	6,403.35
λ(TC + RDist + prec × WF)	0.79	0.25	35	6,405.59
λ(TC + RDist + prec × WF + DSpring + elev)	2.37	0.11	36	6,405.03
λ(FC + prec × WF + DSpring + elev)	9.83	0.00	35	6,414.64
λ(FC + SH + prec × WF + DSpring + elev)	11.86	0.00	36	6,414.52
λ(WF × prec + elev)	12.23	0.00	34	6,419.18
λ(WF × prec)	25.70	0.00	33	6,434.79
λ(elev × prec + WF)	31.28	0.00	34	6,438.22
λ(lek + prec)	39.80	0.00	41	6,431.67
λ(TPC + prec + RDist)	41.11	0.00	33	6,450.19
λ(TPC + prec + RDist + WF)	41.72	0.00	34	6,448.66
λ(TPC + prec)	42.29	0.00	32	6,453.50
λ(TPC + prec + RDist + WF + DSpring)	43.40	0.00	35	6,448.21
λ(year + lek)	52.25	0.00	48	6,428.83
λ(elev + prec)	53.35	0.00	32	6,464.57
λ(lek)	56.03	0.00	40	6,450.07
λ(TPC)	58.01	0.00	31	6,471.36
λ(year + elev)	65.32	0.00	39	6,461.51
λ(prec)	65.38	0.00	31	6,478.73
λ(elev)	68.75	0.00	31	6,482.09
λ(slope)	69.42	0.00	31	6,482.76
λ(SH)	71.73	0.00	31	6,485.08
λ(FH)	76.20	0.00	31	6,489.54
λ(RDist)	76.35	0.00	31	6,489.70
λ(FC)	76.73	0.00	31	6,490.07
λ(year)	77.50	0.00	38	6,475.86
λ(year + WF)	79.15	0.00	39	6,475.35
λ(.)	80.20	0.00	30	6,495.67
λ(DSpring)	80.28	0.00	31	6,493.62
λ(FRich)	81.75	0.00	31	6,495.09
λ(SC)	82.01	0.00	31	6,495.36
λ(WF)	82.06	0.00	31	6,495.41
λ(GC)	82.08	0.00	31	6,495.42
λ(TSC)	82.11	0.00	31	6,495.45
λ(RGH)	82.11	0.00	31	6,495.46
λ(NSC)	82.29	0.00	31	6,495.64
λ(GH)	82.31	0.00	31	6,495.66

[a] All models had identical constraints on survival and detection that allowed survival to vary by year ($K = 9$) and detection to vary by year ($K = 10$) and lek ($K = 11$). Elev and slope represents lek elevation and slope, respectively. Year and lek allowed population growth to vary independently by year and lek, respectively. Prec constrained population growth to vary as a function of total precipitation recorded during the year prior. RDist and DSpring represent distance from lek to nearest road and spring or water source, respectively. Horizontal cover variables included average non-sagebrush shrub cover (NSC), average sagebrush shrub cover (SC), average total shrub cover (TSC), average forb cover (FC), average grass cover (GC), and average total vegetation cover (TC). Vertical cover variables included average shrub height (SH), average forb height (FH), average live grass height (GH), and average residual grass height (RGH). FRich represents average forb taxa richness across all vegetation surveys associated with each lek. WF represents the amount of habitat surrounding each lek within 5 km that was converted to exotic grasslands by wildfire; (.) denotes intercept-only model. Main effects are included in models in which an interaction is specified. All variables were z-standardized prior to analysis. See Blomberg et al. (2012) for parameter estimates, model results, and analytical procedures. We retained the highest ranked model (lowest ΔAIC) in the multivariable model section and considered it as the baseline covariate model for the power-line impact analysis.

[b] The difference in Akaike's Information Criterion between the top ranked and selected model.

[c] The relative likelihood of a model (i.e., Akaike weights).

[d] The number of estimated parameters in a given model.

Golden Eagle Protection Best Practices
Nevada Mineral Exploration and Mining Industry

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GOLDEN EAGLE PROTECTION BEST PRACTICES
NEVADA MINERAL EXPLORATION AND MINING INDUSTRY
PROJECT EVALUATION GUIDANCE

EXECUTIVE SUMMARY

The Nevada Mining Association (NvMA) has prepared this document, in coordination with the United States Fish and Wildlife (USFWS) local and regional offices, the Bureau of Land Management (BLM) Nevada State Office, the United States Forest Service (USFS), and the Nevada Department of Wildlife (NDOW). Its purposes are to provide a clear process for evaluating a mineral exploration or mining project in the context of golden eagle management guidelines and to ensure compliance with the Bald and Golden Eagle Protection Act (BGEPA).

Current golden eagle management guidance and regulations are specific to other industries (e.g., wind energy). Mineral exploration and mining operations differ from other industries with respect to the type, level, and duration of activities that have the potential to disturb golden eagles. Golden eagles are protected by the Migratory Bird Treaty Act (MBTA) and BGEPA, both of which prohibit take. Under BGEPA, take means to pursue, shoot, shoot at, poison, wound, kill, capture, trap, collect, destroy, molest, or disturb. Under the MBTA, take means to pursue, hunt, shoot, wound, kill, trap, capture, or collect, or attempt to do any of those acts. Golden eagle take associated with mineral exploration and mining operations may be reduced or avoided by implementing the golden eagle protection practices outlined in this document, in coordination with resource and land management agencies.

This document presents habitat assessment approaches to determine potential golden eagle use within a project area and vicinity. These approaches vary in level of effort, depending on the type and size of an operation. The focus is on identifying nest sites and breeding behavior. For the purpose of this document, the golden eagle breeding season in Nevada is defined as December through August but varies regionally. Typical nesting habitat in Nevada has been documented on cliffs, rock outcrops, ledges, and trees, where nests are usually placed in a location that predators cannot access. A breeding pair of eagles may have multiple nests in their breeding territory.

Mineral exploration and mining projects in Nevada may be subject to a variety of permitting requirements, particularly if the project is on public land. Action agencies, such as the BLM, USFS, and NDOW, have their own set of directives for gathering biological data to support permitting actions or a project-level National Environmental Policy Act (NEPA) evaluation. The habitat assessment approaches presented in this document are intended to supplement, and not replace, additional biological baseline studies that may be required as part of a project-level NEPA evaluation.

In order to comply with regulations, it is important to identify avoidance, minimization, rectification, reduction or elimination over time, or mitigation measures to reduce potential take, to offset take, or, in some situations, to provide a net benefit to golden eagles. Therefore, if golden eagle habitat is present, project operators are encouraged to incorporate the applicable golden eagle protection practices outlined in this document into their plans of operation or standard operating procedures. Mineral exploration and mining projects risk varies project by project for golden eagles, and implementing best practices further minimizes the potential for take situations.

GOLDEN EAGLE PROTECTION BEST PRACTICES
NEVADA MINERAL EXPLORATION AND MINING INDUSTRY
PROJECT EVALUATION GUIDANCE

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APPENDICES

Appendix A: Sample Data Sharing Agreement
Appendix B: Sample Bird Conservation Plan

ACRONYMS AND ABBREVIATIONS

AB	Activity Buffer
APLIC	Avian Power Line Interaction Committee
BGEPA	Bald and Golden Eagle Protection Act
BLM	Bureau of Land Management
CE	Categorical Exclusion/Exemption
CFR	Code Federal Regulations
DNA	Determination of NEPA adequacy and land use conformance
EA	Environmental Assessment
ECP	Eagle Conservation Plan
EIS	Environmental Impact Statement
EMU	Eagle Management Unit
ENM	Golden Eagle Pre-Construction Surveys & Nest Monitoring
FD	Facility Design
GBBO	Great Basin Bird Observatory
GEPM	Golden Eagle Protection Measure
GIS	Geographic Information System
HME	Habitat Management & Enhancement
IAPP	Industrial Artificial Pond Permit
kV	kilovolt
LAP	Local Area Population
MOU	Memorandum of Understanding
MBTA	Migratory Bird Treaty Act
NAC	Nevada Administrative Code
NDOW	Nevada Department of Wildlife
NEPA	National Environmental Policy Act
NvMA	Nevada Mining Association
OLE	Office of Law Enforcement
PAC	Project Administrative Controls
PDM	Project Design & Management
USC	United States Code
USFS	United States Forest Service
USFWS	United States Fish and Wildlife Service
VHF	Very High Frequency

DEFINITIONS

Action agency—An agency or entity authorizing an action or plan or providing funding for actions and plans.

Alternate nest—One of potentially several nests in a nesting territory that is not an in-use nest at the current time. When there is no in-use nest, all nests in the territory are alternate nests.

Appropriate agencies – means the USFWS, the NDOW, and the applicable land manager (USFS or BLM).

Avoidance and minimization measures—Conservation actions targeted to remove or reduce specific risk factors.

Breeding home ranges—The spatial extent or outside boundary of the movement of individuals from golden eagle pairs during the course of everyday activities during the breeding season.

Compatible with the preservation of the bald eagle or the golden eagle—Consistent with the goals of maintaining stable or increasing breeding populations in all eagle management units and the persistence of local populations throughout the geographic range of each species.

Disturb—To agitate or bother a bald or golden eagle to a degree that causes, or is likely to cause, based on the best scientific information available, (1) injury to an eagle, (2) a decrease in its productivity, by substantially interfering with normal breeding, feeding, or sheltering behavior, or (3) nest abandonment, by substantially interfering with normal breeding, feeding, or sheltering behavior (16 United States Code [USC] 668–668c).

Eagle Conservation Plan (ECP)—A document produced by the project developer or operator, in coordination with the USFWS, that supports issuance of an eagle take permit under 50 Code of Federal Regulations (CFR), Subpart 22.26 and potentially 22.27, or that demonstrates that such a permit is unnecessary. ECPs are voluntary but are often included in a take permit application to provide the necessary information and analysis for permit issuance.

Eagle Management Unit (EMU)—A geographically bounded region within which permitted take is regulated to meet the management goal of maintaining stable or increasing breeding populations of eagles.

Important eagle-use area—An eagle nest, foraging area, or communal roost site that eagles rely on for breeding, sheltering, or feeding, and the landscape features surrounding such nest, foraging area, or roost site that are essential for the continued viability of the site for breeding, feeding, or sheltering eagles (as defined at 50 CFR, Subparts 22.26 and 22.3).

In-use nest—An eagle nest, characterized by the presence of one or more eggs, dependent young, or adult eagles on the nest in the past ten days during the breeding season.

Line-of-sight—Unobstructed visibility of an activity from a nest site. A modification to the spatial restriction (activity buffers), may be considered if all elements of the proposed activity occur in an area totally obstructed from view of a nest site.

Local Area Population (LAP)—The eagle population within the area of a human activity or project bounded by the natal dispersal distance for the respective species. The LAP is estimated using the average eagle density of the EMU or EMU's where the activity or project is located.

Monitoring—Inventories over intervals of time (repeated observations), using comparable methods so that changes can be identified. Monitoring includes analyzing inventory data or measurements to evaluate change within or to defined metrics. Monitoring also includes repeated observations of a known nesting territory.

Nest—Any assemblage of materials built, maintained, or used by eagles for the purpose of reproduction.

Nest buffer—Spatial and seasonal buffer zones for golden eagles relating to the protection of nest sites from disturbance during the nesting season and within a specified distance around the nest site. Protecting the buffer zone can be critical to the continued productivity of a nest site. Activities proposed within these buffer zones are considered potentially impacting. Consultation with the action agency, the USFWS, and NDOW is recommended before establishing a nest buffer for a specific situation.

Nesting territory—An area that contains, or historically contained, one or more nests within the home range of a mated pair of eagles (from the regulatory definition of territory, at 50 CFR, Subpart 22.3). Historical is defined here as a nest present within the previous five years.

Occupied nest—A nest site that has been repaired or tended in the current year by a pair of golden eagles, or one that is used by the member of a pair that returns early and begins displaying. During courtship and breeding, all nests in a territory are considered occupied until the nesting pair selects one of the nest sites, at which time the others are deemed unoccupied. Unoccupied nests are defined below.

Occupied territory—An area that encompasses a nest or nests or potential nest sites and is defended by a mated pair of eagles.

Practicable—Available and capable of being done after taking into consideration existing technology, logistics, and cost, in light of a mitigation measure’s beneficial value to eagles and the activity’s overall purpose, scope, and scale.

Project area—The area where surface disturbance and other project-related activities occurs.

Proponent or operator—Anyone who proposes to conduct mineral exploration or mining activities.

Qualified wildlife biologist—Lead observer with the equivalent of two seasons of intensive experience conducting survey and monitoring of golden eagle and/or cliff dwelling raptors, may include banding, intensive behavioral monitoring, or protocol-driven survey work. Aerial surveys will be conducted by a lead observer who has at least three field seasons of experience in helicopter-borne raptor surveys around cliff ecosystems, as well as another Qualified Wildlife Biologist.

Retrofit—Any activity that modifies an existing power line structure to make it raptor (golden eagle) safe.

Unoccupied nests—Those nests not selected by golden eagles for use in the current nesting season. The exact point in time when a nest becomes unoccupied should be determined by a qualified wildlife biologist, based on observations and that the breeding season has advanced such that nesting is not expected. Inactivity at a nest site or territory does not necessarily indicate permanent abandonment (Kochert and Steenhof 2012).

GOLDEN EAGLE PROTECTION BEST PRACTICES
NEVADA MINERAL EXPLORATION AND MINING INDUSTRY
PROJECT EVALUATION GUIDANCE

1 INTRODUCTION AND PURPOSE

1.1 Purpose

The operations related to the mining industry are different temporally, spatially, and characteristically from other industries. These include those industries involved in electrical distribution, wind energy, and solar energy that have been central to the current regulations and guidance documents related to golden eagle management. The purpose of this document is to provide a clear process for evaluating a mineral exploration or mining project to ensure compliance with the BGEPA and the MBTA.

This document focuses on incorporating best management practices and eagle protection measures into project planning and operations. Its purpose is to reduce the likelihood of triggering the need for a “take” permit. It has been prepared by the NvMA, in technical coordination with the local and regional offices of the USFWS, BLM, USFS, and NDOW. It is specific to the Nevada mineral exploration and mining industry and current applicable regulatory and permitting framework. In addition, this document focuses primarily on the golden eagle (*Aquilia chrysaetos*) and typical habitat characteristics for this species in Nevada.

While this document was prepared to address golden eagles, many parts of this will be applicable to bald eagles. However, the project proponent should coordinate with the USFWS and NDOW if bald eagles are potentially present in the vicinity of the Project Area.

1.2 Organization of Document

This document has been divided into several chapters related to evaluating a project and complying with laws and regulations that protect eagles, as outlined below.

Section 2, Background Information, includes the following elements:

- A description of the BGEPA and its definition of take
- A discussion of the voluntary nature of obtaining an eagle take permit
- Project considerations, including landownership status and existing operations
- Project-level NEPA and applicable State of Nevada laws and regulations considerations
- An overview of basic golden eagle ecology to support the development and implementation of the best practices described herein

Section 3, Project Evaluation and Golden Eagle Habitat Assessment includes the following elements:

- A definition of the main types of mineral exploration and mining projects, which are categorized primarily by the spatial and temporal scale and characteristics of operations
- Site assessment methods for determining golden eagle use by operation type and a discussion for evaluating the results in regard to golden eagle management
- A list of available golden eagle population and habitat data sources and an approach for data sharing within the industry and cross-industry

Section 4, Golden Eagle Protection Measures, includes the following element:

- Golden eagle protection measures applicable to the mining and mineral exploration industry, including the purpose, application, and specifications of each measure

Section 5, Take Evaluation, includes the following elements:

- Examples of industry-specific take scenarios after the golden eagle protection measures are applied to project operations
- A description of the types of take permits
- A decision framework/flow chart to determine whether a take permit is needed
- An introduction to and overview of Take Permit and ECP Process Guidance

Section 6, Agency Coordination, includes the following elements:

- Recommendations for consulting or coordinating with the USFWS and NDOW before and during project operations
- Contact information for local USFWS and NDOW offices
- Agency coordination flow chart between the action agency and the USFWS and NDOW

Section 7, Action Plan if Incidental take Occurs, includes the following element:

- Steps to be taken if an incidental golden eagle take occurs in relation to project operations, including how to report and manage the take

2 BACKGROUND INFORMATION

2.1 Legal Authorities

Bald and Golden Eagle Protection Act
The BGEPA is the primary law protecting eagles. It prohibits taking eagles without a permit (16 USC, Sections 668-668c). BGEPA defines "take" as to "pursue, shoot at, poison, wound, kill, capture, trap, collect, molest or disturb," and prohibits taking individuals and their parts, nests, or eggs. The USFWS expanded this definition by regulation to include the term "destroy" to ensure that take includes destroying eagle nests. Disturb is further defined by regulation as "to agitate or bother a bald or golden eagle to a degree that causes, or is likely to cause injury to an eagle, a decrease in productivity, or nest abandonment" (50 CFR, Subpart 22.3).

2016 Eagle Rule
The 2016 Eagle Rule revises 50 CFR, Parts 13 and 22, regarding eagle permits and revisions to regulations for eagle incidental take and take of eagle nests. Revisions include changes to permit issuance criteria and duration, definitions, compensatory mitigation standards, criteria for eagle nest removal permits, permit application requirements, and fees. This rule modified the definition of the BGEPA's preservation standard, which requires that permitted take be compatible with the preservation of eagles. This document follows the latest guidance in the 2016 Eagle Rule regarding eagle take permits.

Migratory Bird Treaty Act
The MBTA (16 USC, Sections 703-712) is administered by the USFWS and is the cornerstone of migratory bird conservation and protection in the United States. The MBTA implements a series of international treaties that protect migratory birds and authorizes the Secretary of the Interior to regulate the taking of migratory birds. The MBTA makes it unlawful, except as permitted by regulations, "to pursue, take, or kill any migratory bird, or any part, nest or egg of any such bird" (16 USC, Section 703), but it does not regulate habitat. The list of species protected by the MBTA was revised in November 2013 and includes almost all 1,026 bird species that are native to the United States.

Executive Order 13186
Signed on January 11, 2001, this executive order directs each federal agency taking actions that are likely to have a measurable impact on migratory bird populations to develop and implement a memorandum of understanding (MOU) with the USFWS, with the purpose to promote the conservation of migratory bird populations. The USFWS has established MOUs with the USFS (USFS 2008) and the BLM (BLM 2010). The MOUs with the USFS and BLM state, in part, that parties shall, as practicable, take the following actions:

- Protect, restore, and conserve habitat of migratory birds
- Follow the USFWS bald eagle management guidelines
- Follow other migratory bird conservation measures, as appropriate and consistent with agency missions
- Collaborate to identify and address issues that affect species of concern
- Promote and contribute migratory bird population and habitat data to interagency partnership databases

The MOUs also commit the USFS and BLM to, among other measures, participate in planning Bird Conservation Regions and, at the project level, evaluate the impacts of the agency's actions on migratory birds during the NEPA process.

2.2 Golden Eagle Protection Best Practices Document

The methods and approaches suggested in this document are provided to give the mining industry an approach to complying with regulatory requirements and avoiding the incidental take of eagles at mining facilities, while using assessment processes commensurate with industry operations and practices. Project proponents and operators should coordinate with the USFWS, NDOW, and the authorizing agencies to ensure that the approach taken for an individual project meets applicable regulatory and permitting requirements. An eagle incidental take permit is not a prerequisite or an authorization to construct and operate projects that will result in eagles being taken; it only authorizes take of eagles. Encouraging more proponents of activities that incidentally take eagles to apply for permits is a critically important means of reducing incidental take. The take of an eagle without a permit is a violation of BGEPA and could result in prosecution.

2.3 Project Jurisdiction and Status

2.3.1 Private versus Public Land

The BGEPA applies to activities on both public and private land. The practices outlined in this guidance document are recommended for all mineral exploration and mining projects and serve as a tool for complying with the BGEPA for operations on public and private lands.

2.3.2 Existing Projects versus Proposed Projects or Expansions

Existing and ongoing operations are not specifically addressed in this document. However, existing operations are required to comply with certain local, state, and federal requirements that prevent or minimize the potential for taking golden eagles. If a golden eagle chooses to nest within an existing operations area, the operator can consult with the USFWS and NDOW and the appropriate land management agency to establish monitoring activities or protection measures. Proposed projects and expansions, where proposed land use activities may exceed the current levels and timing of disturbances, should be classified into the operations types described in **Section 3** for only the new activities. In such cases, the existing operations would serve as a baseline condition.

2.3.3 Project-Level NEPA Considerations

NEPA was enacted to help public officials make decisions that are based on an understanding of environmental consequences and to take actions that protect, restore, and enhance the environment (40 CFR, Subpart 1500.1[c]). NEPA requires federal agencies to prepare environmental documentation to analyze the environmental impacts of major federal actions, including permitting and funding actions, affecting the quality of the human environment.

The level of NEPA documentation (determination of NEPA adequacy and land use conformance [DNA], categorical exclusion/exemption [CE], environmental assessment [EA], or environmental impact statement [EIS]) is determined by the degree of potential environmental impact. Generally, an EIS-level analysis is required for projects with significant environmental impacts.

Mitigation measures can be incorporated into project plans to reduce impacts to the degree that they are insignificant. If that is accomplished, an EA and finding of no significant impact would be appropriate. **Please note that at the time of the development of this document the federal agencies were undergoing policy changes related to mitigation. It is strongly recommended that the USFWS, NDOW, and the action agencies be consulted early in project development concerning mitigation activities.**

Mitigation is defined under NEPA (40 CFR, Subpart 1508.20) as follows:

2.3.3.1 Avoiding the impact altogether by not taking a certain action or parts of an action

2.3.3.2 Minimizing impacts by limiting the degree or magnitude of the action and its implementation

2.3.3.3 Rectifying the impact by repairing, rehabilitating, or restoring the affected environment

2.3.3.4 Reducing or eliminating the impact over time through preservation and maintenance

2.3.3.5 Compensating for the impacts by replacing or providing substitute resources or environments

Action agencies conducting a NEPA analysis on a mineral exploration or mining project may have different or additional baseline study requirements to support management decisions. Requirements can vary by jurisdiction, depending on resource management objectives or directives. Consultation with the action agency on baseline study requirements is recommended and operators should not rely on this document to determine the appropriate assessment methods or approaches to support agency-specific NEPA analysis.

As discussed below, if activities would result in a golden eagle take, such as removing an unoccupied nest, the USFWS would also require a NEPA analysis. This process and early consultation are encouraged in order to support a take authorization and to identify the appropriate studies (see **Section 7** of this document).

Project proponents have the option of building into their proposed action the eagle protection measures outlined in this document, thereby avoiding and minimizing potential impacts and reducing the need for compensatory mitigation and need for a take permit. This strategy may in some cases help determine the level of NEPA analysis required for a project.

2.4 Basic Golden Eagle Ecology

This account is a basic overview of golden eagle natural history and biology. Its purpose is to aid in project assessment planning, with a focus on nesting habitat and breeding behavior. Specific regional accounts are available and may provide additional insight into local eagle behavior.

Prey Base

Golden eagles are terrestrial hunters and eat small to mid-size reptiles, birds, and mammals, up to the size of mule deer fawns and coyote pups (Bloom and Hawks 1982; Herron et al. 1985). In Nevada, white-tailed (*Lepus townsendii*) and black-tailed jackrabbits (*L. californicus*), cottontails (*Sylvilagus* spp.), yellow-bellied marmots (*Marmota flaviventris*) and Richardson's (*Spermophilus richardsonii*) or Wyoming ground squirrels (*S. elegans*) are important secondary prey (Mcgahan 1966; Reynolds III 1969; Lockhart et al. 1977; Herron et al. 1985; MacLaren et al. 1988). In northwestern Nevada and northeastern California, rabbits comprised 85 percent of the diet in nesting golden eagles (Bloom & Hawks 1982) and at a similar proportion in southeastern Nevada (Joe Barnes pers. comm). In Idaho, black-tailed jackrabbits were the predominant prey species and were favored even during years with lower rabbit populations (Steenhof et al. 1997). Additionally, kit fox (*Vulpes macrotis*) gopher snake (*Pituophis catenifer*), common raven (*Corvus corax*), and other prey items have been documented (Joe Barnes pers. comm.).

A sufficient mammalian prey base is essential for stable or increasing populations of golden eagles and long-term population trends suggest a declining population in Nevada and the western United States (Great Basin Bird Observatory [GBBO] 2010). Potential limiting factors include prey density and availability of adjacent nesting habitat. Potential causes for mortality and/or decline include reduced prey base from degradation or loss of rangeland habitat. In Nevada, the current increase in wildfire recurrence associated with invasive annual grasslands is likely a significant contributor to loss or degradation of shrub-dominated habitats on which many likely prey species depend. Loss or reduction of jackrabbit and other prey populations dramatically influences golden eagle production (Steenhof et al. 1997; Nielson et al. 2012).

Territory, Breeding Behavior, and Nesting

Home range size is variable and based on location, prey density and time of year. Typical home range size is approximately 96.5 square miles per pair during the breeding season. A defended territory is generally a subset of the overall home range and in the western U.S., territory size can range from 7.7 - 13.5 square miles and some will have individuals present year-round (Kochert and Steenhof 2002). Recent NDOW transmitter data (2015-2018) from six adult golden eagles in Lincoln County and two adults in Humboldt County, revealed home range sizes approximately 30.4 to 43.7 square miles year respectively (Joe Barnes pers. comm.).

The onset of courtship, nest building, and egg laying varies regionally, but courtship generally starts in late winter and early spring in the Great Basin (Ryser 1985). Recent research by NDOW in Nevada has indicated breeding adults begin courting by December or January throughout the state (Joe Barnes pers. comm.). In Nevada, golden eagles usually nest on cliffs, with open views of surrounding areas. Proximity to hunting grounds is an important factor in nest site selection (Camenzind 1969). Golden eagles typically avoid building nests on loosely cemented materials (Baglien 1975). Less commonly, they nest on human-made structures, such as electrical transmission towers, windmills, nesting platforms, and have been found to occasionally nest in trees, on ground, clay cliffs, and river banks (Menkens and Anderson 1987; Phillips et al. 1990; Steenhof et al. 1993; Ryser 1985; Houston 1985).

Eagles will reuse old nests and nest ledges, alternating between nests in a territory, or build new nests. Nests are typically constructed with sticks of common local plants in a flat or bowl shape (platform nest), with soft material added. The bowl is lined with a wide variety of vegetation types. Golden eagle nest dimensions are approximately six feet long, four feet wide, and two to three feet tall, with a wide variation in size (Grubb and Eakle 1987; Herron et al. 1985). Approximately 34 percent of nests are reused after more than ten years of vacancy, indicating that unoccupied nests and nest sites need to be protected for longer than ten years (Kochert and Steenhof 2012).

The usual clutch of eggs is two, sometimes one, and rarely three (Baicich and Harrison 2005; Herron et al. 1985). Incubation lasts approximately 41-45 days, with the nestling period lasting around 30-50 days (Kochert et al. 2002). Fledgling occurs over a range of days once young are developed enough to leave the nest under their own power. Various researchers have indicated ages to fledging, but the most reliable sources are from Idaho at 64 days and 70 days in North Dakota. Young are associated with the adults for up to six months after fledging (Kochert et al. 2002).

For the purpose of this document, the golden eagle breeding season is December through August (Kochert et al. 2002). This time frame will allow breeding activities to be documented, even if nest building starts earlier or later than expected. The time frame also allows for monitoring known nests and determining nest success. **Table 1**, below, identifies the duration of each nesting stage for golden eagles.

Table 1: Golden Eagle Nest Stage Duration

Nest Stage	Days
Courtship and nest building/refurbishing	30–90 days before egg laying
Egg incubation	41–45 days
Young in nest	64–77 days
Dependence on parent for temperature regulation	First 20 days
First flight	63–70 days
Post-fledging association with parents	3–6 months

Sources: Birds of North America Online 2017

The timing of golden eagle breeding activity (specifically the critical egg-laying date) can vary between individual pairs within study area, by elevation, and between years and regions within the state. Because of this, it is recommended that federal agencies and project proponents contact regional-NDOW staff with golden eagle expertise early in the survey planning process for project specific recommendations.

Nevada Bird Conservation Region Characteristics

Most of Nevada is in the Great Basin Bird Conservation Region (9), as shown on the map below. Mohave Region (33) also covers a substantial portion of the state. Region 9 in Nevada is coincident with most of the mineral exploration and mining in the state.

This large and complex region includes the Northern Basin and Range, Columbia Plateau, and the eastern slope of the Cascade Range. The area is dry, due to its position in the rain shadow of the Cascade Range and the Sierra Nevada. Grasslands, sagebrush, and other xeric shrubs dominate the flats and lowlands, with piñon-juniper woodlands and open ponderosa pine forests on higher slopes (North American Bird Conservation Initiative 2015).

Recent research on the biology of the golden eagle in the Great Basin and other arid landscapes shows that these populations have unique characteristics. They often differ substantially from populations in less arid landscapes, where much golden eagle research has been done. In Nevada, overall prey density tends to be far lower than other studied golden eagle habitat areas, due to reduced annual precipitation. In these areas, nesting populations of golden eagles are less dense, and both territory size and eagle use of territories are likely different from dense nesting populations. Therefore, considering wildlife habitat values in an area to support a prey base is an important condition to note when evaluating potential golden eagle habitat in Nevada. The USFWS, BLM, and NDOW are conducting limited telemetry studies to better understand golden eagle biology and population dynamics in Nevada.

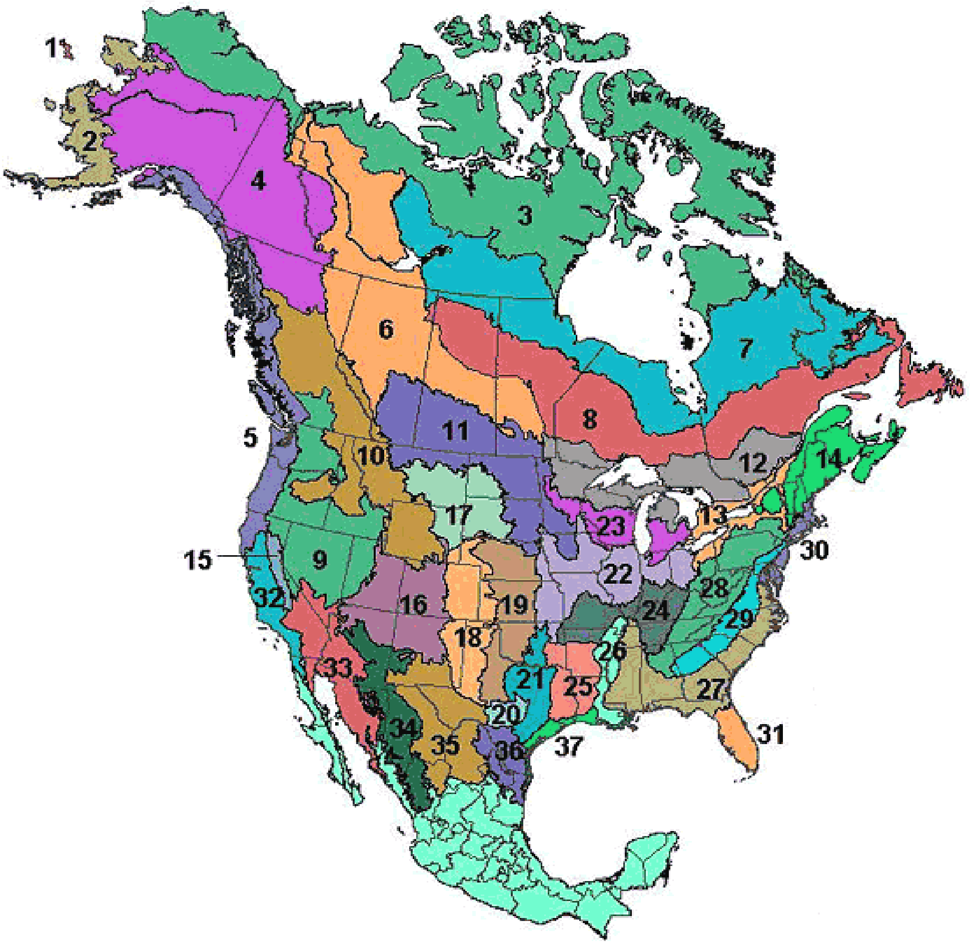

Figure 1: Bird Conservation Region Map[1]

Human Interaction and Eagle Mortality

The USFWS reported in 2016 that approximately 63 percent of adult golden eagle mortalities, approximately 34 percent of first year golden eagle mortalities, and 44 percent of all golden eagle mortalities were human caused (USFWS 2016). Gunshots and electrocution are the leading causes of death, at 11 percent each, followed by poisoning (nine percent), collision (seven percent), traps (three percent), and lead poisoning (two percent) (USFWS 2016). Kochert at al. (2002) also note that golden eagles are vulnerable to collision and electrocution when landing on power poles. Less-adept immature eagles are most susceptible to electrocution, and the risk increases when inclement weather hampers flight or when wet feathers increase conductivity (Avian Power Line Interaction Committee [APLIC] 2006). The USFWS notes that golden eagles are electrocuted more often than any other raptor in North America. Most electrocution deaths occur during winter in the western United States, in areas lacking natural perches (USFWS 2011).

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[1] Map Source: North American Bird Conservation Initiative 2015

3 PROJECT EVALUATION AND GOLDEN EAGLE IMPACT ASSESSMENT

The status and type of the project and operation must be considered when determining measures to be taken for eagle impact assessments. The timing of operations and activities associated with mineral exploration and mining projects can vary, from less than one year to multiple years. Exploration projects may have a project life of only one year or less; the project life for a mine depends on the economics of the resources, which is a dynamic measure. In most cases, once an exploration or mining project ends, all disturbance and activities cease, and the habitat is reclaimed. In some cases, the resulting habitat may provide eagle nesting and foraging opportunities.

Four operation types are described below and represent the major classes of exploration and mining projects. They are based on exploration and mining project types, in relation to Nevada-permitted operations, each with specific levels of scale, duration, and associated activities. Many projects involve both a mining and exploration component, and the operator should choose the highest level of operation to guide golden eagle assessment.

The four operation types are as follows:

- Operation Type 1—Small exploration project
- Operation Type 2—Large exploration project
- Operation Type 3—Small mine project
- Operation Type 4—Large mine project

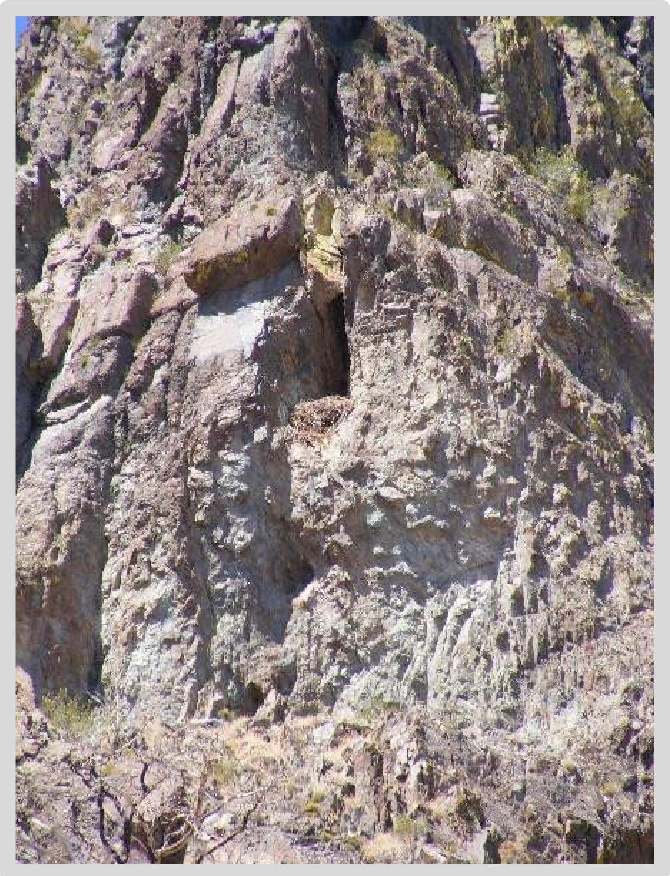

Photo Source: Wildlife Resource Consultants

The purpose of the eagle impact assessment and survey recommendations is to pair each operation type with reasonable assessment approaches for detecting nesting eagles and habitat in the project area and vicinity. These recommended assessments of habitats and survey activities should be conducted during the project planning and permitting stage. The timing for the survey requirements needs to be considered based on geography.

The data collected and analyzed during the assessment and surveys should be used to identify and implement the appropriate Golden Eagle Protection Measures (GEPM) to avoid take or identify the need for a permit. For example, for a small exploration project, conducting a desktop topographical analysis to identify potential cliff areas that may be suitable for golden eagle nesting may help project geologists locate their drill targets away from these areas, if feasible. This would reduce the likelihood of encountering an occupied golden eagle nest close to the proposed activities.

A pre-construction survey (GEPM ENM-1; see **Table 2**, below) following the Interim Golden Eagle Inventory and Monitoring Protocols and Other Recommendations (USFWS 2010) is recommended before drilling activities, to detect occupied nests and comply with BGEPA and the MBTA. Moreover, using habitat evaluation data upfront in the planning process may benefit the project by saving time and money and promoting golden eagle conservation.

3.1 Operation Type 1—Small Exploration Project

Operation Description

Small-scale exploration projects typically will have the following or similar characteristics (requirements may vary depending on the federal land manager):

- For the BLM, notice-level operations, with less than five acres of disturbance. Please note, for these small projects the USFWS may still require some level of NEPA
- Operations and disturbance that are temporary (one to two years)
- Limited, dispersed surface disturbance
- No engineered infrastructure required, such as power lines and ponds
- Minimal vehicular traffic
- Reclamation of all disturbed areas concurrently or following project operations

Habitat Assessment/Survey Recommendations

Step 1—Submit a data request for or run a NDOW database query for known nest locations and golden eagle use areas within a one-mile radius2 of the project area or disturbance footprint. Section 3.5 describes available data sources.

Photo source: Melissa Wendt

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[2] The one-mile radius is a conservative recommendation, based on the golden eagle recommended spatial buffer of 0.5 mile (USFWS 2002).

Step 2—Using desktop resources, evaluate the habitat characteristics of the project area and surrounding area, based on golden eagle habitat preferences, to identify potential nesting habitat. This can include a topographical analysis to identify cliff and rock features.

Step 3—Based on the results of Step 1 and 2, review and implement the protection measures included in **Section 4** of this document for applicability.

3.2 Operation Type 2—Large Exploration Project

Operation Description

Large-scale exploration projects typically will have the following or similar characteristics:

- No acreage limits
- Disturbance that occurs in phases over 2-plus years
- Limited, dispersed surface disturbance
- No engineered infrastructure required, such as power lines and ponds
- Minimal vehicular traffic
- Reclamation of all disturbed areas concurrently or following project operations
- Typically requires a project-level EA for NEPA or similar-scale impact study

Habitat Assessment/Survey Recommendations

Step 1—Submit a data request for or run an NDOW database query to acquire known nest locations and eagle use areas within a 2-mile radius of the project area. A 2-mile radius assessment area was identified for this level of operation, because surface exploration is consistent with the activities evaluated by Pagel et al. (2010), described as extended construction disturbance.

Step 2—Using desktop resources, evaluate the habitat characteristics of the project area and surrounding area, based on eagle habitat preferences, to identify potential nesting habitat. This can include a topographical analysis to identify cliff and rock features.

Step 3—Conduct a field baseline survey, following the Interim Golden Eagle Inventory and Monitoring Protocols and Other Recommendations Pagel et al. (2010), within a 2-mile survey buffer, in consultation with NDOW and the action agency to avoid conflicts with other sensitive species.

Step 4—Conduct a view shed analysis to determine whether planned surface disturbance and drilling are in the line of sight of any nests observed during baseline surveys or of potential nesting habitat within a 2-mile radius of the disturbance footprint.

Step 5—Based on the results of Step 1 through 4, review and implement the protection measures included in **Section 4** of this document for applicability or prepare an ECP and an eagle take application if impact is unavoidable.

Additional Consideration—If eagle habitat is determined to be present and an advanced exploration project is tracking toward a mine operation likely to require a comprehensive cumulative impacts evaluation, consider the approach for Operation Type 4 with surveys to be conducted within a ten-mile radius of the project area.

3.3 Operation Type 3—Small Mine Operation

Small-scale mine projects typically will have the following or similar characteristics:

- Has fewer than 1,000 acres of surface disturbance
- Meets the Nevada Administrative Code (NAC) 445A.411 and 445A.377 definitions of a small-scale facility (36,500 tons of ore per year and no more than 120,000 tons of ore for the life of the project); this operation type also includes mine projects that do not process ore on-site
- Has minimal facilities with potential eagle interaction (power lines, ponds, and chemical exposure)
- Has minimal vehicular traffic
- Has no open pits or pits with limited high walls
- Typically requires a project-level EA for NEPA or similar-scale impact study, as determined by the action agency

Habitat Assessment/Survey Recommendations

Step 1—Submit a data request or run an NDOW database query to acquire known nest locations and eagle use areas within a ten-mile radius of project area[3]. A ten-mile radius assessment area was identified for this level of operation as the operations and surface modification is consistent with the activities evaluated by Pagel et al. (2010) described as extended construction disturbance.

Step 2—Using desktop resources, evaluate the habitat characteristics of the project area and surrounding area, based on eagle habitat preferences, to identify potential nesting habitat.

Step 3—Conduct a field baseline survey, following the Interim Golden Eagle Inventory and Monitoring Protocols and Other Recommendations Pagel et al. (2010), within the ten-mile radius, in consultation with NDOW and the action agency to avoid conflicts with other sensitive species. The surveys at a minimum should identify occupancy, the presence or absence of potential nesting habitat, nests, roosting sites, and prey source.

Photo source: Melissa Wendt

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[3] The ten-mile radius is based on Pagel et al. (2010), page 11.

Step 4—Conduct a view shed analysis to determine whether planned surface disturbance and new project operations are in the line of sight of potential nesting habitat within a ten-mile radius of the proposed disturbance footprint.

Step 5—Based on the results of Step 1 through 4, review and implement the protection measures included in **Section 4** of this document for applicability or prepare an ECP and an eagle take application if impact is unavoidable.

3.4 Operation Type 4—Large/Complex Mine Operation

Large-scale mine projects typically will have the following or similar characteristics:

- Exceeds the small-scale facility definition in NAC 445A.377 (processing more than 120,000 tons of ore over the life of the project)
- Has ancillary facilities with potential eagle interaction (power lines, ponds, chemical exposure)
- Has greater than 1,000 acres of surface disturbance
- Has large open pits with high walls
- Has high traffic volumes in the operations area and on project access roads
- Typically requires an EIS for project-level NEPA or similar-scale impact study, with a comprehensive cumulative effects analysis, as determined by the action agency

Habitat Assessment/Survey Recommendations

Step 1— Submit a data request or run an NDOW database query to acquire known nest locations and eagle use areas within a ten-mile radius of project area. A ten-mile radius assessment area was identified for this level of operation as the operations and surface modification is consistent with the activities evaluated by Pagel et al. (2010) described as extended construction disturbance.

Step 2—Using desktop resources, evaluate the habitat characteristics of the project area and surrounding area, based on eagle habitat preferences, to identify potential nesting habitat.

Step 3—Conduct a field baseline survey, following the Interim Golden Eagle Inventory and Monitoring Protocols and Other Recommendations Pagel et al. (2010), within the ten-mile radius, in consultation with NDOW and the action agency to avoid conflicts with other sensitive species. The surveys at a minimum should identify occupancy, the presence or absence of potential nesting habitat, nests, roosting sites, and prey source.

Step 4—Conduct a view shed analysis to determine whether planned surface disturbance and new project operations are in the line of sight of potential nesting habitat within a ten-mile radius of the proposed disturbance footprint.

Step 5—Based on the results of Step 1 through 4, review and implement the protection measures included in **Section 4** of this document for applicability or prepare an ECP and an eagle take application if impact is unavoidable.

3.5 Data Sources and Sharing

3.5.1 Data Sources

Various data sources are available to evaluate a site's potential for golden eagle use; however, there may always be the potential for eagles to occupy any given area, and these sources do not substitute for nesting surveys when required.

The following data sources have been included for a preliminary evaluation of golden eagle habitat use and occupancy:

- NDOW—NDOW conducts surveys to document raptor nests (including golden eagles) in many regions. Submitting NDOW's Data Request and Eagle Survey Forms to obtain a current list of the nest sites in the Statewide Raptor Nest Database is helpful to determine if any golden eagle nests have been recorded in the vicinity of the project. Specific nest locations may be provided by NDOW under a signed Data Sharing Agreement. The Data Sharing Agreement requests that proponents or contractors share relevant survey data with NDOW. In the case of raptor nests, this is particularly important. NDOW is the primary source of raptor data in Nevada and manages a significant geospatial database of raptor nests. Collectively working to improve and add locations to this database will ultimately help NDOW and proponents by helping to identify nests, understand intra-annual variations, and reduce duplicative survey efforts that increase costs and indirect effects from survey-triggered disturbance.

- The GBBO has a repository of predictive maps, a map of Important Bird Areas, and bird survey data collected in the Great Basin. The individual state Partners in Flight Conservation Plans have additional species information that may be useful to habitat assessments. These documents can be found at the following Internet website: http://www.gbbo.org/public-resources/.

- Local federal agency field offices, in coordination with NDOW, keep their own records and have knowledge of other projects nearby where raptor nesting surveys may have been conducted in the vicinity of a project. Meeting with wildlife biologists in the local office where a project is located may yield data that can be used in a project evaluation.

3.5.2 Data Sharing and Reciprocity

As a best practice, operators and project proponents should seek to understand past, ongoing and future raptor surveys in the vicinity of the project. Project proponents are encouraged to use existing nest data to complement their survey data. Additionally, proponents and their contractors are strongly encouraged to provide timely survey data (nest sites and flight tracks) to NDOW and the action agency in an electronic geospatial format. Providing this data is also a requirement of

Photo source: Melissa Wendt

the Data Sharing Agreement used to obtain existing nest data. Data provided from these surveys will be added to the Statewide Raptor Nest Data. In addition, providing data is often part of the statements of work provided by the action agency and will be needed to complete NEPA analyses.

3.5.3 Recommended Survey Coordination

The purpose of this section is to provide guidance in order to minimize disturbance impacts to golden eagles and to bighorn sheep during critical lambing periods when completing eagle/raptor nest surveys. Minimizing disturbance will be achieved through improved survey planning, agency coordination, and avoidance of important bighorn sheep habitat.

The frequency and spatial overlap of eagle surveys occurring in Nevada has the potential to negatively impact nesting eagles and other wildlife such as bighorn sheep. Incidences of duplicative surveys causing extreme reactions in bighorn sheep has been documented in areas of high mining activity and multiple concurrent surveys. The recommendations in this section are primarily intended to reduce the indirect detrimental effects of intense golden eagle surveys through coordination with NDOW and the action agency. This process should also encourage increased coordination among proponents completing surveys in overlapping areas and provide an opportunity to increase efficiency, reduce survey costs, and ultimately minimize unnecessary disturbance on wildlife. In order to accomplish this, the process seeks to identify the location and timing of all proposed eagle/raptor surveys in Nevada. It is strongly encouraged that the project proponent or their contractor adhere to the following steps:

1. **Pre-Survey Planning:**

    a. Submit an NDOW Eagle Survey Form to data@ndow.org at least 30 days prior to initiating a survey to start the consultation process. This form can also be submitted with the Data Request Form when querying the Statewide Raptor Nest database. Proponents should include the following information with the Eagle Survey Form to NDOW:

        i. Project boundary shapefile
        ii. Survey boundary shapefile
        iii. Proposed survey timing and methodology (aerial vs ground)

    b. Once the Eagle Survey Form is received, the appropriate Regional NDOW biologist will coordinate with the project proponent and the action agency and provide project specific consultation on potential concerns for indirect disturbance to sensitive wildlife or multiple surveys that overlap the same geographic areas. During this coordination, NDOW and the project proponent should discuss which recommendations are suitable for the survey.

        i. In areas of high mining activity, NDOW will assess the survey boundaries relative to other known surveys and provide information to facilitate coordination with other project proponents conducting nearby surveys. The goal of this exercise is to reduce disturbance for sensitive wildlife, in particular golden eagles, raptors and bighorn sheep, by reducing duplicative or repeat survey efforts.
        ii. In bighorn sheep habitat, NDOW will assist the proponent with following NDOW's *Recommendations for Conducting Golden Eagle Surveys in Bighorn Sheep Habitat* (Section 3.5.4). As part of this effort, NDOW will try to determine other on-going survey efforts and facilitate coordination to minimize surveys in general and critical bighorn sheep habitat. NDOW will

provide input on the survey with regards to minimizing disturbance within 14 days of being contacted by the proponent.

c. Enter into a Data Sharing Agreement with NDOW to acquire and use the existing raptor nest database. This information will help identify additional nests in the survey boundary. The NDOW Data Sharing Agreement contains certain restrictions on use in order to protect nests from disturbance or poaching. See Appendix A for an example of NDOW's data-sharing agreement.

2. **Post-Survey Data Sharing**

   a. After the survey is complete and data are processed, within 30 days the project proponent or the proponents' contractor shall provide the following data to NDOW at data@ndow.org:

      i. Nest Data. Preferably provided in an electronic format such as an ESRI Shapefile or .CSV format.
      ii. Flight or Ground Survey Tracks. Preferably provided in an electronic format such as ESRI Shapefile or .GPX file. This data should also be shared with the action agency at the same time.

3.5.4 General Recommendations for Conducting Golden Eagle Surveys

- Aerial (helicopter) surveys are typically acceptable but consider ground surveys if at all possible.

- To minimize disturbance to nesting eagles, cliffs should be approached from the front instead of approaching from behind or suddenly from around corners
- Conduct surveys in the least intrusive manner as possible
- For areas of highest concern, proponents or their contractors should coordinate with regional NDOW biologists to develop the least-impactful survey approach possible.

3.5.5 Recommendations for Conducting Golden Eagle Surveys in Bighorn Sheep Habitat

1. **Timing Considerations:** Flights should account for the following lambing timeframes* and planned accordingly**:

   a. For southern Nevada, bighorn sheep lambing period is January 1 - March 31
   b. For central Nevada, bighorn sheep lambing period is February 1 - April 30
   c. For northern Nevada, bighorn sheep lambing period April 1 - May 31

   *The dates provided above are general guidelines as there are significant differences among bighorn sheep herds within the same region. Narrower timeframes for critical lambing periods can be established at the project-level during coordination with NDOW.

   **Sub-regional and population specific time periods may be different. Consultation with NDOW specific to your survey area is important and will help refine critical lambing season timelines.

2. **Surveys in Bighorn Sheep Habitat, WITHOUT Critical Lambing Areas Identified**

Specific Geographic Information System (GIS) layers are not always available for differences in seasonal habitat use for bighorn sheep (e.g. lambing habitat) or lambing occurs over a broad geographic area and is dispersed across broader areas. In these situations, NDOW recommends surveyors planning and performing cliff-nesting raptor surveys adhere to a general set of recommendations. These recommendations are intended to reduce impacts to bighorn sheep while still allowing a complete survey of cliff-nesting raptor habitat to be completed.

- Aerial (helicopter) surveys are acceptable in these areas but consider ground surveys if at all possible. When appropriate and if two surveys will be completed (based on Pagel et al. 2010), consider completing the first survey from the air and the second survey from the ground.
- Similar to recommendations for minimizing disturbance to nesting eagles, cliffs should be approached from the front instead of approaching from behind or suddenly from around corners.
- Be alert to the presence of bighorn sheep, especially during peak lambing season. Ewes often separate from others to give birth. A few weeks after peak lambing, ewes and lambs often join into larger nursery groups. Disturbance at either time can be highly detrimental to bighorn sheep.
- If bighorn sheep are spotted, suspend the survey for that area and retreat from the area in as least intrusive a manner to the bighorn sheep as possible. Record location and response of bighorn sheep and contact NDOW once the survey is finished.

3. Surveys in Bighorn Sheep Habitat, WITH Critical Lambing Areas Identified

Many areas in Nevada have accurate GIS data where bighorn sheep can be expected to exist. Some bighorn sheep herds will routinely lamb in predictable habitat or specific areas. These areas are often documented through routine observations or via GPS/very high frequency (VHF) tracking collars. Other herds only contain a few individuals, may be under multiple stressors, or are in areas where they may be subjected to multiple overflights, making them highly susceptible to disturbance. In situations where critical lambing areas can be identified, overlapping surveys are anticipated, surveys are consistently completed on an annual or near annual basis, or in other areas of heightened consideration. NDOW recommends additional care is used when planning and completing aerial surveys. These recommendations are intended to reduce impacts to bighorn sheep and while they may reduce the completeness of the golden eagle survey, these recommendations are an important step to ensure surveying one species does not significantly impact another species.

- Obtain a map and GIS layer from NDOW for the critical lambing areas. These areas should be excluded from aerial survey efforts during the lambing period identified for that region or for the specific bighorn sheep herd (project-specific determination).
- Ground survey techniques are less intrusive and result in fewer disturbances to bighorn sheep. Ground surveys should be used in cases when golden eagle surveys cannot avoid critical lambing habitat or be rescheduled outside of critical time periods. When ground surveys are not feasible due to remote or inaccessible topography or large survey areas, NDOW recommends an initial aerial survey be completed prior to critical lambing periods, which will often coincide with the early portion of the golden eagle breeding season. This initial aerial survey can be used to cover all suitable nesting habitat. If follow-up surveys need to be completed and fall within critical lambing periods, these should be ground-based surveys to assess nests of likely or probable golden eagle origin. This mixed-method approach satisfies the need to space occupancy surveys no closer than 30 days and effectively targets the courtship and laying/incubation breeding stages, while minimizing disturbance to bighorn sheep.

- For areas of highest concern (critical lambing habitat within areas of high-mining activity and frequent eagle surveys), proponents or their contractors shall coordinate with regional NDOW biologists to develop the least-impactful survey approach possible given spatial and temporal constraints for both parties.

4 GOLDEN EAGLE PROTECTION MEASURES

For any project with potential impacts to golden eagles, it is important to identify avoidance, minimization, and mitigation measures to reduce potential take or complete an ECP and an eagle take application. As discussed below in more detail, these factors will play a large role in the USFWS's determination to issue a take permit.

The following section presents GEPMs that have been identified as applicable to the mining industry. The following categories of proactive GEPMs are to encourage golden eagle protection and habitat management:

- Project design and management
- Activity buffer
- Project administrative controls
- Facility design
- Habitat management and enhancement
- Golden eagle planning and/or pre-construction surveys and nest monitoring

An operator may choose to select appropriate GEPMs based on the operation and project type and habitat conditions, as outlined in the discussion for each measure further on in this chapter. These recommendations are not all inclusive of available strategies but provide a framework for project proponents and operators to follow. Depending on the application and location, some measures may work better than others.

Table 2, below, presents a summary of the GEPMs described in this section and gives examples of each. Each measure is described in more detail later in this chapter.

Table 2: Golden Eagle Protection Measures (GEPM)

GEPM Number	Name	Purpose
Project Design and Management (PDM)		
PDM-1	Avoidance—Project timing	Avoid new activities and construction during golden eagle nesting season
PDM-2	Avoidance—Habitat	Avoid golden eagle nesting habitat
PDM-3	Limit project footprint	Reduce modification to golden eagle habitat
PDM-4	Concurrent reclamation	Reduce duration of habitat disturbance
Activity Buffer (AB)		
AB-1	In-use nest spatial buffer	Prevent any disturbance to breeding and nesting golden eagles
Project Administrative Controls (PAC)		
PAC-1	Speed limit reduction	Minimize risk of golden eagle/vehicle collisions
PAC-2	Employee training	Increase awareness of project/golden eagle interactions
PAC-3	Carcass removal program	Minimize risk of golden eagle/vehicle collisions
Facility Design (FD)		
FD-1	Power line design or retrofit	Minimize the risk of golden eagle electrocution
FD-2	Chemical exposure management	Minimize the risk for golden eagle direct or indirect mortality
Habitat Management and Enhancement (HME)		
HME-1	Increase prey base	Increase golden eagle use of area after project operations cease
HME-2	Enhance general and nesting habitat	Increase golden eagle use of area after project operations cease
Golden Eagle Pre-Construction Surveys and Nest Monitoring (ENM)		
ENM-1	Pre-construction survey	Identify breeding and nesting golden eagles just before construction during breeding season
ENM-2	Remote and annual eagle nest monitoring	Document status of nests in project area or assessment area

4.1 Project Design and Management (PDM)

PDM-1

4.1.1 PDM-1: Avoidance—Project Buffer or Timing

Purpose: To avoid disturbing breeding or nesting eagles

Applications:

- If an occupied nest or unsurveyed potential habitat is in the project area or vicinity (one mile) in the line of sight (the unobstructed visibility of an activity from a nest site) of planned new disturbance activity
- All operation types

Standards and specifications:

- Begin any new activities or operations with a potential to disturb golden eagles outside of golden eagle breeding season (December through August, varies by geography), or when a known occupied nest is determined to have become unoccupied, either through fledging or nest failure, using the methods in Pagel et al. 2010.

PDM-2

4.1.2 PDM-2: Avoidance—Habitat

Purpose: To avoid disturbing or removing potential eagle nesting habitat and use areas that could influence productivity and survival

Applications:

- When siting project disturbance, when feasible, avoid and preserve eagle habitat features, such as rock outcrops, cliffs, and trees, that can provide suitable nesting habitat
- All operation types

Standards and specifications:

- Avoid removing cliff areas
- Avoid removing trees and snags (dead trees) that provide nesting or perching sites
- Avoid disturbing water sources and riparian areas
- Avoid disturbing roosting or perch sites (detected by white wash)

PDM-3

4.1.3 PDM-3: Limit Project Footprint

Purpose: To minimize disturbing potential golden eagle foraging and nesting habitat

Applications:

- When golden eagle nesting habitat is documented in the project area or surrounding area (appropriate analysis radius)
- All operation types

Standards and specifications:

- When possible, place construction and human activities in areas that are already delineated as disturbed by the permitting agency
- Limit the project footprint to the smallest area necessary to meet project needs

PDM-4

4.1.4 PDM-4: Concurrent Reclamation

Purpose: To minimize the temporal scale of disturbance to habitat areas

Applications:

- When potential golden eagle nesting or foraging habitat is documented in the project area or surrounding area (appropriate analysis radius)
- All operation types

Standards and specifications:

- Conduct habitat reclamation after operations in an area are complete and when no future activities are planned, typically within one calendar year from the time of disturbance
- Conduct reclamation outside of nesting and breeding season (December through August), when feasible
- Coordinate with local natural resource managers on specifying seed mixes and plant types to ensure selection of appropriate species; select seedings and plantings that provide diverse vegetation, which encourages habitat diversity and supports abundant prey populations (see HME-1 and HME-2 in Table 2 for reclamation considerations to enhance or improve golden eagle habitat)

4.2 Activity Buffer

AB-1

4.2.1 AB-1: In-Use Nest Spatial Buffer

Purpose: To prevent nest abandonment or disruption to breeding and nesting activities resulting in take from new operations

Applications:

- Projects where an in-use nest has been located in the project area or in the line of sight of planned disturbance
- All operation types with planned new activity or disturbance

Standards and specifications:

- If possible to do so without disturbing the golden eagles, ensure that a qualified biologist takes photographs and documents the following information to aid in USFWS and NDOW coordination and project timing:
  - Nest location and elevation
  - Number and age class of golden eagles observed
  - Estimate of nest stage and date clutch completed
  - Assess breading success
  - Number of young, if present
- Notify the USFWS, NDOW, and the action agency of the in-use golden eagle nest and discuss an appropriate activity buffer dimension, depending on the age class, stage of nesting activity, number of young, location and visibility of nest in relation to planned project activities, and habitat and topographical conditions
- Place a one-mile activity buffer (two miles for blasting or substantially loud noises), around the in-use eagle nest; the USFWS and NDOW may decrease the one-mile standard buffer if not in the line of sight
- Avoid all surface-disturbing activities, blasting, and new operations that could disturb the nesting eagles in the activity buffer
- Understand that the nest is considered active throughout periods of courtship and nest building, egg laying, incubation, brooding, fledging, and post-fledgling dependency (one month), unless there is some objective evidence that the nest has failed or been abandoned
- Maintain the activity buffer until the young have fledged from the nest or the nest becomes inactive through nesting failure, using the methods in Pagel et al. 2010
- Monitor nest stage and fledging so as to not disturb breeding and brood-rearing activities (see Table 1, above, for approximate lengths

of nest stages, and time monitoring to occur at the estimated end of the nest having dependent young)

4.3 Project Administrative Controls

PAC-1

4.3.1 PAC-1: Speed Limit Reduction

Purpose: To minimize the risk of collisions between project vehicles and eagles eating carrion on project roads

Applications:

- Projects with documented eagle use in the project area or vicinity
- High-traffic roads with daily project-related traffic
- All operations

Standards and specifications:

- Reduce speed limit, as permitted by public safety, project operations, and other considerations
- Enforce the speed limit (operator's management team)
- Place a one-mile activity buffer (two miles for blasting or substantially loud noises), around the in-use eagle nest; the USFWS and NDOW may decrease the one-mile standard buffer if not in the line of sight

PAC-2

4.3.2 **PAC-2: Employee Training**

Purpose: Increase employee awareness of potential sources of project/eagle interaction

Applications:

- All operation types, but more applicable to Operation Type 4

Standards and specifications:

- Establish educational programs for project employees to increase awareness of the potential for vehicular collisions and other encounters with raptor species; include annual training, conducted by a qualified biologist, review best management practices for the project, and show training videos

PAC-3

4.3.3 PAC-3: Carcass Removal Program

Purpose: To reduce the occurrence of collisions between project vehicles with golden eagles by removing road kill from roads on the mine site

Applications:

- Projects with documented golden eagle nests or use areas
- Projects that use high-traffic roads or have an extensive road network on the mine site
- Operation Types 2, 3, and 4

Standards and specifications:

- For facilities with Industrial Artificial Pond Permits (IAPP) requirements, comply with the permit requirements. For operations without IAPP permits, remove or place off the road all observed carcasses[4] the size of a rabbit or larger, within 24 hours, when feasible unless stated otherwise in a NEPA decision.
- Train employees to look for carcasses on access and project roads and report carcasses to a designated employee
- Coordinate with USFWS and NDOW to acquire permits and authorizations, if required

4.4 Facility Design

FD-1

4.4.1 FD-1: Power Line Design or Retrofit

Purpose: To prevent eagle electrocution and death due to interacting with project power facilities by retrofitting existing power lines or constructing new infrastructure to meet APLIC standards. Electrocution typically happens when a bird attempts to perch on a structure with insufficient clearance between electrified elements, often on destruction lines with voltage less than 60 kilovolts (kV) (APLIC 2006).

Applications:

- Projects with documented eagle use and potential or occupied habitat
- Operations Types 3 and 4, where power infrastructure is existing or proposed

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[4] Not including eagle carcasses

Standards and specifications:

- Install new power lines or upgrade existing power lines in a way that will reduce raptor collisions, exposure to chemicals and electrocution.
- Refer to the most recent guidelines with eagle safe construction specifications by APLIC

Photo Source: Melissa Wendt

FD-2

4.4.2 FD-2: Chemical Exposure Management

Purpose: To prevent eagles from coming in contact with chemicals and process solutions that have the potential to be harmful or lethal

Applications:

- Operation Types 3 and 4 with chemical ponds, heap leach facilities, or other facilities that contain concentrated chemicals

Standards and specifications:

- Install netting, bird balls, bird deterrents, or other means to discourage eagles from using areas where there is potential chemical exposure
- Maintain and monitor facilities to ensure the controls are working properly
- To determine toxicity levels and exposure hazards, perform a screening level ecological risk assessment or similar document or analysis to identify the exposure risk to eagles from the types and uses of solutions and chemicals at a project
- If ponds meet size and contents criteria, operate the pond under NDOW IAAP permits, which requires specific operational conditions

(including ponding on leach pads), monitoring, carrion removal, and reporting

4.5 Habitat Management and Voluntary Enhancement

HME-1

4.5.1 HME-1: Increase Prey Base

Purpose: To increase habitat values of existing golden eagle use areas on or next to project areas, following project operations and during site reclamation

Applications:

- Projects in existing golden eagle use areas
- All operation types, including those requiring compensatory mitigation for general habitat disturbance (not related to golden eagle take)

Standards and specifications:

- Construct rock piles, with hiding and denning values for prey species
- Develop revegetation seed mixtures that serve as a food source and habitat for eagle prey species

HME-2

4.5.2 HME-2: Enhance Golden Eagle General and Nesting Habitat

Purpose: To increase nesting habitat values of existing golden eagle use areas on or next to project areas, following project operations and during site reclamation

Applications:

- Projects in existing eagle use areas
- All operation types, including those requiring compensatory mitigation for general habitat disturbance (not related to golden eagle take)

Standards and specifications:

- Construct rock piles to provide perches for eagles
- Restore or rehabilitate previously altered habitat not needed for project operations
- Coordinate specification of seed mixes and plant types with local natural resource managers to ensure selection of appropriate species
- Select seedings and plantings to provide diverse vegetation, which encourages habitat diversity and supports abundant prey populations

4.6 Golden Eagle Nest Monitoring

4.6.1 ENM-1: Pre-Construction Surveys

ENM-1

Purpose: To identify in-use nest sites in the project area and the surrounding area (one-mile buffer) just before the beginning of any new project operations that could disturb nesting golden eagles; the habitat assessment data collected during project planning may serve to support areas that need intensive nest searches

Applications:

- When golden eagle nesting habitat is documented in the project area or surrounding area (analysis radius) during baseline surveys
- Operation Types 1, 2, 3, and 4
- When project disturbance is either dispersed over a large area or concentrated with large blocks of disturbance.

Standards and specifications:

- Before any land clearing or grubbing activities or drilling, conduct a pre-disturbance survey for nesting golden eagles, if project activities are planned during the breeding season (December through August).
- Create a one-mile in-use nest spatial buffer around any occupied eagle nests. The buffer may be reduced, in coordination with USFWS and NDOW, when line-of-sight limitations exist.
- Conduct surveys within 14 days prior to the start of project activities
- Ensure surveys are performed by a third-party qualified biologist, ideally one with at least two seasons of experience in conducting nesting cliff dwelling raptor surveys

Photo Source: Newmont Mining Company

- If an in-use nest is detected, ensure that a qualified biologist documents the following information, if it is possible to do so without disturbing the eagles, to aid in USFWS coordination and project timing:
    - Nest location
    - Nest elevation
    - Nest aspect
    - Nest substrate (tree/cliff, size of either, etc.)
    - Number and age class of eagles observed
    - Photographs
    - Estimate of nest stage and date clutch completed
    - Local breading phenology
    - Nest success and number of young if available
- Understand that the nest is considered active throughout periods of courtship and nest building, egg laying, incubation, brooding, fledging, and post-fledgling dependency, unless there is some objective evidence that the nest has failed or been abandoned
- Document survey results that will be distributed to agencies as requested and kept as an internal memo kept on file for the duration of the project

ENM-2

4.6.2 ENM-2: Remote and Annual Eagle Nest Monitoring

Purpose: To monitor the status of occupied, in-use or unoccupied eagle nests in a project area or within one mile of external project boundaries that have been previously identified during project baseline surveys; if new nests are found, they should be documented and added to the database for future monitoring. Remote monitoring may be used for areas difficult to access or susceptible to disturbance by physical monitoring.

Applications:

- All projects that currently have an occupied or in-use golden eagle nest in the project area or within a one-mile radius or that had an occupied nest in the same area in the previous breeding season
- To be used in concert with other protection measures to avoid take

Standards and specifications:

- Conduct annual ground-based monitoring for the life of the project, until reclamation is completed, during breeding season to identify nest use and success (Pagel et al. 2010).
- Monitor for nests in the project area and within a one-mile radius
- Ensure monitoring is performed by a qualified biologist.

  - Ensure that monitoring observation posts are between 500 meters (approximately 1,600 feet) and 1,200 meters (approximately 3,900 feet) from the nest
  - Consult with the USFWS and NDOW to set up remote cameras in the nest area or on a platform

5 TAKE EVALUATION

This section presents information to help project proponents and operators make informed decisions if an operation would potentially result in take and discusses the types of take permits and the requirements of obtaining a take permit from the USFWS.

5.1 Overview of Project-Level Take

There are three categories of eagle take that may be caused by mining operations: (1) injury to or mortality of individual eagles from, for example, power line collision or electrocution; (2) disturbance of eagles from noise or human presence that significantly interferes with breeding, feeding, or sheltering behavior; and (3) relocation or removal of eagle nests. There are also three categories of take permits available under the Service's regulations: (1) incidental take under Section 22.26; (2) take of alternate golden eagle nests during resource and recovery operations under Section 22.25; and (3) take of in-use or alternate nests of either eagle species primarily to alleviate a health and safety situation, or in a variety of situations, including to protect an interest in a locality, under Section 22.27. Golden eagle nest removal permits for mining operations would almost always be issued under Section 22.25, unless there is a health and safety situation that necessitates immediate removal of a nest from an anthropogenic source such as a power line.

The BGEPA makes it unlawful for a person to "take, possess, sell, purchase, barter, offer to sell, purchase or barter, transport, export or import, at any time or any manner, any bald eagle . . . or any golden eagle, alive or dead, or any part, nest, or egg thereof . . . " Because mining operations do not involve any of the listed acts related to the sale of eagles or their parts, the key prohibition for purposes of the NvMA's guidance is "take."

BGEPA and its regulations define "take" as "pursue, shoot, shoot at, poison, wound, kill, capture, trap, collect, destroy, molest, or disturb." "Disturb" is further defined to mean "to agitate or bother a bald or golden eagle to a degree that causes, or is likely to cause, based on the best scientific information available: (1) injury to an eagle; (2) a decrease in its productivity, by substantially interfering with normal breeding, feeding, or sheltering behavior; or (3) nest abandonment, by substantially interfering with normal breeding, feeding, or sheltering behavior." Based on these definitions, eagle take has the potential to occur during mining operations in the following ways:

1. Mortality or injury of individual eagles (i.e., take in the form of kill or wound) as a result of:

    a. Eagle collision with power lines, other infrastructure, vehicles, or equipment;
    b. Eagle electrocution on power lines; and
    c. Eagle exposure to harmful chemicals.

2. Disturbance of eagles from mining activities, usually as a result of noise and human presence, to an extent that significantly interferes with their breeding, feeding, or sheltering behavior.

3. Removal or relocation of eagle nests.

Companies can apply for take authorization to cover each of these types of take.

5.2 When is a Permit Recommended?

In 2009, regulations were passed to allow the USFWS to permit limited take of eagles and their nests. Under these regulations, the USFWS can issue permits that authorize take of eagles or eagle nests when the take is associated with an otherwise lawful activity and cannot practicably be avoided.

As mentioned in Section 2.1, these permitting regulations were revised by the 2016 Eagle Rule. Under the revised rule, permits may be granted only when the applicant agrees to specific measures to first reduce take to the greatest extent practicable. To ensure permit issuance is consistent with the goal of stable or increasing eagle populations, compensatory mitigation that offsets eagle impacts may also be required for permit issuance. The permittee may also be asked to assume additional responsibility for monitoring eagle loss at its facilities, which is critical to developing a better understanding of ways impacts to eagles can be reduced in the future. Permits can be short-term (five years or less) or long-term (five to 30 years). Long-term permits are re-evaluated every five years. The different types of take permits and the permitting process are described in Section 5.3.1.

The USFWS cannot require a federal eagle take permit, but will recommend a permit when take seems likely. This permit will help protect both the eagle population through mitigation and monitoring and the project proponent from prosecution of an illegal eagle take.

The NvMA, in cooperation with the USFWS, is preparing a complete legal analysis of eagle take permit options. Once completed, it will become an appendix or addendum to this document. **Figure 2,** below, is a guide for project proponents to make decisions on when protection measures are sufficient to manage the risk of take, or whether a take permit and eagle conservation plan may be needed to ensure compliance with BGEPA. This assessment is recommended to be done in consultation with the USFWS.

5.3 Summary of Golden Eagle Best Management Practices

This section presents a brief summary of the permitting and ECP guidance. This section is primarily focused on the golden eagle incidental take and golden eagle nest take permitting process and the development of an ECP.

5.3.1 Take Permits

There are two categories of eagle take permits that apply to the mineral exploration and mining industry - an eagle incidental take permit, and an eagle nest take permit. An eagle incidental take permit relates to actual loss of birds, which may be indirect or direct, as described in Section 5.1. An eagle nest take permit allows for removal of an unoccupied nest. There are two types of nest removal permits. The most applicable permit is specific for resource development or recovery operations. The second type of nest removal permit is applicable to nests that need to be removed from pre-existing human-engineered structures, such as an electric utility pole or a piece of mining equipment.

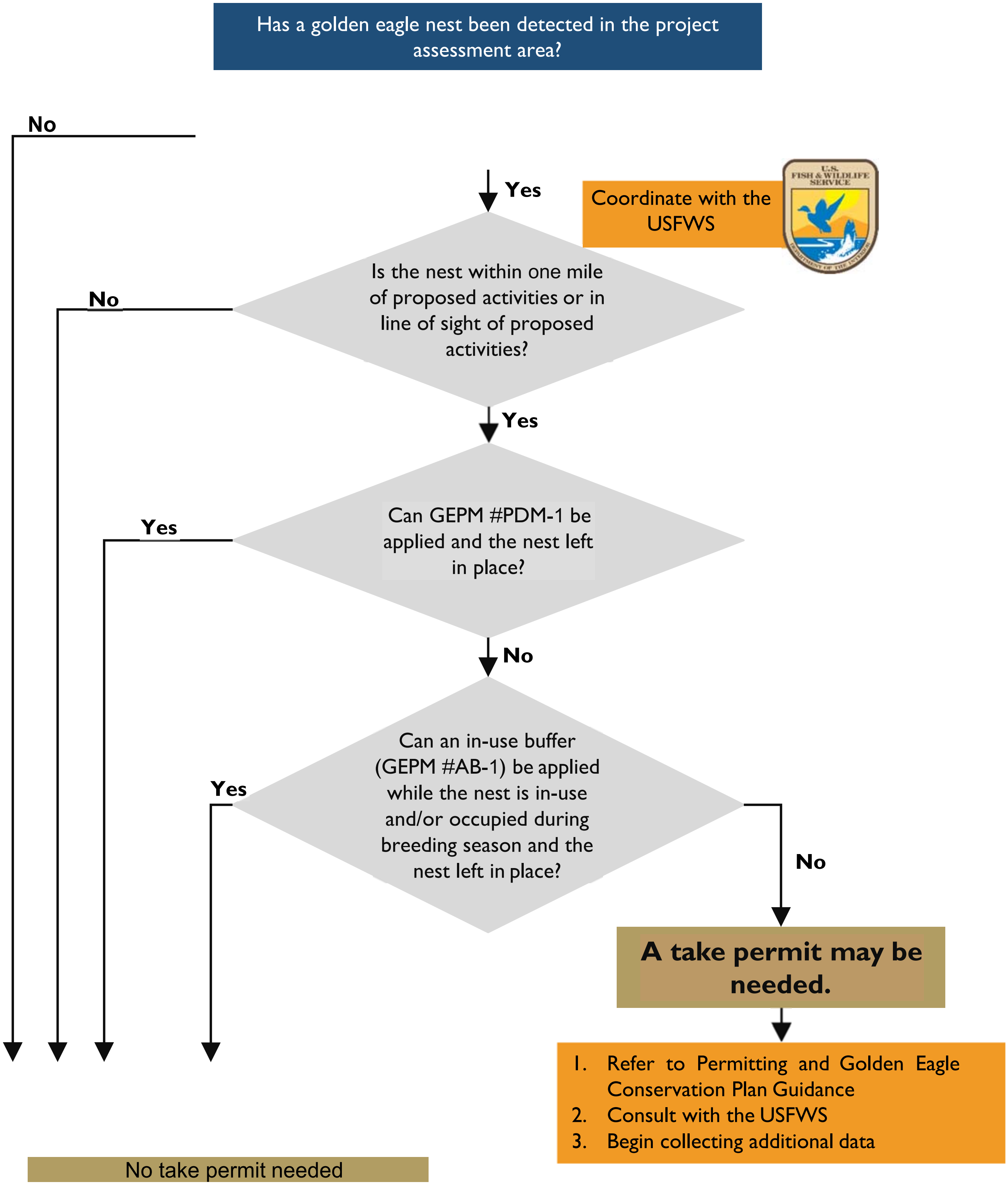

Figure 2: Golden Eagle Protection Measures Flow Chart

In some circumstances, two permits may be needed. For example, if a nest is to be removed and no alternative nests are detected within the breeding territory for that pair, the loss of the territory would result in an indirect take. An incidental take permit would likely be recommended or needed for the USFWS to be able to issue the nest removal permit.

The basic parameters of each type of take permit is outlined below.

Eagle Incidental Take Permit

- Reference 50 CFR, Subpart 22.26
- Long term permits with one to 30-year terms and a five-year review periods
- Permit applies when take cannot be practicably avoided
- Eagle Take Permit Application (Form 3-200-71)

Eagle Nest Take Permit—Nest Removal During Resource Development and Recovery

- Reference 50 CFR, Subpart 22.25
- More applicable to the mining and exploration industry in typical situations
- Take of an unoccupied/alternate nest for resource development or recovery operations
- Permit issuance must be compatible with the preservation of golden eagles.
- If removal would result in a take, an incidental permit under 50 CFR 22.26 may be needed. Contact USFWS in this circumstance.
- Two-year permit life
- Issuance of permit must be compatible with the preservation of golden eagles
- Eagle Nest Take Permit Application (Forms 3-200-18)

Eagle Nest Take Permit

- Reference 50 CFR, Subpart 22.27
- Appropriate for mining in very limited circumstances
- Covers both nest removal and relocation
- Under this regulation, nest removal is necessary to
    - Alleviate a safety emergency to people or eagles
    - Ensure public health and safety
    - Allow the use of a pre-existing human-engineered structure
    - Providing a net benefit to eagles
- Only unoccupied nests may be taken, except in the case of safety emergencies
- Eagle Nest Take Permit Application (Forms 3-200-72)

Prospective permittees apply to the USFWS Regional Migratory Bird Permit Office using an application form specifically tailored to their proposed activity. The information collected through permit applications is used to determine whether or not the individual qualifies for the type of migratory bird-related permit for which you have applied. You may obtain an application online, or by contacting a Regional Migratory Bird Permit Office near you. The form used for permits is the "Eagle Incidental Take" form found here.

5.3.2 Eagle Conservation Plans

The USFWS issued Eagle Conservation Plan Guidance: Module 1—Land-Based Wind Energy, Version 2, in April 2013 ECPG. The guidance provides recommendations for agency staff and developers to use an iterative process to avoid and minimize negative impacts on eagles and their habitats from the construction, operation, and maintenance of land-based, wind energy facilities. The guidance is intended to promote compliance with the MBTA and BGEPA. This section is adapted from Module 1 and is specific to the mineral exploration and mining industry in Nevada. If a project is likely to require a take permit, project proponents and operators should submit an ECP to the USFWS to determine whether a take permit is warranted and what type of take permit is appropriate for the action. The ECP can document the project area eagle population along with avoidance and minimization measures.

The five stages of collecting and analyzing data for an ECP are as follows:

- Stage 1: Assess the potential impacts on eagles and their habitats at the landscape level; this includes a thorough review of available literature and public data sources, as well as site reconnaissance, if necessary
- Stage 2: Conduct site-specific surveys. Data are used to assess risk on a project-specific basis and to estimate an annual fatality rate. Surveys should identify eagle and large raptor nests (as they may be utilized by eagles). Data should be sufficient to delineate eagle nesting territories so that if a nest removal is requested, the Service may determine if nest removal would result in eagle take (decreased productivity or territory abandonment).
- Stage 3: Conduct risk analysis and pre-construction studies to determine impacts to eagles, take requests or avoidance strategies.
- Stage 4: Develop compensatory mitigation, if necessary, to offset unavoidable take; mitigation is evaluated and determined necessary in the context of the operation and the potential for incidental take of eagles. Mitigation may include on-site measures or off-site measures. If on-site mitigation is not practicable, then off-site mitigation is preferred to be located in the local breeding population area (i.e. the eagle management area which is the Pacific Flyway for Nevada. Alternatively, if a permit is issued, mitigation may be accomplished through deposits in the USFWS Regional National Fish and Wildlife Foundation Eagle Mitigation Account. Mitigation typically must occur within the eagle management unit.
- Stage 5: Conduct post-construction monitoring to validate impact assessment.

5.3.3 Golden Eagle Risk Identification for Project Operations

Part of the ECP process is assessing the level of risk of a project on local golden eagle breeding populations.

Site specific eagle surveys, exploration and operational plans will be used to determine each site's risk to eagles. By implementing the GEPMs outlined above, the risk of eagle take any be minimized and avoided even further. A major component of the risk assessment is to identify project activities that could result in a take. For each of these risk factors, project operators should determine if they have some form of control, such as the ability to implement GEPMs.

Table 3, below, is a general outline of potential risks for the various operation types described in this document.

Table 3: Risks to Golden Eagles by Operation Type

Operation Type	Risk
3, 4	Exposure to chemicals
3, 4	Electrocution on improperly designed power facilities
3,4	Permanent habitat loss (i.e. loss cliff/rocky nesting habitat, large areas of foraging habitat)
1, 2, 3, 4	Incidental disturbance
1, 2, 3, 4	Collisions with vehicles or equipment
1, 2, 3, 4	Unintentional disturbance from activity near nest sites
1, 2, 3, 4	Temporary habitat loss (less than three years)

Impacts should be addressed with coordinated appropriate measures with the USFWS. By applying the appropriate GEPMs identified in this document, the risks for mineral exploration and mining for a given operation type have been controlled to the greatest extent possible.

6 AGENCY COORDINATION

6.1 Federal Land Management Agency Coordination

The primary point of contact for a mine operator or project proponent is the land management agency if the project is on public land administered by the BLM or National Forest System lands administered by the USFS. Project proponents and operators should coordinate early on with the appropriate agency if golden eagle habitat is detected or if golden eagle nests are observed in the project area during baseline studies to support a project-level NEPA evaluation. Additional coordination and consultation with NDOW or the USFWS may be required.

6.2 NDOW Coordination

In accordance with state regulations, NDOW manages game and non-game species. The agency conducts raptor nesting surveys (including those for golden eagles) throughout the state and are often cooperating agencies for federal NEPA actions. NDOW is typically engaged by the lead action agency. They also issue and administer site-specific IAPP permits, which often require that avian protection measures be implemented. This permit requires ongoing monitoring and reporting of any wildlife and avian mortalities at a site related to interaction with pond facilities. If a project is on private land, NDOW is the primary contact.

Nevada Mining Industry Contact:

Matt Maples
Nevada Department of Wildlife
6980 Sierra Center Parkway, Suite 120
Reno, Nevada 89511
(775) 688-1568

6.3 United States Fish and Wildlife Service Coordination

An operator or proponent should contact the USFWS if they determine that there is potential take and a take permit may be necessary. Prospective permittees apply to the USFWS Regional Migratory Bird Permit Office using the appropriate application form (included), or accessed online at https://www.fws.gov/birds/policies-and-regulations/permits/need-a-permit.php.

In addition, the land management agency or NDOW may recommend that the operator or proponent contact the USFWS based on baseline survey information or observations of eagles or eagle nests within the project area. Specifically, USFWS should be contacted in the following situations:

- An occupied golden eagle nest is detected within a 2-mile radius of project area. A need exists to consult on the appropriate buffer and protection of the nest during breeding season if the nest were to become in-use.
- An employee finds a golden eagle carcass in the project area or along project access roads (proponent should contact the USFWS law enforcement in this case).
- A golden eagle nest (any status) is detected in an area that cannot be avoided by project operations.

A project proponent or operator also should contact the USFWS in writing for questions or concerns relating to any of the following:

- To confirm a habitat assessment approach.
- To discuss any atypical situation.
- Prior to any nest monitoring activities (see ENM-1 and ENM-2 in Table 2).

Regional Contact:

For Technical Assistance:
Migratory Bird Program
USFWS Pacific Southwest Region
2800 Cottage Way W-2606
Sacramento, California 95825
(916) 414-6464
Email: permitsr8mb@fws.gov
Ask for Eagle Permits Biologist

To report an eagle incident:
Office of Law Enforcement (OLE)
USFWS Pacific Southwest Region
Rebecca Roca, Resident Agent in Charge
(916) 569-8488
Email: rebecca_roca@fws.gov

7 ACTION PLAN IF TAKE OCCURS

Project operators are encouraged to have an action plan if an incidental take of an eagle occurs at the project or nearby as a result of an exploration or mining company's activities. The following steps are general; site-specific plans should be developed with site contact information and appropriate agencies contact information for reporting purposes.

Eagle mortalities and injuries are generally reported on a voluntary basis, unless a court order, IAPP, formal agreement, or applicable permit requires reporting. NDOW permits often require reporting; however, failure to report undermines the relationship between industry and the regulatory agencies.

Step 1—Secure the scene

- Do not move the golden eagle carcass or disrupt the area surrounding the carcass
- Take measures to ensure others do not disturb the area

Step 2—Collect information

- Document important information, as follows:
  - Location
  - Circumstances (such as date discovered, condition of the specimen, and suspected cause of death)
  - Project representative contact information

Step 3—Contact the appropriate agency (in sequence)

- Notify the company's environmental representative or person responsible for contacting regulatory agencies, if applicable
- If the mortality is associated with an NDOW IAPP, contact NDOW first, and it will contact the USFWS, if required
- If a golden eagle carcass is found, contact both the USFWS OLE and the NDOW and, if applicable under project stipulations, contact the lead action agency representative (BLM or USFS)
- Follow the appropriate agencies' requirements of what to do with the carcass, feathers, or parts
- Do not keep eagle carcasses, feathers, parts, nests, or eggs
- Handle as instructed in writing by the USFWS OLE. If directed ship all eagle carcasses, feathers, and parts to the National Eagle Repository
- See Section 6, above, for Nevada agency contacts

Step 4—Root-cause determination

- Work with the agencies to try to determine the cause of death

Step 5—Remedy any hazards to prevent reoccurrence (if applicable)

- Work with the agencies to determine appropriate measures to resolve the issue

Step 6—Education

- Educate project employees on the situation and perform an after-action review

Step 7—Incident documentation

- Prepare a memo that documents the incident and any steps taken to remedy an identified hazard

8 REFERENCES

Avian Power Line Interaction Committee (APLIC). 2006. *Suggested Practices for Avian protection on Power Lines: The State of the Art in 2006*. Edison Electric Institute, APLIC, and the California Energy Commission. Washington, DC, and Sacramento, California.

________. 2012. *Reducing Avian Collisions with Power Lines: The State of the Art in 2012*. Edison Electric Institute and APLIC. Washington, DC.

Baicich, P.J., and J.O. Harrison. 2005. *Nests, Eggs, and Nestlings of North American Birds*. Second Edition. Princeton University Press, Princeton, NJ.

Baglien, J.W. 1975. *Biology and habitat requirements of the nesting Golden Eagle in southwestern Montana*. M.S. thesis. Montana State University, Bozeman, Montana. 63 pages.

Bureau of Land Management (BLM). 2010. *Memorandum of Understanding between the United States Department of the Interior, Bureau of Land Management, and the United States Fish and Wildlife Service to Promote the Conservation of Migratory Birds*. BLM MOU WO-230-2010-04. April 2010.

Bloom, P.H., and S.J. Hawks. 1982. *Food habits of nesting Golden Eagles in Northeast California and Northwest Nevada*. Journal of Raptor Research. 16:110-115. North American Bird Conservation Initiative. 2015. Bird Conservation Region Map and Plan. Internet website: http://www.nabci.net.

Camenzind, F.J. 1969. *Nesting ecology and behavior of the Golden Eagle (Aquila chrysaetos L.)*. Brigham Young Univ. Sci. Bull. Biol. Ser. 10(4):4-15.

Great Basin Bird Observatory (GBBO). 2010. *Nevada Comprehensive Bird Conservation Plan, ver. 1.0*. Great Basin Bird Observatory, Reno, Nevada.

Grubb, T.G.; and Eakle, W.L. 1987. *Comparative Morphology of Bald and Golden Eagle Nests in Arizona*. Journal of Wildlife Management. 51:744-748.

Herron, G.B., C.A. Mortimore, and M.S. Rawlings. 1985. *Nevada Raptors: Their Biology and Management*. Nevada Department of Wildlife, Biological Bulletin No. 8. 114 pp.

Houston, C.S. 1985. *Golden Eagle Banding in the South Saskatchewan River Valley*. North American Bird Bander 10:110-114.

Kochert, M.N., and K. Steenhof. 2002. *Golden Eagles in the US and Canada: Status, trends conservation challenges*. *J. Raptor Res.* 36(supplement):33-41.

____________. 2012. *Frequency of nest use by Golden Eagles in southwestern Idaho*. Journal of Raptor Research 46: 239–247.

Kochert, M.N., K. Steenhof, C.L. McIntyre, and E.H. Craig. 2002. Golden Eagle (*Aquila chysaetos*). In The Bird of North America Online. No. 684 (A Poole and F. Gill Eds), Cornell Lab of Ornithology, Ithaca, NY.

MacLaren, P.A., H.A. Stanley, and D.E. Runde. 1988. *Foodhabits and nest characteristics of breeding raptors in southwestern Wyoming*. Great Basin Naturalist 48:548–553.

McGahan, Jerome. 1966. *Ecology of the golden eagle*. Graduate Student Theses, Dissertations, & Professional Papers. 6571. https://scholarworks.umt.edu/etd/6571.

Menkens, G., Jr., and S. Anderson. 1987. *Nest Site Characteristics of a Predominantly Tree nesting Population of Golden Eagles*. Journal of Field Ornithology. 58:22-25.

Nielson, R.M., L. McManus, T. Rintz, and L.L. McDonald. 2012. *A survey of golden eagles (Aquila chrysaetos) in the western U.S.: 2012 Annual Report*. A report for the U.S. Fish & Wildlife Service. Western EcoSystems Technology, Inc., Laramie, Wyoming.

Pagel, J.E., D.M. Whittington, and G.T. Allen. 2010. *Interim Golden Eagle Technical Guidance: Inventory and Monitoring Protocols and Other Recommendations in Support of Golden Eagle Management and Permit Issuance*. Division of Migratory Bird Management. U.S. Fish and Wildlife Service.

Phillips, R.L., Wheeler, A.H., Lockhart, J.M., McEneaney, T.P. & Forrester, N.C. 1990. *Nesting Ecology of Golden Eagles and other Raptors in Southeastern Montana and Northern Wyoming*. Washington, DC: Fish and Wildlife Technical Report 26.

Reynolds, H.V., III. 1969. *Population status of the Golden Eagle in south-central Montana*. MS. thesis, Univ. of Montana, Missoula.

Ryser, F.A., Jr. 1985. *Birds of the Great Basin*. Reno, Nevada: University of Nevada Press.

Steenhof, K., M.N. Kochert, and J.A. Rappe. 1993. *Nesting of raptors and common ravens on electrical transmission line towers*. Journal of Wildlife Management 5H71-28I.

Steenhof, K., M.N. Kochert, and T.L. McDonald. 1997. Interactive Effects of Prey and Weather on Golden Eagle Reproduction. *Journal of Animal Ecology* 66: 350–362.

United States Forest Service (USFS). 2008. Memorandum of Understanding between the U.S. Department of Agriculture Forest Service and the U.S. Fish and Wildlife Service to Promote the Conservation of Migratory Birds. FS Agreement # 08-MU-1113-2400-264.

United States Fish and Wildlife Service (USFWS). 2002. Utah Field Office Guidelines for Raptor Protection from Human and Land Use Disturbance.

_______. 2011. Draft Eagle Conservation Plan Guidance.

APPENDIX A

SAMPLE DATA SHARING AGREEMENT

Sample Data-Sharing Agreement

DATA SHARING AGREEMENT

between

Nevada Department of Wildlife

and

RECIPIENTNAME

This Data Sharing Agreement is entered into on July 26, 2018, by and between the Nevada Department of Wildlife (NDOW) and RECIPIENTNAME (Recipient) to establish the content, use, and protection of data requested by Recipient.

1.0 Rationale for Protection of Sensitive Information

Informed land-use decisions sometimes require information about specific fish, wildlife, and habitat locations. In working to protect wildlife resources for the people of Nevada, it is recognized that some data may require appropriate safeguards due to the risk and magnitude of loss or harm which would result from inadvertent or deliberate disclosure. This agreement outlines required use and distribution of information in order to reduce the possibility of such loss or harm.

The NDOW shall consider the following criteria for determining data sensitivity:

- Would harm, theft or destruction occur to a species if specific knowledge of [present or historical] individual locations were known?
- Would harm, theft or destruction occur to a species, isolated population, or sub-species if knowledge of its specific location were known?
- Would harm, theft or destruction to this species occur if specific knowledge of essential breeding, nesting, or overwintering sites were known? In addition, for individual location data, the following shall be considered sensitive:
    - Federal endangered, threatened, and candidate species;
    - Species petitioned for Federal listing and are undergoing status review;
    - State endangered and threatened species;
    - Sage-grouse lek sites;
    - Bat hibernacula and maternity roosts;
    - Raptor nest sites and aeries;
    - Species that have significant demonstrated commercial/collector value that may encourage illegal or ecologically irresponsible activity (e.g., Sonoran mountain

kingsnake, Gila monster); and

  - Resources where locations are more or less fixed on the landscape and an animal's relationship with that location places it at a certain level of vulnerability (e.g., isolated desert spring sites). Data deemed to be sensitive may be delivered in a manner that masks or obscures the original spatial precision of the data, or without the spatial component of the data, in order to reduce the possibility of loss or harm to sensitive species.

2.0 Data Use

Sensitive NDOW data shall not be released without the receipt of a complete NDOW Data Request Form, including a description of the project or planning effort for which the data will be utilized. All appropriate measures should be taken to ensure that the use of spatial data provided by the NDOW is strictly limited to serve the intentions stated on the NDOW Data Request Form. The anticipated use of these data may include, but not be limited to:

3.0 Constraints on Use of Data and Recipient Data Use Responsibilities

Management of the environment, biological resources, and land; need for continued conservation actions to maintain species and population health; and environmental assessment and impact studies; Inquiries from government agencies and professional organizations for policy decisions and resource management; Species and conservation planning and management and conservation assessment; Species distribution studies, species modeling, vegetation survey and mapping, landscape scale analysis, and/or monitoring and resurvey activities; Scientific research and analysis, the advancement of scientific understanding, and/or collaborative projects; and Protection of species where lack of disclosure could endanger species environmental sustainability.

3.1 Data may be stored for use on future projects that are reasonably similar and consistent with the use reported on the original Data Request Form. Data shall not be used in any manner that would facilitate or knowingly result in the commission of a crime. Data shall not be used in a manner that knowingly misrepresents the information contained therein.

3.2 Data Ownership

All data distributed by the NDOW is the sole property of the NDOW, and, as such, the NDOW retains sole ownership unless otherwise indicated. Data or information provided to Recipient shall not be shared with any other individual, party (whether public or private), or academic entity without obtaining prior written permission from the NDOW.

3.3 Data Access

Recipient shall restrict access to Sensitive NDOW data to individuals and entities that are considered directly associated with the Recipient organization, including, but not limited to, organization personnel, subcontractors, and reviewing entities. Sensitive data will not be shared with any party, public, private or academic entity without obtaining prior written approval from the NDOW.

3.4 Derived Data Products

Maps and other products derived or produced using NDOW data must clearly and accurately represent the information contained therein; must clearly list the Nevada Department of Wildlife as a data source; and must ensure that Sensitive data is represented as a scale no greater than the Public Land Survey System township, range, and section in which they are located. Under no circumstances does the Recipient have the right or permission to publicly publish, display, or represent specific location information (e.g. geographic coordinates, written descriptions, or addresses) for Sensitive NDOW data.

3.4 Recipient Responsibilities

Upon receipt of NDOW data it is the responsibility of Recipient to recognize that data can rapidly become obsolete and/or out-of-date relative to the environmental conditions on the ground. Recipient is responsible for determining if data previously received from the NDOW is still temporally and spatially appropriate for its intended use. Recipient is responsible for contacting the NDOW to validate previously received data's currentness and/or request updated or new data for future use. Recipient is responsible for destroying any and all data deemed obsolete or expired.

Recipient is responsible for fully reviewing the geographic extents of the data received from the NDOW and determining if the spatial scope of the data is appropriate for its intended use. Recipient is responsible for fully reviewing the attribute data associated with spatial data formats and understanding the scope, intent, and limitations of the information contained therein. Recipient is responsible for fully reviewing any and all metadata and understanding the definitions, explanations, limitations, and restrictions contained therein.

Recipient is responsible for understanding the scope and potential limitations of the data provided by the NDOW and shall not use the data in a manner that misconstrues or misrepresents the information contained therein. Recipient is responsible for understanding that the absence of data does not necessarily represent the absence of wildlife resources on the ground. Recipient is responsible for contacting the NDOW should any aspect of the scope, use, limitations, or information contained in the data or metadata is unclear or absent prior to use.

The absence of clear or complete information regarding the description or limitation of the data does not excuse Recipient of any of the responsibilities stated herein.

4.0 Data Format

Data will be made available to Recipient in the following formats upon request:

- ESRI ArcGIS shapefiles;
- Microsoft Excel spreadsheets;
- Microsoft Access database tables;
- Delineated text files; and/or
- GoogleEarth™ KML files. All spatial data will be provided in Universal Transverse Mercator, Zone 11 North projection, North American Datum 1983 (NAD83).

5.0 Data Security

5.1 Best Practices

Recipient shall employ industry best practices, both technically and procedurally, to protect data classified as Sensitive by the NDOW from unauthorized physical and electronic access.

5.2 Compulsory Disclosure

In the event that Recipient becomes legally compelled to disclose any Sensitive information received from the NDOW, Recipient shall provide the NDOW with prompt written notice so that the NDOW may take appropriate action and/or waive compliance with the terms of this Agreement.

6.0 Compliance with Applicable Laws and Regulations

Recipient shall comply with all applicable federal, state, and local laws and regulations affording protection to wildlife species and their habitat. Such laws and regulations include, but are not limited to, Nevada Revised Statute (NRS) Title 45 – Wildlife, specifically NRS 501.100 Legislative declaration regarding wildlife; NRS 501.110 Classification of wildlife; NRS 503.610 Protection of bald eagle and golden eagle; NRS 503.620 Protection of birds included in Migratory Bird Treaty Act; and federal regulations pertaining to threatened and endangered species.

7.0 Indemnification

Recipient shall defend, indemnify, release, and hold the NDOW harmless from and against all Claims, Losses, and Expenses when arising out of the use or misuse of any and all data provided.

8.0 Reciprocity of Data

As a recipient of data from the NDOW, Recipient agrees to submit any observations of wildlife, fish, and habitat occurrences recorded in association with the use of the NDOW's data. Recipient shall provide data in a compatible format within 6 months of completion of field activities.

9.0 Data Collection

As a recipient of data from the NDOW, Recipient agrees to utilize data collection protocols reviewed and approved by the NDOW, as necessary.

10.0 Amendments and Alterations to this Agreement

This Agreement may not be superseded, amended or modified except by written agreement between the NDOW and Recipient.

11.0 Signatures

By the signatures of their duly authorized representative below, the NDOW and Recipient, intending to be legally bound, agree to all of the provisions of this Data Sharing Agreement.

RECIPIENTNAME
ADDRESS1
ADDRESS2

By:

Title:

Phone:

Email:

Signature: ______________________

Date: ______________________

Nevada Department of Wildlife
6980 Sierra Center Parkway, Suite 120
Reno, Nevada 89511

By:

Title:

Phone:

Email:

Signature: ______________________

Date: ______________________

Jinna Larkin GIS/Data Coordinator

775.688.1580 jhlarkin@ndow.org

APPENDIX B

SAMPLE BIRD CONSERVATION STRATEGY

HYCROFT MINE GOLDEN EAGLE CONSERVATION PLAN
HUMBOLDT AND PERSHING COUNTIES, NEVADA

Prepared by:

Hycroft Resources and Development, Inc.
P.O. Box 3030
Winnemucca, Nevada 89446

Contact: *[Responsible Party]*
[Responsible Party Phone Number]

Contributions from:

Wildlife Resource Consultants LLC
P. O. Box 68
Cedarville, CA 96104

EM Strategies, Inc.
1650 Meadow Wood Lane
Reno, NV 89502

Revised May 2018

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LIST OF ACRONYMS AND ABBREVIATIONS

ACP	Advanced Conservation Practices
APLIC	Avian Power Line Interaction Committee
BBCS	Bird and Bat Conservation Strategy
BCR	Bird Conservation Region
BLM	Bureau of Land Management
CESA	Cumulative Effects Study Area
CFR	Code of Federal Regulations
Module 1 Guidance	USFWS 2013 Eagle Conservation Plan Guidance, Module 1- Land-based Wind Energy, Version 2
EA	Environmental Assessment
Eagle Act	Bald and Golden Eagle Protection Act
ECP	Eagle Conservation Plan
EIS	Environmental Impact Statement
GPS	Global Positioning System
HRDI	Hycroft Resources and Development, Inc.
JBR	JBR Environmental Consultants, Inc.
KDE	Kernel Density Estimators
MBTA	**Migratory Bird Treaty Act**
NDOW	Nevada Department of Wildlife
PoO	Plan of Operations
ROD	Record of Decision
ROW	Right-of-Way
SwReGAP	Southwest Regional Gap Analysis Project
US	United States
USFWS	United States Fish and Wildlife Service
WRC	Wildlife Resources Consultants

DRAFT HYCROFT MINE GOLDEN EAGLE CONSERVATION PLAN
HUMBOLDT AND PERSHING COUNTIES, NEVADA

1.0 PURPOSE OF THIS PLAN

The purpose of the Hycroft Mine Eagle Conservation Plan (ECP) is to support a request to remove inactive golden eagle (Aquila chrysaetos) nests and an eagle take permit application under the Bald and Golden Eagle Protection Act (Eagle Act) Title 50 CFR §22.25 and 50 CFR §22.26, respectively. This request relates to current and proposed operations at the mine site by Hycroft Resources and Development, Inc. (HRDI), as summarized below. Title 50 CFR §22.25 allows for "take [of] alternate golden eagle nests during a resource development or recovery operation if the taking is compatible with the preservation of golden eagles." Title 50 CFR §22.26 is the regulation that allows the USFWS to issue permits for "Eagle take that is associated with, but not the purpose of, an activity." Per Eagle Act regulations, the USFWS Director can utilize permit applications to authorize take of golden eagles and their inactive/alternate nests in accordance with issuance criteria that, "authorizes take of bald eagles and golden eagles where take is compatible with the preservation of the bald eagles and golden eagles; necessary to protect an interest in a particular locality; associated with but not the purpose of the activity."

Some terminology and definitions were updated in the revised Eagle Act permit regulations, as defined in the PEIS (USFWS 2016). In this ECP, we present both the old terminology and updated terminology together when sensible.

Current Operations

The United States (US) Department of the Interior, Bureau of Land Management (BLM) Winnemucca District, Black Rock Field Office completed an Environmental Impact Statement (EIS) on a proposal by HRDI, a wholly owned subsidiary of Hycroft Mining Corp., to expand mining and mineral exploration activities on private and BLM-administered lands at the existing Hycroft Mine, located near the historical town of Sulphur in Pershing and Humboldt Counties, Nevada. The BLM issued a Record of Decision (ROD) on the EIS in August 2012.

Proposed Operations

In April 2014, HRDI submitted a modification to the PoO for the Phase II Expansion to the BLM. Golden eagle baseline surveys identified three additional nests (in addition to the Silver Camel nests mentioned under Current Operations) within the footprint of the proposed Northeast Tailings Facility. The cliff face where two of the nests are located will not be physically altered, however, the construction of the dam may cause disturbance to existing nests. In addition, twenty percent of the South of Sawtooth breeding territorial area would be lost by construction of the Northeast Tailings Facility. This territory would likely be lost due to incidental disturbance and loss of habitat. HRDI is requesting authorization to take the three nests at Silver Camel and one fallen and deteriorated nest in the Northeast Tailings Facility Area, as well as a disturbance take of five nests in the Northeast Tailings Facility area, to proceed with approved and proposed expansion activities in this area under the Bald and Golden Eagle Protection Act (Eagle Act) Title 50 Code of Federal Regulations [CFR] Part 22, Subpart C- Eagle Permits §22.25. Because these takes may result in the loss of three breeding territories, HRDI must apply for a programmatic take permit application under Eagle Act Title 50 CFR §22.26. Based on this information, the United States Fish and Wildlife Service (USFWS) agreed to serve as a cooperating agency in the current EIS.

ECP and Permit Application Overview

This document presents HRDI's request for authorization for take (i.e., removal) of three nests (two viable and one deteriorated) on the Silver Camel feature within the existing mine area; a take and removal of a deteriorated nest within the proposed Northeast Tailings Facility footprint; and for incidental disturbance take associated with nest removals and mining activities that would could result in the loss of up to three golden eagle nesting territories (Silver Camel, East Kamma, and South of Sawtooth). This ECP serves as the foundation for HDRI's eagle take permit application.

This ECP has been developed in consultation with USFWS to ensure HRDI's request for take of golden eagle nests and any associated take is consistent with the Eagle Act and has been prepared following the USFWS recommended process. We adapted the procedures outlined in the USFWS Eagle Conservation Plan Guidance document entitled *Eagle Conservation Plan Guidance Module 1 – Land-based Wind Energy, Version 2* (Module 1 Guidance; USFWS 2013) in development of this ECP to support our take permit application.

Components of this ECP include:

- A short history of mining activity at the Hycroft Mine;
- A description of approved and proposed activities at the mine;
- The regulatory framework related to programmatic/incidental permitting activities involving the take of golden eagles and golden eagle nests, and guiding the development of this plan;
- A review of golden eagle biology;
- A discussion of habitats found in the study area;

- A description of the Hycroft Mine golden eagle area-nesting population;
- A risk analysis;
- Protection measures and adaptive management;
- Mitigation measures; and
- A monitoring plan designed to assess the efficacy of existing and proposed protection and conservation practices and status and trend of the local area-nesting population.

2.0 BACKGROUND

2.1 MINE HISTORY

[Insert Property historical information]

2.2 EXISTING AND AUTHORIZED ACTIVITIES

Based on the 2015 eagle survey results, there were a total of six golden eagle nests within the project area, including three within the proposed footprint of the Northeast Tailings Facility, one of which is fallen and has not been occupied during the period of monitoring. Due to the golden eagle nests identified, USFWS was requested to be a cooperating agency with the BLM. In a July 29, 2015 letter, USFWS requested a programmatic take permit application be completed by HRDI to include golden eagle nest removal and loss of territories because of the 2012 EIS approval and the Phase II Expansion.

HRDI has developed a Bird and Bat Conservation Strategy (BBCS) as a separate document that includes measures to minimize the risk of avian and bat mortality and to minimize the risk of impacts on golden eagles and golden eagle nesting near the mine. The BBCS presents HRDI's good-faith efforts to minimize the possibility of unintentional but unavoidable take of birds, including golden eagles, and bats to comply with the provisions of the Migratory Bird Treaty Act (MBTA) and the Eagle Act and ensure the Hycroft golden eagle area-nesting population is sustained. The avoidance/minimization measures included in the BBCS as they apply to golden eagles are the following:

- NDOW Industrial Artificial Pond Permit
- MBTA – seasonal restrictions and clearance surveys
- Monitoring Surveys
- APLIC standards to minimize the potential for avian electrocution
- Seasonal avoidance buffers during the breeding season, defined as spanning from the arrival of adults on a territory to post-fledging dependency of young.

This document presents HRDI's request for authorization for the take of six nests, including four that would be removed (102 and 8A-8C) and five that would be a disturbance take (3A,3B, 821A, 821B, and 101), and associated take of the three golden eagle territories directly affected on the Silver Camel feature and within the Northeast Tailings Facility footprint. The Hycroft Mine Eagle Conservation Plan (ECP) has been developed by adapting the procedures outlined in the USFWS document entitled *Eagle Conservation Plan Guidance Module 1 – Land-based Wind Energy, Version 2* (Module 1 Guidance; USFWS, 2013). (Although the Module I Guidance was written to cover wind energy industry under 50 Code of Federal Regulations (CFR) 22.26, it is the best guidance available.) HRDI is applying under 50 CFR 22.25 and 50 CFR 22.26 for the take of golden eagle nests and loss of territories resulting from the Phase I and Phase II Expansion projects. HRDI understands that development of a stand-alone ECP will assist the USFWS to support a permit decision.

2.3 PROPOSED EXPANSION

[Insert details of proposed operations]

3.0 REGULATORY FRAMEWORK

The USFWS is charged with implementing statutes that protect eagles, including the Eagle Act and the MBTA.

3.1 EAGLE ACT

The Eagle Act of 1940, as amended, prohibits the "take" or possession of bald and golden eagles with limited exceptions. Take, as defined in the Eagle Act, includes, “to pursue, shoot, shoot at, poison, wound, kill, capture, trap, collect, molest or disturb.” Disturb means, “to agitate or bother a bald or golden eagle to a degree that causes or is likely to cause, based on the best scientific information available, 1) injury to an eagle, 2) a decrease in its productivity, by substantially interfering with normal breeding, feeding or sheltering behavior, or 3) nest abandonment, by substantially interfering with normal breeding, feeding or sheltering behavior.”

The Eagle Act authorizes the USFWS to issue eagle take permits when the take is compatible with the preservation of each eagle species, defined as “consistent with the goals of maintaining stable or increasing breeding populations in all eagle management units (EMUs) and the persistence of local populations throughout the geographic range of each species” (USFWS, 2016). The permits are designed to ensure cumulative take does not exceed levels that would result in regional or local eagle population declines from historic levels.

In January 2017, the USFWS revised the regulations for eagle nonpurposeful/incidental take permits and eagle nest take permits. Revisions include changes to permit issuance criteria and duration, definitions, compensatory mitigation standards, criteria for eagle nest removal permits, permit application requirements, and fees. The USFWS intended for the revisions to add clarity to the eagle permit regulations, improve their implementation, and increase compliance, while maintaining strong protection for eagles. As a result, some terminology and definitions were updated in the revised Eagle Act permit regulations, as defined in the PEIS (USFWS 2016). HRDI had been in coordination with the USFWS for several years, and both the old and updated terminology is contained within this ECP and various reports and documents. In this ECP, we attempted to reduce confusion by presenting both the old terminology and updated terminology together when sensible. HRDI has elected to apply for a 30-year permit under the updated 2017 Eagle Act regulations, which would account for the extended mine life.

Under the Eagle Act, the USFWS may issue a permit for inactive/alternate nest removal during a resource development or recovery operation if the taking is compatible with the preservation of golden eagles (50 CFR 22.25). The USFWS may also issue a permit that “authorizes incidental take of bald and golden eagles where the take is compatible with the preservation of the bald eagle and golden eagle; necessary to protect an interest in a particular locality; associated with but not the purpose of the activity and cannot practicably be avoided."

3.2 EAGLE CONSERVATION PLAN GUIDANCE

The Module 1 Guidance (USFWS, 2013) describes the circumstances under which a proponent may apply for a permit to take an eagle nest and reviews the issues that the USFWS will consider in determining the applicability of such a permit. The Module 1 Guidance was developed specifically for wind energy projects to provide a vehicle to address permit requirements (presented within 50 CFR 22.26 and 50 CFR 22.27) but, with modification, may be applied to other types of projects. As stated in the Module 1 Guidance, "Eagle take permits may be issued only in compliance with the conservation standards of Eagle Act. This means that the take must be compatible with the preservation of each species, defined (in USFWS 2009) as consistent with the goal of stable or increasing breeding populations." In addition, "for programmatic take permits, the regulations require that any authorized take must be unavoidable after the implementation of advanced conservation practices (ACPs)." The ACPs are discussed as being used on an "experimental" basis in the Module 1 Guidance due to the fact that they would not meet the current definition of an ACP in the eagle regulations.

In the Module 1 Guidance and accompanying appendices (USFWS, 2013), the USFWS attempts to quantify sustainable take for eagles. In this document, the USFWS notes that for falconry, an annual take level of five percent of annual production is considered sustainable for a range of healthy raptor populations, and that annual take level of one percent of annual production is considered relatively benign when population status is considered uncertain (USFWS, 2013). The population for which this take is calculated is regional. Specifically, the population considered is defined as the population within the Bird Conservation Region (BCR).

The Module 1 Guidance calls on renewable energy developers and others whose projects may affect eagles to consult with the USFWS in a five-tiered process that includes:

1) Early landscape-level site assessments;
2) Site-specific surveys;
3) Risk assessment;
4) Avoiding, minimizing, and mitigating impacts; and
5) Post-construction monitoring.

The Module 1 Guidance calls for categorizing the projects into one of three categories:

Category 1 – High risk to eagles with low potential to avoid or mitigate impacts;
Category 2 – High to moderate risk to eagles with opportunities to mitigate impacts; and
Category 3 – Minimal risk to eagles.

3.3 **MBTA**

The MBTA (16 United States Code 703-712) is administered by the USFWS and is the cornerstone of migratory bird conservation and protection in the US. The MBTA implements a series of international treaties that provide for migratory bird protection. The Act authorizes the Secretary of the Interior to regulate the taking of migratory birds. The Act provides that it shall be unlawful, except as permitted by regulations, “to pursue, take, or kill any migratory bird, or any part, nest or egg of any such bird” (16 United States Code 703); but the Act does not regulate habitat. The list of species protected by the Act was revised in March 2010 and includes almost all bird species (1,007 species) that are native to the US.

3.4 EXECUTIVE ORDER 13186

Signed on January 11, 2001, this Executive Order directs each federal agency taking actions that are likely to have a measureable effect on migratory bird populations to develop and implement a Memorandum of Understanding with the USFWS that promotes the conservation of migratory bird populations. The USFWS’ Memorandum of Understanding with the BLM states, in part, that both parties shall, as practicable, protect, restore, and conserve habitat of migratory birds; follow the USFWS Bald Eagle Management Guidelines; follow other migratory bird conservation measures as appropriate and consistent with agency missions; work collaboratively to identify and address issues that affect species of concern; promote and contribute migratory bird population and habitat data to interagency partnership databases (BLM, 2010). The Memorandum of Understanding also commits the BLM to, among other measures, participate in planning efforts of Bird Conservation Regions and, at the project level, evaluate the effects of the BLM’s actions on migratory birds during the National Environment Policy Act process (BLM, 2010).

4.0 GOLDEN EAGLE BIOLOGY

4.1 GENERAL BIOLOGY

The golden eagle is a bird of open and semi-open habitats (Kochert et al., 2002). The species is found primarily in mountainous canyon land, rimrock terrain of open desert, tundra, and grassland areas of the western US. Golden eagles typically forage in open habitats including grasslands and steppe. Preferred foraging habitat in southwestern Idaho is shrubland, particularly sagebrush (*Artemisia* spp.), and rabbitbrush (*Chrysothamnus/Ericameria* spp.) habitats. Similar habitat is present at the Hycroft Mine project area. Salt desert scrub and sagebrush shrubland make up approximately 72 percent of the 10-mile buffer surrounding the existing mine and expansion areas (JBR unpubl).

Food is primarily small- to medium-sized mammals, particularly black-tailed jackrabbits (*Lepus californicus*), but golden eagles have been known to take larger prey (Kochert et al., 2002). Black-tailed jackrabbits and cottontails (*Sylvilagus nuttallii*) are reported to be the main prey in the Great Basin, with yellow-bellied marmots (*Marmota flaviventris*) and Paiute ground squirrels (*Spermophillus mollis*) or rock squirrels (*S. variegatus*) as the chief secondary prey (Arnell, 1971; Bloom and Hawks, 1982). Marzluff et al, (1997) reported that black-tailed jackrabbits, Townsend’s ground squirrels (*Spermophilus townsendii*), and rock doves (*Columba livia*) were the primary prey species taken during a 1992 to 1994 study in the Snake River Birds of Prey area in southwestern Idaho. Kochert et al. (2007) stated that leporids (rabbits and hares) and sciurids (squirrels) constituted 49 to 94 percent of individual prey items taken during the nesting season, as reported in 24 studies throughout western North America. The abundance of black-tailed jackrabbits identified as the principal prey of golden eagles in several of these studies, tends to be cyclical, and populations may vary by nine-fold over the course of these cycles (Best, 1996; Gross et al., 1974).

Golden eagles are territorial, defending an area of approximately 7.7 to 11.5 square miles from other eagles. Three studies conducted in southeastern Idaho found that breeding-season home range varied from approximately 11 to 13 square miles. Breeding home ranges may be smaller than winter home ranges, and patterns of use may shift seasonally. Home range boundaries may remain fairly consistent for long periods (over 20 years), but pairs may expand their home range into adjacent vacant territories (Kochert et al., 2007).

It has been noted that golden eagles do not use all areas within their home range but instead concentrate activity within core areas (Platt, 1984; in Kochert et al., 2007; Marzluff et al,. 1997). Radio-tagging studies conducted in southwestern Idaho found that 95 percent of detections were recorded in core areas, but these areas occupied less than 15 percent of the breeding-season home range and about 25 percent of the non-breeding season range (Marzluff et al,. 1997). These studies also found that the ranges of neighboring pairs overlapped slightly in the breeding season, but that overlap increased during non-breeding season. Kochert et al. (2007) notes that related individuals may be tolerant of each other, citing a case of four generations of six related individuals flying together on multiple occasions. Trios of birds have also been reported together during the nesting season.

Golden eagles typically nest on cliffs or outcrops, but they also nest in trees, and occasionally on transmission line structures and other anthropogenic features. Ground nests have also been reported in areas where no other suitable substrate occurs, such as on the tundra in Alaska. The nest site often provides a commanding view of the surrounding landscape (Beecham, 1970; Kochert et al., 2002). In Nevada, golden eagles generally nest on cliffs and outcrops or, less commonly, in trees.

Nest building may begin one to three months prior to egg laying, though material may be added to nests at any time (Kochert et al., 2002). Peak nest building or refurbishing occurs from January to March (Watson, 1997). Bowl construction, the final stage of nest construction, occurs during the final three to four weeks before egg laying. Alternate nests are common, with the number of alternate nests within a single territory varying from 2 to 14 (Kochert et al., 2002). Of 65 golden eagle pairs nesting on cliffs in the Snake River Canyon, all had alternate nests (USGS, unpublished, in Kochert et al., 2002).

A more recent study conducted by Kochert and Steenhof (2012) documented as many as 18 alternate nests within a single territory. In a long-term southwestern Idaho study conducted between 1966 and 2011, Kochert and Steenhof (2012) found that the period between reuse of nests ranged from 1 to 39 years. This study found that over a period of 45 years, golden eagles used a total of 454 nests in 66 territories. Individual nests were used between 1 and 26 times. Nest switching was associated with turnover of at least one member of an eagle pair, but also occurred due to unknown factors. Golden eagles utilized the same nest for 3 to 20 consecutive years. This study also found the distance between alternate nests varied from less than 1 meter (3.3 feet) to more than 1,800 meters (1.1 miles). Only 10 percent of these alternate nests were more than 500 meters (1,640.4 feet) apart. Kochert and Steenhof note, however, that this study was conducted in an area with a relatively high density of nesting golden eagles, with nesting habitat distributed in a linear fashion along the Snake River in southwestern Idaho. Greater distances between alternate nests have been reported in habitats with non-linear and presumably less dense potential nesting habitat (McGahan, 1968; Lockie and Ratcliffe, 1964).

Golden eagles typically breed after attaining adult plumage, which is usually acquired in the fifth summer, but are capable of breeding earlier (Steenhof et al., 1984). Egg laying begins as early as late January or early February in southwestern Idaho and southern California (Dixon, 1937; Hickman, 1968). In northern Nevada, Worley (1984) recorded eagles on nests as early as late February. Females are reported to settle into an incubation posture on the nest before the first egg is laid. Incubation ranges from 41 to 45 days (Kochert et al., 2002). In southwestern Idaho, hatching dates were correlated with both winter severity and jackrabbit abundance; eagles hatched earlier when rabbits were abundant and later after severe winters (Steenhof et al., 1997). Young are reported to leave the nest as early as 45 days of age (USGS, unpublished, in Kochert et al., 2002) and as late as 81 days (Gordon, 1955). US Geological Survey data documented 101 chicks from 61 broods in southwestern Idaho averaged 64.4 days (a range of 45 to 77 days) old at departure from nest (USGS, unpublished, in Kochert et al., 2002).

Reproductive success varies from year to year depending on prey availability and weather. In southwestern Idaho, the percentage of females that laid eggs each year was positively related to jackrabbit abundance and inversely related to winter severity, while the percentage of females successfully raising broods was positively related to rabbit abundance and inversely related to the frequency of hot spring days, when nestlings are susceptible to heat stress (Steenhof et al., 1997). Steenhof et al. (1997) noted that in southwestern Idaho, jackrabbit abundance limited reproduction during 15 of 23 years. Several authors have noted that many pairs do not lay eggs during periods of low prey abundance (Smith and Murphy, 1979; Steenhof et al., 1997; McIntyre and Adams, 1999). Kochert et al. (2007) stated that the percentage of pairs that lay eggs each year was the most variable reproductive component in both southwestern Idaho and in interior Alaska. Steenhof et al. (1997) found that over a 22-year period in southwestern Idaho, this percentage varied from 38 to 100 percent. Over a 10-year period in Denali National Park, McIntyre and Adams (1999) found this figure varied from 33 to 90 percent of pairs.

Kochert et al. (2007) cite several studies that found that the percentage of eggs that hatch varies from 57 to 86 percent of eggs laid, and that the percentage of hatched young that fledge varies from a low of 46 percent in Montana (Reynolds, 1969) to 77 percent in southwestern Idaho and 80 percent in Utah.

Kochert et al. (2002) cite several studies that indicate the number of successfully fledged young per year from individual nests varies from 0.66 young per nest per year in Alaska to 1.08 young per nest per year in Oregon. The number of successfully fledged young may be somewhat higher in Nevada. Newmont (2012) provides a review of golden eagle biology and population status in Nevada. The Newmont review cites a study by Page and Seibert (1973) that found 50 nests in Elko County fledged an average of 1.1 young fledged per nest per year. Worley (1984) documented a fledging rate of over 1.7 young per nest per year from 27 northeastern Nevada nests studied in 1979 and 1980. Ryser (1985) notes the Nevada Department of Wildlife (NDOW) also documented a fledging rate of 1.7 young per nest per year during this same two-year period (Herron and Lucas, 1979; Herron et al., 1980). These studies date to the 1980s or earlier and may not capture more recent habitat changes caused by wildland fire within Nevada. Recent research by fire ecologists has documented that over the last four decades, wildfires have become larger, and large fires have become more frequent across the western US (Miller and Safford, 2012); that increases in fire-adapted grasses, primarily cheatgrass, have increased the rate of fire spread (Chambers, 2008); and that cheatgrass invasion has resulted in fires burning arid salt desert scrub ecosystems that did not previously burn (Brooks and Pyke, 2001). These changes may reduce the golden eagle prey base and in turn, result in lower fledging rates. In southwestern Idaho for example, Kochert et al. (1999) note that "some pairs abandoned territories after wildfires destroyed jackrabbit habitat adjacent to Snake River Canyon; remaining pairs expanded their ranges and subsumed neighboring vacant territories, resulting in a smaller nesting population."

Per the Module 1 Guidance (USFWS 2013), the extent of golden eagle take that may be allowable is determined by population estimates for the BCR and cumulative impacts at the Local Area Population level. The Hycroft Mine project area is located within the Great Basin BCR, which includes portions of northeastern California, eastern Oregon and Washington, most of Nevada, western Utah, southern Idaho, and southern British Columbia. Newmont (2012) notes that data on golden eagle population trends in the US are inconsistent, but that it is generally believed golden eagle populations are declining. Data gathered from migration observation count sites ("watchsites") and used as the basis to develop a Raptor Population Index also suggests a decline in golden eagle numbers in the western US (Bildstein et al., 2008). Farmer et al. (in Bildstein et al., 2008) note the declines in the mid-1980s and in the late 1990s through the early 2000s reflected in the Raptor Population Index data correlate to periods of drought in the interior west. These authors note other factors that may contribute to observed declines in the western US golden eagle migration counts are cyclical prey populations and the loss of shrubland habitat due to wildland fire, a factor also identified by Kochert et al., (1999). A second study based on dedicated golden eagle transects correlated with Breeding Bird Survey counts suggests the western US golden eagle population was relatively stable from 2006 to 2010 (Millsap et al., 2013). Note that the methodologies of these two trend studies differ considerably.

For Nevada, Newmont cites the population estimates of Herron et al. (1985), which suggest a population of 1,200 golden eagle pairs, and Rich et al. (2004), who estimated the golden eagle population in the Great Basin BCR to be 12,000 birds. In another study, Blancher et al. (2007) provided a population estimate of 6,000 golden eagles in the Great Basin BCR based on

Breeding Bird Survey data from the 1990s. The USFWS cites an estimated golden eagle population in the Great Basin BCR of 6,859 (USFWS, 2009a).

Kochert et al. (2002) attribute over 70 percent of golden eagle mortality to direct and indirect anthropogenic causes. Accidental trauma, including collisions with vehicles, power lines, or other structures is the leading cause of death at 27 percent, followed by electrocution at 25 percent, gunshot at 15 percent, and poisoning at 6 percent (Franson et al., 1995; Kochert et al., 2002). Kochert at al. (2002) also note that golden eagles are vulnerable to collision and electrocution when landing on power poles. Less-adept immature eagles are most susceptible to electrocution and the risk of electrocution increases when inclement weather hampers flight or when wet feathers increase conductivity (APLIC, 2006). The Module 1 Guidance notes that golden eagles are electrocuted more often than any raptor in North America. Most electrocution mortalities occur during winter in the western US in areas where natural perches are lacking (USFWS 2011).

4.2 **RECENT** RESEARCH ON **GOLDEN** EAGLES IN ARID LANDSCAPES

Recent research on the biology of the golden eagle in the Great Basin and other arid landscapes shows that these populations have unique characteristics, often differing substantially from populations in less arid landscapes where much golden eagle research has been done. The arid landscape research is valuable for evaluating data collected on golden eagles in the Hycroft area, and is reviewed below.

Golden eagles are widely distributed across western North America, in highly variable habitats. In areas such as the Snake River in southwestern Idaho or Altamont Pass in California, prey is relatively abundant and high-density golden eagle breeding populations are clustered in areas of quality nesting habitat. Much of the research on golden eagles has been conducted in these areas. In the Great Basin, however, overall prey density tends to be far lower due to reduced annual precipitation. In these areas, nesting populations of golden eagles are less dense, and both territory size and eagle use of territories are likely different than in dense nesting populations.

Katzner et al. (2012) used GPS telemetry to evaluate breeding season home range in the Mojave Desert of California. Data from the 2012 breeding season were analyzed using both 50 percent and 90 percent Kernel Density Estimators (KDE). Home ranges based on the 50 percent KDE did not overlap, but the home ranges based on the 90 percent KDE did. This suggests that the 50 percent KDE may represent core areas as described in Section 4.2. The size of these 50 percent KDE home ranges varied from 1.2 (0.5) to 35 (13.5) square kilometers (square miles). Home ranges based on the 90 percent KDE ranged from to 10.9 to 290 square kilometers. Katzner et al.

(2012) note, “these home ranges are larger than typical for eagles, perhaps to be expected because of the relatively low prey densities in the Mojave.”

Katzner et al. (2012) also found the distance from the nest to the farthest edge of the home range estimated by the 90 percent KDE ranged from 1.6 to 40.6 kilometers, and for the 50 percent KDE from 0.8 to 13.7 kilometers. They also noted:

> The large difference between the closest and farthest edge of home ranges shows that eagles do not necessarily nest in the middle of their home range. Their movements are in some cases limited by barriers (likely topographic features that mark intersections of defended territories), but in other cases may extend for much larger distances. Likewise, core areas of the home range (50 percent KDE) include areas close to the nest as expected, but also include regions quite distant from nests. These distant core areas suggest that important resources such as food sources may not always be obtained near nest sites.

In a long-term study of eagles in the Utah West Desert, an area ecologically similar to the Great Basin of northern Nevada, Slater et al. (2013) found that 90 percent of alternate nests were found within 1.5 kilometers of each other, three times the distance cited above by Kochert and Steenhof (2012) for the Snake River area. Ninety percent of all nests in separate territories were at least 2 kilometers apart. Based on average and median territory spacing, Slater et al. (2013) used 4-kilometer radius buffers around nests to represent golden eagle territories in their study area.

In an analysis of 21 Utah Great Basin territories with a minimum of 25 years consecutive nest survey data, Slater et al. (2013) found that from 1 to 8 nests were used for egg laying at least once (mean=3.14; S. E. = 0.43) over the period of monitoring within a single territory. They compare this to southern Idaho, where between 1 to 18 nests (mean = 6.9) were used in a territory (Kochert and Steenhof 2012). These data suggest that Great Basin territories tend to have fewer alternate nests.

Occupancy is the typical standard for evaluating reproductive status of a nest. As defined by Pagel et al. (2010), occupancy requires evidence of a breeding attempt. Pagel et al. (2010) do not provide recommendations for terminology standards when referring to a territory. Slater et al. (2013) use the terms occupancy (birds present) and activity (eggs laid) to define the status of territories. Although the use of these terms in reference to a territory can be confusing, as they have a different specific meaning when applied to a nest, we will use them in references to territories throughout the rest of this section to allow for consistency with relevant published literature. For clarity, when referring to a territory, we will specifically use the term territory occupancy.

Slater et al. (2013) examined long-term trends in rates of territory occupancy and activity in the Utah Great Basin. Generally, rates of territory occupancy tended to be at least 10 to 20 percent higher than rates of territory activity. The highest differences between territory occupancy and activity rates tended to be years when territory activity was low, presumably years of low prey abundance. Territory occupancy rates were more stable over time than territory activity rates, and appeared less susceptible to environmental variability.

These findings suggest that Utah Great Basin eagles move to territories early in the breeding season, evaluate environmental conditions (prey abundance), and make breeding attempts based on conditions encountered during this early period of developing affinities for specific nests. Monitoring for territory occupancy therefore requires observations early in courtship and nest selection, when birds are active and visible (Driscoll, 2010).

Available research suggests that rates of territory occupancy are lower in Great Basin populations than in less arid, higher-density populations. Slater et al. (2013) found that long-term rates of territory occupancy generally varied from 50 to 70 percent in western Utah. In contrast, territory occupancy rates in southwestern Idaho, where eagle nesting density is high, ranged from 81 to 89 percent between 1986 and 1994 (Kochert et al. 1999). In an assessment of the very high density golden eagle population near Altamont Pass in California, Hunt (2002) states “a healthy population of golden eagles fills all serviceable breeding locations.’”.

In high density populations, it may be advantageous for pairs to remain on territory even in years when prey conditions are unfavorable for reproduction to avoid losing territories to competitors (Newton, 1979). For populations in arid landscapes, where prey availability may be more of a limiting factor to nesting populations than the availability of suitable nesting substrate, the fidelity to territories in years of low prey availability may be low. Katzner et al. (2012), in their telemetry studies of eagles in the Mojave desert, note that the three largest home ranges measured were from eagles that, when breeding attempts failed, changed their behavior and dramatically increased the amount of space used.

In most if not all eagle populations, productivity is not equal among territories. Driscoll (2010) notes that, in a healthy golden eagle population, there are usually primary and secondary breeding areas. Primary breeding areas are consistently occupied and productive, while secondary breeding areas are reproductively less consistent. Driscoll (2010) suggests that habitat quality is the main variable responsible for productivity.

Variability in productivity among territories has been noted in Great Basin eagle populations, and may be more pronounced than in high-density nesting populations. Pair experience may also be more important than habitat in determining productivity. For example, the Utah Legacy Raptor Project (2013) recommends providing additional protection to experienced breeders based on research by Slater et al. (2013), noting that, "In the West Desert of Utah, it is not uncommon to find proximate eagle territories occupying similar habitats, but with vastly different reproductive output, suggesting that individual or pair experience and fitness may be more important than local habitat quality. A handful of territories in the West Desert are consistently active (i.e., eggs are laid) and produce a disproportionate number of fledglings across years."

5.0 HABITAT TYPES WITHIN THE STUDY AREA

USFWS Module 1 Guidance recommends that an analysis of potential impacts on nesting golden eagles include a project area itself and a surrounding 10-mile buffer area (Pagel et al., 2010). Vegetation communities in the Hycroft Mine project area and the USFWS-recommended 10-mile buffer area have been mapped by the Southwest Regional Gap Analysis Project (ReGAP) in land cover files (USGS, 2011). The ReGAP mapping shows approximately 48 percent of the Hycroft Mine project area and surrounding 10-mile buffer is mapped as Inter-Mountain Basins Mixed Salt Desert Scrub (Appendix A, Figure 4). Other common mapped vegetation types in the area include Inter-Mountain Basins Big Sagebrush Shrubland, which comprises approximately 24 percent of the area, Inter-Mountain Basins Playa that comprises approximately 12 percent of the Hycroft Mine project area and surrounding buffer, and Inter-Mountain Basins Greasewood Flat, which comprises about seven percent of the Hycroft Mine project area and surrounding buffer. The vegetation communities and their relevance for eagle use are described below.

Inter-Mountain Basins Mixed Salt Desert Scrub

This extensive ecological system includes open-canopied shrublands of typically saline basins, alluvial slopes, and plains across the intermountain western US. The vegetation is characterized by a typically open to moderately dense shrubland composed of one or more *Atriplex* species. Other shrubs may include *Artemisia tridentata* ssp. *wyomingensis*, *Chrysothamnus viscidiflorus*, *Ericameria nauseosa*, *Ephedra nevadensis*, *Grayia spinosa*, *Krascheninnikovia lanata*, or *Tetradymia* spp. Various forbs are also present in the Inter-Mountain Basins Mixed Salt Desert Scrub vegetation type (USGS, 2011). This community occurs within and north of the Hycroft Mine project area and represents potential golden eagle foraging habitat. The potential golden eagle prey base is limited, as much of the mammalian fauna that occurs in this habitat type includes small nocturnal mammals, but black-tailed jackrabbits do occur in this habitat type.

Inter-Mountain Basins Big Sagebrush Shrubland

This ecological system occurs throughout much of the western US, typically in broad basins between mountain ranges, plains, and foothills between 1,500 and 2,300 meters (4,920 to 7,550 feet) in elevation. These shrublands are dominated by *Artemisia tridentata* ssp. *tridentata* and/or *Artemisia tridentata* ssp. *wyomingensis*. Scattered *Juniperus* spp., *Sarcobatus vermiculatus*, and *Atriplex* spp. may be present in some stands. Perennial herbaceous components typically contribute less than 25 percent vegetative cover (USGS, 2011).

Within the Hycroft Mine eagle-use area, this community occurs in foothills and mountains at higher elevations, in contrast to the mixed salt desert scrub or greasewood flats that are found at lower elevations. A more diverse diurnal golden eagle prey base occurs in this habitat type than is found in the two lower-elevation communities. In addition to black-tailed jackrabbits, mountain cottontails and larger diurnal rodents, including yellow-bellied marmots, may be found in this community. As such, this community would represent higher-value golden eagle foraging habitat.

Inter-Mountain Basins Greasewood Flat

This ecological system occurs throughout much of the western US in the intermountain basins and extends onto the western Great Plains. It typically occurs near drainages on stream terraces and flats or may form rings around more sparsely vegetated playas. Sites typically have saline soils, a shallow water table, and flood intermittently but remain dry for most growing seasons. The water table in these areas remains high enough to maintain vegetation despite salt accumulations. This system usually occurs as a mosaic of multiple communities, with open to moderately dense shrublands dominated or codominated by *Sarcobatus vermiculatus*. Occurrences are often surrounded by mixed salt desert scrub (USGS, 2011). Like the mixed salt desert scrub community, potential golden eagle prey base is limited because much of the potential prey species present in this community is small and nocturnal.

Inter-Mountain Basins Playa

This ecological system is composed of barren and sparsely vegetated playas (generally less than 10 percent plant cover) found in the intermountain western U.S. Salt crusts are common throughout, with small saltgrass (*Distichlis spicata*) beds in depressions and sparse shrubs around the margins. These systems are intermittently flooded and the water is prevented from percolating through the soil by an impermeable soil subhorizon, leaving it to evaporate. The soil salinity varies greatly with soil moisture and greatly affects species composition (USGS, 2011).

This community type is found northwest of the Hycroft Mine and characterizes the Black Rock Desert that continues north and west of the mine. The lack of vegetation limits the types of prey species (e.g., nocturnal species). This community represents poor golden eagle foraging habitat.

6.0 GOLDEN EAGLE NESTING POPULATION

To assess risks to golden eagles from the Hycroft Mine Expansion and the impact of removing the Silver Camel and Northeast Tailings Facility nests, the following landscape-level assessment broadly identifies potential eagle nesting habitat in the Hycroft Mine project area and within the surrounding 10-mile buffer area, which is defined as the golden eagle “area-nesting population.”

In support of the Hycroft Mine Expansion Project EIS, eagle nest surveys were conducted annually by JBR Environmental Consultants, Inc. (JBR) between 2010 and 2013, and an aerial nest survey was conducted by NDOW in 2011. Nest surveys were also conducted by Wildlife Resource Consultants LLC (WRC) in 2014, 2015, 2016, and 2017, including intensive monitoring early in the 2014 breeding season to assess eagle use of nests and territories near the mine. A summary of monitoring and assessment prior to 2014 is provided in Sections 6.1.1 and 6.1.2. A summary of findings from the 2014 - 2017 monitoring surveys is provided in Sections 6.1.3 to 6.1.6.

Data from these baseline surveys have been evaluated and identify the mountainous areas of the Kamma and southern Jackson Mountains, a portion of the Antelope Range to the east, and the Majuba Mountain to the southwest as potential golden eagle nesting habitat (Appendix A, Figure 2). Habitats in the Kamma Mountains and areas to the north and west of the mine may be used as foraging habitat, but except for anthropogenic features such as transmission line structures, the areas north and northwest of the mine largely lack potential nesting features. The survey findings from the Hycroft Mine project area represent Stage 2 of the risk assessment (USFWS 2013, Appendix C) described in Section 7.0 of this document.

The status of a golden eagle nest is determined by occupancy. Three potential statuses are defined in the Interim Golden Eagle Technical Guidance: Inventory and Monitoring Protocols (Pagel et al., 2010), and were applied in this document, previous versions of this document and other HRDI reports. Some terminology and definitions were updated in the revised Eagle Act permit regulations, as defined in the PEIS (USFWS 2016, 50 CFR 22.3). Both the old and updated terminology is contained within the various reports and documents. To reduce confusion, this ECP presents both the old terminology and updated terminology together when sensible. In the definitions presented below, the updated terminology appears before the old terminology.

> **In-use/Occupied Nest** - A nest used for breeding in the current year by a pair. Presence of an adult, eggs, or young, freshly molted feathers or plucked down, or current years’ mutes (whitewash) suggest site occupancy. Additionally, for the purposes of these guidelines, all breeding sites within a breeding territory are deemed occupied while

raptors are demonstrating pair bonding activities and developing an affinity for a given area. If this culminates in an individual nest being selected for use by a breeding pair, the other nests in the nesting territory are no longer considered occupied for the current breeding season. A nest site remains occupied throughout the periods of initial courtship and pair-bonding, egg laying, incubation, brooding, fledging, and post-fledging dependency of the young.

Alternate/Unoccupied Nests - Those nests not selected by raptors for use in the current nesting season. Nests are also considered unoccupied for the non-breeding period of the year. The exact point in time when a nest becomes unoccupied should be determined by a qualified wildlife biologist based upon observations and that the breeding season has advanced such that nesting is not expected. Inactivity at a nest site or territory does not necessarily indicate permanent abandonment.

Alternate/Vacant Nest - Old nests that do not appear to have been utilized for an extended period of time (e.g., more than five years), as evidenced by absence of any whitewash, general lack of maintenance, or degradation of nest materials.

In addition, the following terms are utilized based on the definitions noted:

Area-nesting Population - The USFWS term used to describe the golden eagle population nesting within a 10-mile radius of a project area and known to have made a nesting attempt during the preceding 12 months.

Local Area Population – A recent USFWS term identifying the golden eagle population occurring within 109 miles of a project area.

6.1 GOLDEN **EAGLE** NESTING SITES

Golden eagle surveys have been conducted in relationship to the Hycroft Mine since 2010. The survey area and survey intensity varied between years, as listed below:

- 2010 – 4-mile buffer ground surveys (JBR);
- 2011 – 10-mile buffer aerial survey (conducted by NDOW);
- 2011 – 5-mile buffer ground survey (JBR);
- 2012 – 5-mile buffer ground survey (JBR);
- 2013 – ground surveys and 10+-mile buffer aerial surveys (JBR);
- 2014 – ground surveys and 10+-mile buffer aerial surveys (WRC);
- 2015 – 10+mile buffer aerial surveys (WRC);

- 2016 – 10+mile buffer aerial surveys (WRC); and
- 2017 – ground surveys and 10+mile buffer aerial surveys (WRC).

The results of each survey are presented in sections 6.1.1 to 6.1.6. A compilation of nest data and nest productivity data over all survey years is presented in Appendix B. The nest locations and territories from the most recent survey (2017) are shown in Appendix A, Figure 5.

6.1.1 2010 – 2013 Survey Results

Table 1 lists the occupied, unoccupied, or vacant golden eagle and possible golden eagle nests found during surveys conducted from 2010 to 2013. The Silver Camel nests are listed as Nest Site 8 and the two East Kamma nests that are located in the Northeast Tailings Facility area as Nest Site 3. Figure 6 (Appendix A) depicts the locations of these nests. The nests surveyed by JBR personnel are described below, followed by a summary of nests reported by NDOW. Note that in this latest version of the report, individual nests or groups of nests are referred to as “nest sites,” rather than territories, since the extent of individual territories and the relation between nests or groups of nests is not always clear.

The nest site descriptions below represent nests that were known prior to the 2013 nesting season and were the focus of the 2013 monitoring effort. The 2013 golden eagle monitoring survey identified an additional 37 nests. Most did not appear to be newly constructed, and were found in areas that had not been previously surveyed. Including the 2013 surveys, a total of 54 nests were identified. Based on proximity, these nests appeared to represent on the order of 28 to 29 territories. Locations of the newly recorded nests are provided in *Hycroft Mine 2013 Golden Eagle Nests Monitoring Report* (JBR, 2013).

Nest Site 1, North Cliff Nests

The North Cliff face is an approximately 0.75-mile long, 100-foot-high cliff band located between the Hycroft Mine and Jungo Road, north of the existing mine facilities within the Hycroft Mine PoO boundary. At least three alternate golden eagle nests have been built on this feature. One of the three nests has been occupied and produced fledglings in all four years that baseline studies have been conducted (from 2010 to 2013), though a different nest was used in each year from 2010 through 2012. The nest used in 2013 is the same nest that was used in 2010.

Nest Site 2, Mandalay Spring Narrows Nests

A series of three vacant golden eagle nests were present on a dark cliff north of Jungo Road southeast of the Mandalay Springs area. Two more nests were located on top of the outcrop east of the cluster of three nests. While a prairie falcon pair has nested on this cliff during each year

Table 1. Status of Golden Eagle Nests in the Hycroft Mine Survey Area 2010-2013

Nest Site	Easting	Northing	2010 JBR Status	2011 JBR Status	2011 NDOW Status	2012 JBR Status	2013 JBR Status	Comments
Nest Site 1, 2010 North Cliff Nest No. 1 (2010 nest site)			Occupied	Unoccupied	-	-	Occupied	One of at least three nests on cliff face. Single young fledged in 2013.
Nest Site 1, 2011 North Cliff Nest No. 2 (2011 nest site)			-	Occupied	Occupied	Third nest in this territory occupied in 2012	Unoccupied	Nest in same territory as 2010 North Cliff Nest pair; 2011 nest located approximately 100 yards east of 2010 nest. NDOW identified two large young in the nest in 2011. A third nest in this same territory was occupied in 2012
Nest Site 1, 2012 North Cliff Nest No. 3 (2012 nest site)			-	-	-	Occupied	Unoccupied	Nest in same territory as 2010 and 2011 North Cliff Nest pair; A third nest in this same territory was occupied in 2012.
Nest Site 2, Mandalay Spring Narrows Nests			Unoccupied /Vacant	Unoccupied /Vacant	Unoccupied	Unoccupied /Vacant	Unoccupied	Five unoccupied and apparently vacant nests.
Nest Site 3, East Kamma Mountains Nest			Occupied	Occupied	Occupied	Unoccupied	Occupied	JBR identified one large downy young in this nest in May 2010; NDOW identified one large dark young in the nest in May 2011. No activity observed in 2012. Single young fledged in 2013.
Nest Site 4, Sawtooth Knob Nests			-	Occupied	Occupied	Occupied	Unoccupied	Four nests on south side of Sawtooth Knob feature. NDOW identified one young in the nest in 2011. In 2012, the nest used in 2011 was occupied by a red-tailed hawk and an alternate nest on the same feature was occupied by a golden eagle. No nesting activity observed in 2013.

Nest Site	Easting	Northing	2010 JBR Status	2011 JBR Status	2011 NDOW Status	2012 JBR Status	2013 JBR Status	Comments
Nest Site 5, Rosebud Canyon Nests			Occupied	Unoccupied	Unoccupied	Unoccupied	Unoccupied	Three nests in close proximity on the same cliff face in Rosebud Canyon. Attendant adult observed at nest in 2010.
Nest Site 6, Upper Rosebud Nest			Occupied	Occupied	Occupied	Occupied	Unoccupied	A single young was visible in this nest in 2010. NDOW identified two large young in the nest in 2011. An adult was observed on this nest in 2012. No nesting activity observed in 2013.
Nest Site 7, South Woods Canyon Nest No. 1			Unoccupied /Vacant	Unoccupied /Vacant	-	-	Unoccupied	Very old vacant nest.
Nest Site 7, North Woods Canyon Nest No. 2			-	Unoccupied	Unoccupied	Unoccupied	Unoccupied	JBR identified a territorial prairie falcon in 2011. NDOW identified six nests on the rocky outcrop in 2011. No active eagle nests identified in 2011, 2012, or 2013.
Nest Site 8, Silver Camel Nest			-	Unoccupied	Unoccupied	Unoccupied	Unoccupied	Nest on northwest side of Silver Camel outcrops, 2010. NDOW identified two alternate nests on other sides of outcrop – one old and one occupied by ravens in 2011. Birds present but no nesting, 2012 and 2013.
Nest Site 9, West Jungo Flat Nest No. 1			-	-	Occupied	-	Occupied	NDOW identified one adult in the area and two young in the nest in 2011. Occupied alternate nest found in 2013; one young believed fledged.
Nest Site 10, West Jungo Flat Nest No. 2			-	-	Occupied	-	Unoccupied	NDOW identified two adults nearby and one small young on the nest in 2011. No nesting activity observed in 2013.

Nest Site	Easting	Northing	2010 JBR Status	2011 JBR Status	2011 NDOW Status	2012 JBR Status	2013 JBR Status	Comments
Nest Site 11, Wild Rose Nest			-	-	Unoccupied / Vacant (?)	-	Unoccupied	Empty nest with old nest debris below probably vacant site.
Nest Site 12, West Kamma Mountains Nest No. 1			-	-	Unoccupied	-	Unoccupied	Large old, unoccupied nest presumed to be golden eagle, 2011. No nesting activity observed in 2013.
Nest Site 13, West Kamma Mountains Nest No. 2			-	-	Unoccupied	-	Unoccupied	Large unoccupied nest presumed to be golden eagle, 2011. No nesting activity observed in 2013.
Nest Site 14, West Kamma Foothills Nest No. 1			-	-	Unoccupied	-	Unoccupied	Large unoccupied nest presumed to be golden eagle, 2011. No nesting activity observed in 2013.
Nest Site 15, Rabbithole Nest			-	-	Occupied	-	Unoccupied	NDOW identified one young in the nest in 2011. No nesting activity observed in 2013.
Nest Site 16, Sulphur Power Line Nest			-	-	Occupied	-	No longer present	NDOW identified this nest in a transmission pole with three young present in 2011. Identification as a golden eagle nest uncertain. Nest fell or removed in 2013.
Nest Site 17, West Kamma Foothills Nest No. 2			-	-	-	-	Unoccupied	Found by JBR during ground surveys in March, 2013. Possibly an alternate to the West Kamma Foothills nest. Not occupied in 2013, but much whitewash present. Possibly occupied in 2012.

-: No data collected

from 2010 to 2013, and a ferruginous hawk nested on the outcrop in 2012, no eagles have been found nesting on this feature during the last four years, and all eagle nests present on this feature appear old and unmaintained.

Nest Site 3, East Kamma Mountains Nests

Two nests have been built on a cliff east of the Kamma Mountains. One of these nests was occupied in 2010, with a single young observed in the nest. NDOW observed one large, dark young in the nest in 2011. Eagle activity was not observed at either nest in 2012. One of the East Kamma nests became active and fledged a single young in 2013.

Nest Site 4, Sawtooth Knob Nests

Sawtooth Knob is a prominent rocky feature located south of Jungo Road approximately four miles east of the Hycroft Mine project area. The area was not surveyed in 2010, but an occupied golden eagle nest was found on the southern side of the feature in 2011. A group of four nests were located on the western side of the feature. In 2011, the NDOW documented one young in a nest on the feature. In 2012, one of the nests on the western side of the feature was occupied by golden eagles, while the nest on the southern side of the feature (which was occupied by golden eagles in 2011) was occupied by red-tailed hawks in 2012. In 2013, one to two eagles were observed perched on top of the Sawtooth Knob feature during three ground visits, but no activity was observed on any of the nests.

Nest Site 5, Rosebud Canyon Nests

A series of three nests were found on a cliff on the eastern side of Rosebud Canyon, above the Rosebud Canyon Road. An attendant adult eagle was present at one of these nests in 2010, but no eagles were seen near these nests in either 2011 or 2012. No nesting occurred in 2013, although in late March 2013, an adult bird landed in one of the nests. JBR biologists did observe one instance of an eagle flying into the Silver Camel nests from the direction of the Rosebud Canyon nests; however, the relationship was not determined.

Nest Site 6, Upper Rosebud Canyon Nest

The Upper Rosebud Canyon nest was located on the southeastern side of a rock pinnacle east of the upper end of Rosebud Canyon. This nest was occupied during three years of the surveys in 2010 through 2012. A single young was observed in the nest in May 2010. NDOW documented two young in this nest in May 2011. An adult was present on this nest in May 2012, and the nest was heavily whitewashed when checked in August 2012, suggesting young had been present in the nest. No activity was observed in 2013.

Nest Site 7, Woods Canyon Nests

The Woods Canyon nests were located on a red basaltic feature located approximately four miles north of the Hycroft Mine project area. Only the southernmost of several outcrops was surveyed in 2010. Eagles were not observed in the area at that time. Surveys were extended to the north in 2011 and identified two large nests on a large outcrop north of the site surveyed in 2010 but no evidence of eagle activity was noted. NDOW documented a total of six nests in this area in 2011, none of which were occupied. No evidence of occupancy was found at these nests when the area was visited in 2012. A pair of golden eagles was observed in the area of the Woods Canyon nests in March 2013, but no eagles were observed in the area on several subsequent visits.

Nest Site 8, Silver Camel Nests

Two birds were observed at the Silver Camel nest in late April 2011, but no reproductive activity, in the form of incubation or evidence of egg laying or brood rearing, was observed. The nest was located on the north side of an outcrop on the Silver Camel feature, in the southwestern portion of the Hycroft Mine. In May 2011, three weeks after birds were observed at the site, the NDOW observed no birds in the area and the nest was identified as inactive and unoccupied. A single bird was observed roosting at the site in the spring of 2012, but the nest showed no sign of having produced young. The limited whitewash present later in the season indicated young were not raised in this nest in 2012. In 2013, a pair of eagles with white plumage indicating they were juveniles was repeatedly observed at the Silver Camel feature. New nesting material was brought to the nest early in the breeding season. Later in the breeding season, one bird was observed rearranging sticks on the nest; however, the nest was not used for reproduction in 2013. An old dilapidated nest is present on a second outcrop on the feature.

In addition to the nests described above, NDOW reported nests at the following locations:

Nest Site 9, West Jungo Flat Nest No. 1

The NDOW found 2 nests west of the Jungo Flat area of Desert Valley, approximately 10 and 11 miles east of the Hycroft Mine project area. One of these nests was located near the edge of the 10-mile buffer around the Hycroft Mine project area; the other was located outside of this buffer area but was included in NDOW's 2011 aerial raptor survey (Appendix A, Figure 5). The northern nest, located beyond the 10-mile buffer, held 2 young in late May 2011. During aerial monitoring conducted on June 3, 2013, a large, dark young was found in a nest located 0.15 mile to the north of the nest used in 2011. It is presumed that this is an alternate nest.

Nest Site 10, West Jungo Flat Nest No. 2

The second nest found west of Jungo Flat in 2011 was approximately 1.2 miles southwest of the Jungo Flat Nest No. 1, and north of irrigated fields in the western portion of Desert Valley. This nest was just within the 10-mile buffer around the Hycroft Mine project area. A single young was present in this nest at the time of the May 2011 NDOW flight. No activity was observed in 2013.

Nest Site 11, Wild Rose Canyon Nest

NDOW identified two nests in Wild Rose Canyon, which is located south of the active mine area at the boundary of the Hycroft Mine PoO. The NDOW described an older, fallen nest on a north-facing outcrop in the canyon below Wild Rose Spring. A large amount of older nest material was located beneath the nest which strongly suggests that material was from an old golden eagle nest. Another raptor or common raven (*Corvus corax*) has been the most recent occupant of the site. A follow-up visit to this nest determined the size and amount of material present on the ground below the nest suggested the nest was probably constructed by golden eagles. The second nest, closer to Wild Rose Spring, was occupied by common ravens at the time of the NDOW 2011 flight. This nest was clearly smaller than known golden eagle nests in the area, and no birds of any species were seen near the nest in 2013. The lower Wild Rose Canyon nest was approximately two miles southeast of the Silver Camel nests and represented the closest known potential nesting habitat to Silver Camel.

Nest Site 12, West Kamma Mountains Nests No. 1

The NDOW flight identified three nests in the higher parts of the Kamma Mountains west of Rosebud Canyon. None of these nests were occupied at the time of the May 2011 NDOW flight. Two of the nests were approximately 0.3 miles apart. One of these nests was small and was probably a raven nest. The two were described as a single site. In 2013, two eagles were observed perched on top of the outcrop near the larger nest early in the breeding season. No activity was observed in the area during three subsequent visits.

Nest Site 13, West Kamma Mountains Nests No. 2

A third nest (Nest Site 13), described by NDOW as an older nest, was found approximately 0.6-miles northeast of the Nest Site 12, West Kamma Mountains No. 1 nests. Two were large nests, possibly golden eagle nests. It is uncertain if these West Kamma Mountains nests were alternate nests in the same territory, or if the nests represented different territories. A fourth nest found farther west in the foothills of the range was identified as the West Kamma Foothills nest. No activity was observed at these nests in 2013.

Nest Site 14, West Kamma Foothills Nests

As noted above, the NDOW identified a fourth large but unoccupied/inactive nest farther to the west in the West Kamma Mountains, east of the Rabbithole Creek drainage. A probable alternate nest to the West Kamma Foothills nest was located during 2013 monitoring (Nest Site 17). The nest was heavily whitewashed and may have been occupied in 2012. No activity was observed at this nest in 2013.

Nest Site 15, Rabbithole Nests

The NDOW found an occupied golden eagle nest with a single young near the Rabbithole Creek drainage, west of the Kamma Mountains. No activity was observed at this nest in 2013.

Nest Site 16, Sulphur Power Line Nest

The NDOW identified a nest constructed on a power pole paralleling the Union Pacific Railroad tracks north of the Hycroft Mine as a golden eagle nest. The nest held three young at the time of the May 2011 flight, but apparently, no adult birds were observed at this nest, making identification of this nest as a golden eagle nest uncertain. The nest was fairly small and did not contain large nest material that would be typical of an eagle nest. In 2013, the nest was not observed and was either blown away by wind or removed.

Nest Site 17, West Kamma Foothills Nest No. 2

The West Kamma Foothills Nest No. 2 was found by JBR in March 2013. It is likely an alternate nest to the other Kamma Foothills nest based upon proximity, but the nest was not occupied in 2013. A lot of white wash was present indicating recent use in past years.

6.1.2 2013 Monitoring Results

Monitoring results for the 2013 nesting season are described in the *Hycroft Mine 2013 Golden Eagle Nests Monitoring Report* (JBR 2013). In 2013, JBR monitored the 16 nests that had been identified in previous surveys. A 17th nest was identified during 2013 ground surveys. All nests were visited on multiple occasions during the 2013 nesting season, with emphasis placed on nests nearest to the mine (within the calculated 3.6-mile inter-nest distance). Between March and June 2013, the golden eagles were observed incubating eggs through the date young fledged from nests. Nests that became active (used in reproduction) were monitored for periods of up to several days every other week.

In addition to nest monitoring, a new expanded 10-mile buffer area was defined to include additional activities being conducted or considered at the mine. Aerial surveys were conducted of the new 10-mile buffer area. The first of these flights was conducted over a two-day period in early June (June 3 and 4, 2013). A total of 37 new golden eagle nests (several near and recorded with a single Global Positioning System [GPS] point) were identified within the expanded 10-mile buffer. Most of these newly identified nests were outside of the areas previously surveyed, though a few additional nests were found in areas that had been included in previous surveys. These latter nests did not appear to be newly constructed but were probably missed during previous surveys. Eight of the new nests found were just beyond the revised 2013 10-mile buffer survey area but were none-the-less recorded as they represent additional data points. Including the 2013 surveys, a total of 54 nests were identified within approximately 10 to 15 miles of the Hycroft Mine. Based on proximity, these nests appeared to represent 28 to 29 territories. Some of these nests are older and may not represent recently active territories (but see Kochert and Steenhof, 2013). Except for one nest located near the West Kamma Foothills Nest (Nest No. 14) found during the 2013 ground surveys, these newly located nests were identified by the GPS point number used to record the nest during the aerial surveys. The new nest found near the West Kamma Foothills Nests was identified as the West Kamma Foothills No. 2 Nest (Nest No. 17).

The 2013 monitoring and nest searches documented very limited golden eagle reproduction in the Hycroft area in 2013. Incubating or brooding golden eagles were found in only two of the original 16 nests that had been identified during previous years' surveys. Both of these nests (the North Cliffs Nest, Nest No. 1, and the East Kamma Nest, Nest No. 3) fledged a single young, each. A third nest, believed to be an alternate to the Jungo Flats Nest No. 1 (Nest No. 9) but only discovered in 2013, is also believed to have fledged a single young. Eagles were observed near several other nests, but no evidence of incubation or brooding was observed. JBR believed the very low nesting effort observed in 2013 was due at least in part to a low prey base (see Smith and Murphy, 1979; Steenhof et al., 1997; McIntyre and Adams, 1999). In their twice-monthly visits to the survey area, JBR biologists monitoring the Hycroft nests (up to four personnel per monitoring visit) did not observe a single jackrabbit. The area was also experiencing its second below-normal precipitation year in a row, resulting in limited vegetation productivity and presumably reducing alternate (non-jackrabbit) golden eagle prey populations.

Of the four nest sites closest to the Silver Camel nests, two nest sites were assigned to separate territories (the North Cliffs nests, Nest Site 1; and the East Kamma Mountains, Nest Site 3). A third nest site continued to be inactive, though non-nesting prairie falcons were observed at this site (Wild Rose Canyon, Nest Site 11); and the fourth nest site no longer supports a nest and was likely reported as an eagle nest in error (Sulphur Power Line; Nest Site 16).

6.1.3 2014 Monitoring Results

Hycroft Mine project area golden eagle monitoring was conducted in 2014 by Wildlife Resource Consultants LLC (WRC). Monitoring results for the 2014 nesting season are described in the *Hycroft Mine 2014 Raptor Nesting Surveys and Golden Eagle Monitoring Report* (WRC 2014). Two types of monitoring were conducted in 2014. Intensive nesting surveys were conducted early in the breeding season, focused on Silver Camel and other nesting areas close to the mine. The objective per the 2012 ROD stipulations and USFWS correspondence was to better understand the relationship of Silver Camel nests to other nests and breeding areas near the mine. Aerial surveys were conducted later in the breeding season, focused on quantifying breeding attempts and fledging success in the 10-mile buffer area.

Intensive Early Breeding Season Monitoring of Silver Camel Nests

The targeted time for intensive monitoring in 2014 was early in the breeding season, during the period of nest selection, egg laying, and early incubation. To assure that intensive monitoring occurred during this period, reconnaissance surveys were conducted on February 13 and 14, and on February 21. No eagles were seen on February 14, but birds were seen at both the North Cliffs (JBR Nest Site 1) and Silver Camel (JBR Nest Site 8) areas on February 21. Intensive surveys were therefore scheduled to begin on February 25.

Initially, intensive monitoring was planned for two full weeks. However, nest attendance was continuous at nearly all sites in the survey area by March 3, and incubation was observed at most. Because eagles are very sensitive to disturbance in early incubation, the first intensive monitoring session was terminated on March 3 to avoid disturbance that could result in the loss of nests. A second period of monitoring was conducted from March 12 to March 18, with the primary intent of verifying the status of nests in the survey area and investigating nest status in other portions of the 10-mile buffer around the mine.

The objective of the intensive monitoring surveys was to clarify the relationship of nests on Silver Camel to other surrounding areas. The study area therefore included all nesting areas within the inter-nest distance calculated by JBR in Section 6.1.2: North Cliffs (JBR Nest Site 1); Mandalay Springs Narrows (JBR Nest Site 2); East Kamma (JBR Nest Site 3); Rosebud Canyon (JBR Nest Site 5); Upper Rosebud Canyon (JBR Nest Site 6); Wild Rose Canyon (JBR Nest Site 14); and JBR Nest Site 804, just south of Rosebud Canyon. Simultaneous observations by three biologists were made at different locations in the survey area with the objective of gathering the following types of information to assist in delineating nest and territory relationships:

1) Continuous observations of golden eagles in transit between Silver Camel and other locations;

2) Simultaneous observations of eagles attendant at nests in different locations, which indicates that the locations are located within separate territories. Over long periods of observation, the lack of eagle presence in one area while another is attended suggests that the nests being observed may be in the same territory;

3) Departures of eagles from one location closely followed by arrivals at another, suggesting transit between the nests.

During the first two days of the first monitoring session, February 25 and 26, the three biologists visited nests throughout the survey area evaluating patterns of eagle use. Significant eagle activity was observed to the south and east of Silver Camel. Therefore, observation effort for the rest of the first session, February 27 through March 2, was focused on nests to the south and east of Silver Camel, which were nearly continuously monitored. Silver Camel itself was continuously monitored from February 27 through March 2, with a nest check on March 28.

During the second session, March 12 to 18, Pagel et al. (2010) protocol surveys were conducted at all nest sites in the survey area. Nests were observed until verification of occupancy/incubation, or for four hours. Three protocol surveys were conducted at Silver Camel during this period.

As in previous years, eagles were observed at Silver Camel early in the breeding season. Eagles were present on February 21, 25, 27, and March 1. On February 27, two birds were observed on the nest for a brief period. Nest decoration and copulation were also recorded. Nest decoration occurred on March 1. No eagle presence was observed after March 1, and at no point was incubation posture indicative of a breeding attempt observed.

On two of the days that birds were present at times at Silver Camel (February 27 and March 1), observers were also stationed at nest sites to the south in Rosebud Canyon and at East Kamma. Like the experiences of JBR in 2013, it was not possible, due to steep topography and lack of communications, to continuously maintain observations of eagles from one nest site to another. However, simultaneous observations recorded by the multiple biologists indicated that eagles active at Silver Camel were also active at Rosebud Canyon (JBR Nest Site 5). On three separate instances (twice on February 27 and once on March 1), an observer recorded eagle departures from one nest site, traveling in the direction of the other, closely followed by an observer at the second site recording the arrival of a golden eagle. In one instance on February 27, an observer stationed on Rosebud Peak midway between the two nest sites recorded an observation of the eagle in transit. In addition, although observers were present the entire day at both Silver Camel and Rosebud Canyon on February 27 and 28, and March 1, at no time were eagles observed simultaneously at both sites.

Other findings of the intensive surveys included:

- Multiple observations of eagles transiting between Rosebud Canyon (JBR Nest Site 5) and JBR Nest Site 804, to the south, indicating that this nest site was also visited by Silver Camel birds. This nest site was included in a Geographic Information System database provided by JBR, which indicated that two nests are present, but only one was found during aerial surveys conducted in 2014.
- Simultaneous observations of eagles at North Cliffs, East Kamma, Rosebud Canyon (JBR Nest Site 5) and Upper Rosebud Canyon (JBR Nest Site 6), suggesting that these areas all represent individual territories. No eagles were observed during the intensive monitoring period at Wild Rose Canyon (JBR Nest Site 6).
- Nest occupancy (incubation posture) was confirmed at North Cliffs, East Kamma, and Rosebud Canyon (JBR Nest Site 5). Nest occupancy was suspected at Upper Rosebud Canyon, but observations points with clear views into the nest were not available without disturbing the eagles.

Data collected during 2014 intensive monitoring was thought to support the conclusion that nests on the Silver Camel feature are part of a larger territory that includes the Rosebud Canyon nest site (JBR Nest Site 5) and JBR Nest Site 804. This however was proven incorrect during the 2015 golden eagle monitoring surveys as both Silver Camel nest 8 and nest 804 were occupied. Although the territory would be relatively large, it is within the range of published home ranges for eagles in the Great Basin region. Slater et al. (2013), in their study of west Utah eagles, state that regional home range sizes have been found to average near 23 square kilometers but were as large as 83 square kilometers (equivalent to a circle with a radius of 5.1 kilometers). Based upon past monitoring and current known data, the Silver Camel nests are considered to be in their own territory.

Aerial Nesting Surveys

Two aerial surveys were conducted of the 10-mile buffer around the Hycroft Mine in 2014. The first, on May 14, established nest occupancy and the status of breeding attempts. Fledging success was evaluated on the second aerial survey conducted on June 10. Breeding attempts were documented at eight nests (Table 2). Of these, six nests successfully fledged young.

Of the nest sites near the Hycroft Mine included in intensive surveys, North Cliffs and East Kamma were both successful. As suspected during intensive monitoring surveys, a nesting attempt did not occur at Upper Rosebud Canyon (JBR Nest Site 6). The nest within the Silver Camel/Rosebud Canyon territory contained two eggs on the first flight but was unattended by an

Table 2. Aerial Survey Nest Status, 2014

JBR Nest Site	May 14 Status	June 10 Status
North Cliffs, Nest Site 1	1 chick	Successful (1 fledgling)
East Kamma, Nest Site 3	1 chick, 1 egg	Successful (1 fledgling)
Silver Camel/Rosebud Canyon, Nest Site 5	2 eggs	Unsuccessful
Woods Canyon, Nest Site 7	2 chicks	Successful (2 fledglings)
Rabbithole, Nest Site 15	2 chicks	Successful (2 fledglings)
Nest Site 724	1 chick	Successful (1 fledgling)
Nest Site 756	1 chick	Successful (1 fledgling)
Nest Site 821	1 chick	Unsuccessful

adult. The second flight confirmed that the eggs did not hatch, and the nesting attempt was unsuccessful.

The North Cliffs territory (successful in five of five years of monitoring) and the East Kamma territory (successful four of five years) are clearly primary breeding areas. It is interesting to note that neither of these territories appears to be in areas of high habitat quality; North Cliffs is mostly surrounded by vegetation communities dominated by greasewood, and the East Kamma territory is located near areas that have recently burned. Pair experience may be an important factor in the success of these territories, as described by other researchers (see Section 4.0). Other territories near the mine, including the Silver Camel/Rosebud Canyon territory, are located in presumably higher-value sagebrush habitats but have lower rates of success over the period of monitoring. These secondary breeding areas may be occupied by less experienced birds, a possible explanation for the unsuccessful breeding attempt at the Rosebud Canyon nest, occupied by birds that were also active at Silver Camel. This is consistent with observations made by JBR in 2013 that eagles active at Silver Camel may have been sub-adults.

6.1.4 2015 Monitoring Results

The 2015 golden eagle nest monitoring was conducted by WRC. Monitoring results for the 2015 nesting season are described in *the Hycroft Mine 2015 Raptor Nesting Surveys and Golden Eagle Monitoring Report* (WRC 2015). Early season intensive ground nesting surveys were not completed. Instead, two aerial surveys were conducted 30-days apart, focused on quantifying rearing attempts and fledging success in the 10-mile buffer around the full proposed expansion boundary. The aerial surveys did focus on evaluating all new and old nests, not just known nests in the radius. Based upon the information being collected and the need to provide detailed information, nests were individually labeled versus previous use of numbering an area containing a closely distributed number of nests. For example, Silver Camel rock outcrop nests in previous JBR surveys were labeled as one site, Nest site 8. The three separate nests have now been labeled for clarity as Nests 8A, 8B, and 8C.

Aerial Nesting Surveys

The aerial survey monitoring in 2015 was conducted during the rearing season versus the early breeding and nest selection phase conducted in 2014. The aerial survey did however focus on searching for nests missed during earlier surveys or that had recently been constructed. The surveys were completed with recommendations from NDOW for recording nest attributes. This information is summarized in the *Hycroft Mine 2015 Raptor Nesting Surveys and Golden Eagle Monitoring Report* (WRC 2015).

Two aerial surveys were conducted of the 10-mile buffer around the Hycroft Mine. The first, in May, and the second in June 2015. The first survey established nest rearing but not attempts of breeding. Fledging success was evaluated on the second aerial survey and is summarized in Table 3.

Table 3. Aerial Survey Nest Status, 2015

Nest ID	May Status No. of Young	June Status No. of Young (Fledged)
9	2	0 (2 fledgling)
722	2	2 (2 fledgling)
748	2	0
8B	2	1 (1 fledglings)
53	1	0 (1 fledglings)
7B	1	1 (1 fledgling)
66	2	1 (1 fledgling)
5B	2	0
78	1	0 (2 fledgling)
79	2	0
Total Number of Fledglings		**10**

The results of the 2015 monitoring showed there were approximately 22 territories that contributed to the local area nesting population. Thirteen territories were occupied. However, due to refinements in the spatial arrangement of territories in 2017, the number of territories was increased to 24, and the 2015 occupancy was recalculated as 63% (see Section 6.1.6) (WRC 2017).

The productivity for 2015 was recalculated in 2017 as 1.08 golden eagles fledged per occupied territory. The mean brood size was one to 1.4 fledglings, resulting in a nest success rate of 76.9%. A compilation of nest data from 2010 to 2017 is provided in Appendix B.

One nest, designated 8B, on the Silver Camel outcrop was active and successful in fledging one young. The second aerial survey had revealed one young approximately 10-weeks old in the nest while one egg had not hatched.

The nests in the Phase II Expansion area (Appendix A, Figures 5 and 6) includes six separate nest sites, which were not active in 2015, including the East Kamma Nests 3A, and 3B. The other nests include Nest 101, Nest 102 that is classified as fallen and deteriorated, and Nests 821A and B. The 2014 surveys showed two of the sites 3A and 821B active. The surveys did indicate nest decoration took place in a few locations.

6.1.5 2016 Monitoring Results

The 2016 golden eagle nest monitoring was conducted by WRC. Monitoring results for the 2016 nesting season are described in the *Hycroft Mine 2016 Raptor Nesting Surveys and Golden Eagle Monitoring Report* (WRC 2016). Two aerial surveys were conducted, the first on April 7, 2016, and the second on June 1, 2016. The two surveys were separated by 55 days. Early spring weather in 2016 was relatively cool and stormy. During the first survey, numerous eagles were observed on nests with no eggs. In a few instances, eggs were observed. Based on these observations, the first survey in the Hycroft area was conducted during late courtship-early incubation. The second was conducted during late rearing, near when fledging would occur. Fledging success was evaluated on the second aerial survey and is summarized in Table 4.

Table 4. Aerial Survey Nest Status, 2016

Nest ID	April Status No. of Young/Eggs	June Status No. of Young (Fledged)
717	0	1
721	2 eggs	0
762B	1 egg	1
767	0	3
771B	1 egg	0
8B	0	1
5B	0	2
821B	0	2
51B	1 chick	1
53	2 chicks	2
60A	0	2
63	0	2
66	2 chicks	1
88	1 egg	1
7B	0	1
Total estimated number of Fledglings		**20**

The results of the 2016 monitoring showed there are 24 territories in the local nesting population area. Territories were classified as occupied when they contained at least one occupied nest. Twenty-two of the 24 estimated territories were occupied in 2016. Therefore, the territory occupancy rate reported in the 2016 survey report was 92% (WRC 2016). However, due to refinements in the spatial arrangement of territories in 2017, the 2016 occupancy was recalculated as 79% (see Section 6.1.6) (WRC 2017).

The productivity for 2016 (number of young fledged / number of occupied territories) was 0.91. There were 20 fledged young. The mean brood size was one to 1.54 fledglings. A compilation of nest data from 2010 to 2017 is provided in Appendix B.

The nest designated 8B on the main Silver Camel outcrop was active in 2016. The nest was successful and a single eaglet in the nest was estimated to be nine to ten weeks old on the second flight. This nest also fledged one young in 2015, estimated to be ten weeks old on the second flight. Eagles were also observed at this nest in 2013 and 2014.

No new golden eagle or other raptor nests were found in the Phase II Expansion area during the 2016 Surveys. Six nests classified as golden eagle are located within this area, one of which (Nest 102) is fallen and deteriorated. Nest 3A was designated occupied based on an adult bird sitting in the nest and another adult bird perched on top of the rock outcrop during the first survey flight. No activity was recorded on the second flight. One of the golden eagle nests in the proposed Phase II Expansion area was active in 2016 – Nest 821B. Two chicks fledged from this nest. This nest was last recorded as active in 2014, with one chick observed on the first flight, but no activity on the second flight.

6.1.6 2017 Monitoring Results

The 2017 golden eagle nest monitoring was conducted by WRC. Monitoring results for the 2017 nesting season are described in the *Hycroft Mine 2017 Raptor Nesting Surveys and Golden Eagle Monitoring Report* (WRC 2017).

Ground Occupancy Survey

A ground occupancy survey was conducted on February 25, 2017 at territories most likely to be affected by mine activities and accessible by road at the time. A summary of the results is presented in Table 5.

Table 5. Ground Survey Occupancy Status, 2017

Nest ID	Territory	Status
8A-C	Silver Camel	Nest/territory was occupied. The eagles were in the period of courtship/nest establishment.
3A-B	East Kamma	Nest/territory was occupied. The eagles were either in late courtship/nest establishment or early incubation.
1A-D	North Cliffs	Occupancy was likely, but not conclusive. Courtship behavior was not observed.

Nest ID	Territory	Status
5A-C	West Rosebud Canyon	Occupancy was questionable.
6, 68	East Rosebud Canyon	Nest/territory was classified as occupied. The eagles at this site were in courtship/nest establishment.

Aerial Nesting Survey

Two aerial surveys were conducted, the first on March 1-2, 2017, and the second on May 31, 2017. The two surveys were separated by 89 days. Early spring weather in 2017 was relatively cool and stormy. During the first survey, numerous eagles were observed on nests with no eggs. In a few instances, eggs were observed. Based on these observations, the first survey in the Hycroft area was conducted during late courtship-early incubation. The second was conducted during late rearing, near when fledging would occur.

Seventeen golden eagle nests were occupied by golden eagles in 2017, including 14 active nests. The other three golden eagle nests occupied by golden eagles were classified as occupied based on the presence of an adult sitting on the nest or two adults in the vicinity. No eggs or young were seen in these nests on the second flight. Fledging success was evaluated on the second aerial survey and is summarized in Table 6.

Table 6. Aerial Survey Nest Status, 2017

Nest ID	Evidence of Occupancy	Number of Young, May 31	No. of Young (Fledged)
10	Active	1	0.5
54	Adult on nest	0	0
78	Active	2	2
101	Active	2	2
678	Active	2	2
748	Active	2	2
764	Active	2	1
774	Two adults nearby	0	0
13A	Active	2	2
1C	Active	2	1
3A	Active	1	1
4D	Active	2	2
51A	Active	1	1
5A	Active	2	2
756A	Active	1	1
7A	Eagle on nest, another nearby	0	0
8A	Active	1	1
Total estimated number of fledglings			**20.5**

Territory Occupancy

The results of the 2017 monitoring showed there are 24 territories in the local nesting population area. The spatial organization of the territories was adjusted in 2017 based on the nests that were active during each year throughout the period of monitoring (2010-2017) (Appendix A, Figure 5). In 2014, there were an estimated 18 territories, compared with the current estimate of 24. As the current map is the best estimate of territory distribution, all golden eagle nests have been assigned to a territory based on it. Occupancy of individual nests was then used to evaluate individual territory occupancy and recalculate project area territory occupancy rates over the period of monitoring (Table 7). Territories were classified as occupied when they contained at least one occupied nest. Seventeen of the 24 estimated territories were occupied in 2017. This results in a territory occupancy rate of 71%. The project area occupancy rate, based on the 10-mile buffer around the project area, can be calculated and compared from 2015 through 2017 (Table 7). It varied from 63% to 79% (WRC 2017).

Table 7. Golden Eagle Territory Occupancy Status, 2010 to 2017[1]

Territory Number	Territory Name	2010	2011	2012	2013	2014	2015	2016	2017
1	Silver Camel	ns	***occ***	***occ***	***occ***	***occ***	occ	occ	occ
2	North Cliffs	occ	occ	occ	occ	occ	unocc	unocc	occ
3	Rabbithole Peak	ns	***inact***	ns	***inact***	***inact***	occ	occ	unocc
4	West Jungo Flats 2	ns	occ	ns	unocc	***inact***	unocc	occ	occ
5	West Jungo Flats 1	ns	occ	ns	occ	***inact***	occ	unocc	occ
6	Alkali Flats	ns	ns	ns	inact	***inact***	unocc	unocc	unocc
7	Haystack Mine	ns	ns	ns	unocc	***inact***	occ	occ	occ
8	Moonshine Spring	ns	ns	ns	***inact***	***inact***	unocc	unocc	occ
9	Woods Canyon	***inact***	***inact***	***inact***	unocc	occ	occ	occ	occ
10	Black Rock Point	ns	ns	ns	***inact***	***inact***	occ	occ	unocc
11	Sheep Spring	ns	***inact***	ns	***inact***	***inact***	unocc	occ	unocc
12	Lava Beds Creek	ns	***inact***	ns	***inact***	***inact***	occ	occ	occ
13	West Jackson Mtns.	ns	ns	ns	***inact***	occ	occ	occ	unocc
14	Majuba Mountain	ns	ns	ns	***inact***	***inact***	occ	occ	occ
15	Antelope Range	ns	***inact***	ns	***inact***	occ	occ	occ	occ
16	South of Sawtooth	ns	***inact***	ns	***inact***	occ	unocc	occ	occ
17	Abel Camp Spring	ns	***inact***	ns	***inact***	***inact***	unocc	occ	unocc
18	Placerites	ns	***inact***	ns	***inact***	***inact***	unocc	occ	occ
19	East Kamma	occ	occ	***inact***	occ	occ	occ	occ	occ
20	Sawtooth Knob	ns	occ	occ	***occ***	***inact***	unocc	unocc	occ
21	West Rosebud Canyon	occ	***inact***	***inact***	***occ***	occ	occ	occ	occ
22	Cow Creek	ns	***inact***	ns	***inact***	***inact***	occ	occ	occ
23	Rabbithole Creek	ns	occ	ns	unocc	occ	occ	occ	unocc
24	East Rosebud Canyon	occ	occ	occ	***occ***	***occ***	occ	occ	occ
			Project-area Yearly Territory Occupancy				**0.63**	**0.79**	**0.71**

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[1] Territories not surveyed in each year denoted with ns. Where the territory was surveyed for activity (egg laid) but data are insufficient to assess occupancy it was given the status inactive (inact). Where occupancy determinations have been revised from the original reports based on updated occupancy definition the status is in bold italics.

Of territories that have been surveyed throughout all or most of the monitoring period (2010-2017), East Rosebud Canyon is the only territory that has been confirmed occupied in all survey years. While the Silver Camel territory was never active (an egg was laid) prior to 2015, it was occupied (adult birds present) all years except 2010, when it was not surveyed. Occupancy over the period of monitoring has also been consistent at the West Rosebud, East Kamma and North Cliffs territories.

Nest Productivity

The productivity for 2017 (number of young fledged / number of occupied territories) was 1.21. There were 20.5 fledged young. The mean brood size was one to 1.46 fledglings, making the nest success 82.4 percent.

The nest designated 8A on the smaller, northerly Silver Camel outcrop was active in 2017. This nest has not previously been occupied in the period of monitoring. The nest was successful and a single eaglet in the nest was estimated to be seven to eight weeks old on the second flight. An alternate nest on the nearby main Silver Camel outcrop (Nest 8B) was active and successful in 2015 and 2016. Eagles were also observed at this nest in 2013 and 2014 and it was therefore occupied under the definition in Section 1.1.2.

No new golden eagle nests were found in the Phase II Expansion Area during the 2017 survey. Nest 3A was active and produced one fledgling in 2017. This nest was occupied but not active in 2015 and 2016. Prior to 2017, it was last active in 2014, with two chicks fledged. Nest 3B is very small, and confidence that it is currently a viable eagle nest is low, but it is nonetheless classified as an eagle nest.

Nest 101 in the southeast corner of the Phase II Expansion Area was also active in 2017, and fledged two young. This nest has been surveyed since 2015 and has not been active before this year. Nearby Nest 102 was classified as deteriorated and fallen off the nesting platform when first found in 2015, and it was in the same unsuitable condition in 2017.

Nests 821A and 821B, likely part of the same territory as Nests 101 and 102, were both unoccupied in 2017. Nest 821B was active in both 2014 and 2016; Nest 821A has not been active in the period of monitoring.

6.2 NEST DENSITY

During 2010 to 2012 surveys, NDOW and JBR biologists identified a total of 32 nests potentially representing approximately 12 golden eagle nesting territories, occupied and unoccupied, within 5 miles of the Hycroft Mine project area. Based on these surveys, the average nest density within 5 miles of the Hycroft Mine project area (179 square miles) is one territory per 14.9 square miles. Within 10 miles of the Hycroft Mine project area (336 square miles), the average nest density is lower, at one territory per 22.4 square miles. The 2013 surveys identified additional nests within the 5- and 10-mile areas around the Hycroft project but did not change the earlier findings that there is a higher nest density within 5 miles of the mine, and density decreases with distance from the mine (JBR, 2013). The higher density of nests closer to the Hycroft Mine project area can be attributed to a concentration of suitable nesting habitat located in the Kamma Mountains within the 5-mile buffer, and the lack of habitat associated with the large area of barren and sparsely vegetated playa north and northwest of the mine within the 10-mile buffer. The playa habitat lacks potential golden eagle nesting substrate, such as cliffs, outcrops, or trees.

Note that the Module 1 Guidance states that, "where eagle nesting density is especially high and data are available (either from prior studies or a pilot study) to do so, the project area inter-nest distance can be calculated and used as the width of the perimeter survey area, as the territories immediately adjacent to the footprint are the ones most likely to be affected by the project. This approach is especially appropriate in areas with high densities of nesting bald eagles" (USFWS, 2011). Potential golden eagle nesting habitat is not uniformly distributed in the Hycroft Mine 10-mile buffer area. Specifically, the areas northwest of the mine contain minimal areas of potential golden eagle nesting habitat. Accordingly, the USFWS recommends surveying the full 10-mile buffer area for golden eagle nests. This in fact was done during golden eagle monitoring and nest searches conducted in 2013-2017.

6.**3** NEST PRODUCTIVITY

A compilation of nest data from 2010 to 2017 organized by territory is provided in Appendix B. Twenty-three of the 24 territories have been documented as active over the period of monitoring, and 22 have been documented to have successfully fledged young.

Surveys in 2010 and 2012 were part of general baseline wildlife surveys and not focused on golden eagle nesting. While nest activity was detected at some sites, the surveys did not provide sufficient data to calculate productivity parameters that are comparable to later surveys. Monitoring in 2011 consisted of one comprehensive aerial survey in late May, but this survey was conducted on a slightly smaller area than surveys from 2013 to 2017 and territory occupancy was not assessed. While there was sufficient data to calculate metrics such as mean brood size, productivity parameters based on occupied territories could not be determined.

Nesting surveys from 2013-2014 were comprehensive across the larger, 10-mile buffer survey area. The 2013 and 2014 surveys both consisted of two aerial flights, and these were augmented in 2013 with early season ground surveys at territories closest to the mine. However, in both years, occupancy was assessed according to interpretation of the 2010 USFWS definition and is not therefore comparable to 2015-2017. In monitoring years 2015-2017, two aerial surveys were conducted, and nest and territory occupancy were assessed consistently according to the USFWS 2013 guidance.

Productivity was low in 2012 and 2013, but has increased significantly since then, from three fledglings in 2013 to 20.5 in 2017, likely in response to an increase in abundance of jackrabbits; our qualitative observation in this part of the Great Basin are that rabbit abundance has been increasing since 2013 and may be at or nearing a peak in the cycle.

The area-nesting golden eagle population appears to be relatively high and self-sustaining, based on the production estimate obtained from the 2011 NDOW flight (between 1.4 and 1.6 young fledged per active nest in 2011). A single young (1.0) fledged per nest from three occupied nests in 2013, but 2013 was considered an unusually low year for nesting attempts. Rates seen in 2014, 2015, 2016, and 2017 were 1.3, 1.4, 1.54, and 1.46 young fledged per nest, respectively. The relatively high rate of fledgling in 2014-2017 indicate a stable area nesting population.

7.0 RISK ASSESSMENT

Part of the ECP process is assessing the level of risk of a project on local-area golden eagle breeding populations. Related to the wind-energy industry, the USFWS (2013) identified three project categories by their potential risk to eagles:

- Category 1—High risk to eagles; potential to avoid or mitigate impacts is low
- Category 2—High or moderate risk to eagles; opportunity to mitigate impacts
- Category 3—Minimal risk to eagles

The standard operations associated with the mining and mineral exploration industry pose a low risk to golden eagles. There is a low risk for interaction with most of the operations and facilities on a mine site. HRDI currently employs protection measures associated with the BBCS, the 2012 ROD and the 2015 ROD. Additional applicant-committed protection measures are included in the amended 2014 PoO related to the proposed Phase II expansion (see Section 8.0). By implementing these protection measures, the risk to eagle interactions is lowered even further.

A major component of the risk assessment is to identify project activities that could result in a take. HRDI is requesting to remove three nests from the Silver Camel Nest site (8A-8C). Two of these nests have been documented as active in the period of monitoring (8A-8B). One of the nests (8C) is smaller and deteriorated. Currently, the best estimate is that there are four nests within the Silver Camel territory; however, the fourth nest (11) is completely fallen. Removal of 8A-8C therefore will therefore likely result in the loss of an eagle territory. Mitigation would be required for the loss of productivity until it could be shown that productivity is restored. This could be achieved by monitoring that shows the establishment of a successful nest within the current Silver Camel territory, at a new location, or potentially at a rebuilt nest 11, with evidence of no displacement of birds at neighboring territories (*i.e.* active nests in neighboring territories).

Two nests (3A-3B), are within a territory focused on the East Kamma mountains. Although nests will not be removed, they will be disturbed by the construction and operation of a tailing facility in clear sight lines of the nests and within a few hundred feet. It is likely that these impacts will result in the loss of an eagle territory. In 2017, three additional nests were assigned to the East Kamma territory (Nests 2C, 2D and 2E). The nests are on an outcrop just north of the main Jungo Road near Mandalay Springs. The Mandalay Springs nests are very near the county road (<500 feet) and have never been active or occupied in the period of monitoring. Given their proximity to the road, it is highly unlikely that they would be used for breeding. Therefore, a disturbance take of nests 3A and 3B would result in the loss of a breeding territory. Mitigation would be required to replace this productivity until it could be shown that productivity is restored. This could be through monitoring that shows the establishment of a successful nest within the current East Kamma territory, at a new location, or potentially at the Mandalay Springs nest site, with evidence of no displacement of birds at neighboring territories (*i.e.* active nests in neighboring territories).

One deteriorated nest (102) will be removed within the footprint of the Northeast Tailings Facility in the South of Sawtooth territory. This nest is not currently viable. The South of Sawtooth territory contains three additional alternate nests (nests 821A, 821B, and 101) located as a cluster of nests all in close proximity to each other. Approximately 20 percent of the habitat that comprises the South of Sawtooth breeding territorial area would be lost by construction of the Northeast Tailing Facility. The USFWS has determined that this territory would likely be lost due to incidental disturbance and loss of habitat. The South of Sawtooth territorial pairs may continue to occupy their territory in the short term, although it is expected that disturbance from construction of the tailings facility would ultimately cause them to abandon the territory.

8.0 PROTECTION MEASURES AND ADAPTIVE MANAGEMENT

HRDI currently employs protection measures associated with the BBCS, the 2012 ROD and the 2015 ROD. Additional applicant-committed protection measures are included in the 2014 amended PoO related to the proposed Phase II expansion. Ongoing or proposed management techniques to avoid deaths or reduce the risk to the maximum degree practicable include:

1. Silver Camel nest complex removal will occur outside of the nesting season and a biologist will confirm that the nests are not active;
2. Compliance with the NDOW Artificial Pond Permit which contains measures that are intended to prevent wildlife mortality from occurring as a result of exposure to chemicals at the heap leach facility and chemical-laden water impoundments. Specifically, the permit includes specifications for fencing and covering and containment, as well as reporting requirements for mortalities;
3. Monitoring surveys within 10 miles of the project area (project area population) (see Section 10) to demonstrate trends;
4. APLIC standards to minimize the potential of avian electrocution and collision;
5. Spatial buffers will be applied to active nests (a nest in which eggs have been laid) during the nesting season, here defined as spanning from the arrival of adults on a territory to post-fledging dependency of young. The buffer size will depend on the nature and duration of the disturbance and whether the nest is within line-of sight. The buffer size will be decided with input from the USFWS, NDOW, and/or the BLM;
6. Daily inspections of heap leach pad for ponding to minimize chance of cyanide poisoning;
7. Inspections of wildlife exclusion measures at process ponds;
8. Employee training;
9. Facility design considerations and speed limits to reduce chances of collision; and
10. Regular reviews of avoidance and protection measures and application of adaptive management.

9.0 MITIGATION

With the goal of maintaining stable or increasing breeding populations in all eagle management units, and the persistence of local populations throughout the geographic range of each species, the following mitigation measures will be implemented to compensate for the removal of nests and the possible loss of breeding territories:

1. HRDI will contribute to the USFWS' Pacific Southwest Region Bald and Golden Eagle Mitigation Account with the National Fish and Wildlife Federation; or a bond authorized under 43 CFR Subpart 3809: Surface Management. The contributions will be applied to retrofitting high-risk power poles within the same Eagle Management Unit (Pacific Flyway), although efforts will be made to implement mitigation within the natal dispersal range (109 mile-radius) if practicable. HDRI will work in coordination with BLM, USFWS, and NDOW to implement compensatory mitigation locally if practicable. The goal is to implement all or most of the retrofits on Harney Electric's poles located within the Kings River area.

   The amount of compensatory mitigation required will be determined through the USFWS Golden Eagle Resource Equivalency Analysis (GOEA REA) (USFWS 2013). Currently, the compensation rate is 6.49 eagles per territory lost. Therefore, compensatory mitigation equivalent to 19.5 golden eagles would be required to offset take of three territories. A range of 305–701 electric utility poles would be retrofitted to offset impacts of three lost territories. The exact number of retrofits depends on the longevity of each pole's retrofit.

2. HRDI may construct or repair nests to enhance potential breeding habitat within the eagle management unit, the local area population, or to encourage relocation of nesting activity within the vicinity of the mine. Nest sites will be chosen in coordination with the USFWS and the BLM. Nesting platforms may be placed on larger power transmission line towers and/or constructed as independent structures. Nests may be created or repaired within the territories where nests will be removed or disturbed to serve as alternate nests within those territories.

3. HRDI will coordinate with the USFWS and the BLM on the creation of suitable nest platforms on the Hycroft pit high walls during mine closure. Mine planning activities including pit wall design and development will consider suitable nesting platforms for post operation nesting sites.

4. Nest site mitigation could entail treating nests or young for parasites if they are identified as occupying nests or contributing to efforts within the EMU.

5. HRDI will minimize the disturbance to the South of Sawtooth and East Kamma nest sites by conducting construction activities on the Northeast Tailings Facility and the stormwater diversion ditch south of the tailings facility outside of the breeding season. Monitoring of the East Kamma nests will focus on a return to occupancy status post construction as it is expected that no disturbance will take place during operations.

6. HRDI will provide annual environmental training for personnel working onsite during operations. The training will include eagle recognition, identification and ecology awareness to encourage proper operational conduct, response and reporting if an eagle is observed or encountered onsite. Any eagle mortality encountered by personnel will be immediately reported to onsite environmental staff, who will in turn report to BLM, USFWS and NDOW within 24 hours of discovery.

7. HRDI will continue to maintain safety netting over open process ponds to avoid eagle injury or mortality through contact with process solution.

10.0 MONITORING

HRDI proposes to continue monitoring during operations within a 10-mile radius of the active Hycroft project area to obtain additional data on golden eagle nests following removal of the Silver Camel feature and disturbance of the nests located within the proposed Northeast Tailings Facility in the East Kamma and South of Sawtooth sites.

Current monitoring of the area-nesting population, includes a 10-mile buffer around the Hycroft Mine project area, and focuses on nest occupancy and productivity. The current monitoring effort follows the USFWS Interim Monitoring Protocols (Pagel et al. 2010), two aerial surveys will be conducted each year, separated by at least one month. The timing of the first survey will be determined in conjunction with the USFWS. These data will be used for the following purposes:

1) To further delineate and refine understanding of eagle territories near the mine.
2) To evaluate trends in rates of territory occupancy and activity. Territory occupancy will be particularly valuable, as rates tend to be more stable over time than rates of activity, which vary from year to year due to environmental conditions.
3) To assess any potential effects on territories near the mine following removal of the Silver Camel nests and disturbance of the East Kamma and South of Sawtooth nests.
4) To determine what level of mitigation, if any, is required for a loss of breeding territories.

In addition, adult golden eagles that may be affected by the disturbance or loss of breeding territories as a result of the proposed mine expansion will be fitted with transmitters during the 2018 breeding season. The eagles will be tracked for multiple years over a period that spans pre- and post-mine expansion. The data collected will help inform Hycroft and the regulatory agencies about golden eagle breeding behavior and movements within breeding territories in relation to mining activities.

Continued data collection will allow for evaluation of trends in nest occupancy and success which will lead to a determination of whether the local-area population appears to be stable. Post-project monitoring requirements will be determined during the current EIS process. In addition, the monitoring methodology and frequency may be adjusted based on the analysis and recommendations developed in the EIS currently being prepared and may be adjusted over time because of new data and scientific information related to golden eagle biology. Survey results will be provided annually to BLM and USFWS.

A monitor can be assigned to any in-use/occupied nests that are within one-mile of mining activities during the breeding season (January 1 to July 31). Monitoring will be conducted in accordance with ‘USFWS Bald Eagle Monitoring Guidelines (2007)’ or an equivalent protocol. The purpose of monitoring will be to evaluate the behavioral response of the adult eagles or their chicks to mining activities and detect any abnormal behavior that could result in abandonment of the nest or death of the eggs or eaglets. In lieu of continued biomonitoring, an appropriate spatial buffer can be applied to the nest site based on the behavioral response of the eagles to the disturbance.

11.0 CONCLUSION

Within the 10-mile buffer of the project area, a total of 183 nests were observed and recorded in 2017. Ninety-five nests were classified as likely belonging to golden eagles, of which 14 were active with golden eagles. Twenty-three (23) nests were active with other raptors (WRC 2017).

HRDI is requesting authorization for removal of inactive nests and disturbance take associated with nest removals and mining activities that could result in the loss of up to three golden eagle nesting territories (Appendix A, Figure 6). HRDI is requesting a permit that would allow for removal of four nests (8A-8C; and 102), two of which are currently viable under 50 CFR 22.25. Disturbance take authorization is also requested for planned mining activities near five additional nests (3A, 3B, 821A, 821B, and 101) and to the Silver Camel feature should these actions result in the loss of breeding territories under 50 CFR 22.26 per July 29, 2015 USFWS correspondence. Three nests are located on the Silver Camel feature, a rocky outcrop located immediately southwest of the existing Hycroft Mine approved for mining in the 2012 BLM's ROD for the Hycroft Expansion. Six additional nests are in the Phase II Expansion area, specifically the North Tailings Facility, currently being evaluated as an EIS by the BLM jointly prepared with the USFWS. Two of the North Tailings Facility nests (3A-3B) would only be a disturbance take during the construction phase of the facility and are expected to be used during operation. The removal of one deteriorated nest (102) and a loss of habitat and incidental disturbance take to three additional nests (821A, 821B, and 101) could result in the loss of the South of Sawtooth breeding territory. Actions presented in this ECP represent HRDI's good-faith effort to comply with the provisions of the Eagle Act and to ensure the area-nesting golden eagle population is sustained. All nests are located on BLM-administered lands. No loss of golden eagles would occur as the nest removal would occur outside of the nesting season.

This ECP is a living document which will be updated and finalized after the current EIS process.

12.0 REFERENCES

Avian Power Line Interaction Committee (APLIC). 2012. *Reducing Avian Collisions with Power Lines: The State of the Art in 2012.* Edison Electric Institute and APLIC. Washington, D.C.

_____. 2006. *Suggested practices for Avian protection on Power Lines: The State of the Art in 2006.* Edison Electric Institute, APLIC, and the California Energy Commission. Washington D.C. and Sacramento, CA. 207pp.

Arnell, W. B. 1971. Prey utilization by nesting Golden Eagles (*Aquila chrysaetos*) in central Utah. Master's Thesis. Brigham Young Univ. Provo, UT.

Beecham, Jr., J. J. 1970. Nesting ecology of the Golden Eagle in southwestern Idaho. Master's Thesis. University of Idaho, Moscow.

Best, T.L. 1996. Lepus californicus. Mammalian Species, No. 530:1-10.

Bildstein, K.L., J.P. Smith, E.R. Inzunza, and R.R. Veit, 2008. Eds. State of North America’s Birds of Prey. Series in Ornithology No. 3. Nuttall Ornithological Club and the American Ornithologists’ Union. Cambridge Massachusetts. 466pp.

Blancher, P. J., K. V. Rosenberg, A. O. Panjabi, B. Altman, J. Bart, C. J. Beardmore, G. S. Butcher, D. Demarest, R. Dettmers, E. H. Dunn, W. Easton, W. C. Hunter, E. E. Iñigo-Elias, D. N. Pashley, C. J. Ralph, T. D. Rich, C. M. Rustay, J. M. Ruth, and T. C. Will. 2007. Guide to the Partners in Flight Population Estimates Database. Version: North American Landbird Conservation Plan 2004. Partners in Flight Technical Series No 5. http://www.partnersinflight.org/

Bloom, P. H. and S. J. Hawks. 1982. Food habits of nesting Golden Eagles in northeast California and northwest Nevada. Raptor Res. 16:110-115.

Brooks, M.L., and D.A. Pyke. 2001. Invasive plants and fire in the deserts of North America. In: Galley, K.M., and T.P. Wilson, eds. Proceedings in the Invasive Species Workshop: the Role of Fire in the Control and Spread of Invasive Species. Fire Conference 2000: the First National Conference on Fire Ecology, Prevention and Management.; 2000 November 27-December 1; San Diego, CA. Misc. Pub. No. 11, Tallahassee, FL: Tall Timbers Research Station: pp. 1-14.

Bureau of Land Management (BLM). 2012a. Final Environmental Impact Statement. Hycroft Mine Expansion Project. DOI-BLM-NV-WO30-2011-0001-EIS. Plan of Operations Number NVN-064641. July 2012.

_____. 2012b. Record of Decision and Plan of Operations Approval. Hycroft Mine Expansion Project. DOI-BLM-NV-WO30-2011-0001-EIS. Plan of Operations Number NVN-064641. August 2012.

_____. 2010. Memorandum of Understanding between the U.S. Department of the Interior, Bureau of Land Management and the U.S. Fish and Wildlife Service to Promote the Conservation of Migratory Birds. BLM MOU WO-230-2010-04. April, 2010. 14pp.

_____. 2004. Black Rock Desert-High Rock Canyon Emigrant Trail National Conservation Area and Associated Wilderness, and Other Contiguous Lands in Nevada. Record of Decision and Resource Management Plan. Accessed December 2012 via:http://www.blm.gov/pgdata/etc/medialib/blm/nv/field_offices/winnemucca_field_office/programs/planning/black_rock_nca_resource.Par.65040.File.dat/cover%20plus%20chapters%201%202%203.pdf

Chambers, J.C. 2008. Fire and the Great Basin. USDA Forest Service General Technical Report. RMRS-GTR-205. Pp-33-37.

Dixon, J. B. 1937. The Golden Eagle in San Diego County, California. Condor 39:49-56.

Driscoll, D. E. 2010. Protocol for golden eagle occupancy, reproduction, and prey population assessment. American Eagle Research Institute, Apache Jct., AZ. 55 pp.

Farmer, C.J., L.J. Goodrich, E.R. Inzunza and J.P. Smith. 2008. Conservation Status of North Americ'a Birds of Prey. pp. 303-491. *in* Bildstein, K.L., J.P. Smith, E.R. Inzunza, and R.R. Veit, 2008. Eds. State of North America's Birds of Prey. Series in Ornithology No. 3. Nuttall Ornithological Club and the American Ornithologists' Union. Cambridge, Massachusetts. 466pp.

Franson, J. C., L. Sileo, and N. J. Thomas. 1995. Causes of eagle deaths. Pages 68 *in* Our living resources. (LaRoe, E. T., G. S. Farris, C. E. Puckett, P. D. Doran, and M. J. Mac, Eds.) U.S. Dep. Int., Natl. Biol. Serv. Washington, D.C.

Gordon, S. 1955. The Golden Eagle; king of birds. 1st Am. ed. Citadel Press, New York.

Gross, J.E., L.C Stoddard, and F.H. Wagner. 1974. Demographic analysis of a northern Utah jackrabbit population. Wildlife Monographs 40:1-68.

Herron, G.A., C.A. Mortimore, and M.S. Rawlings. 1985. *Nevada Raptors, Their Biology and Management.* Nevada Department of Wildlife. Biological Bulletin No. 8. Reno, Nevada.

Herron, G. B. S.J. Stiver and R. Turner. 1980. Population surveys, species distribution, and key habitats of selected nongame species. Nevada Department of Wildlife. Job Performance Report.

Herron, G. B. and P.A Lucas. 1979. Population surveys, species distribution, and key habitats of selected nongame species. Nevada Department of Wildlife. Job Performance Report.

Hickman, G. L. 1968. The ecology and breeding biology of the Golden Eagle in southwestern Idaho and southeastern Oregon. draft no. 2. U.S. Department of the Interior, Bureau of Sport Fisheries and Wildlife. Washington, D.C.

JBR Environmental Consultants, Inc. Unpublished. 2013 Golden Eagle Nest Monitoring Hycroft Mine Expansion Project. Conducted for Allied Nevada Gold Corporation.

_____. Unpublished. 2012 Hycroft Baseline Surveys. Conducted for Allied Nevada Gold Corporation.

_____. 2011a. *Baseline Survey Report. Hycroft Mine, Mine Expansion Project, Humboldt and Pershing Counties, Nevada.* Prepared for Allied Nevada Gold Corporation. 23 pp.

_____. 2011b. Baseline Survey *Report Addendum, 2011 Nesting Golden Eagle Survey and Bat Survey, Hycroft Mine, Mine Expansion Project, Humboldt and Pershing Counties, Nevada.* Prepared for Allied Nevada Gold Corporation. 6 pp. Katzner, T., P. Turk, A. Duerr, D. Brandes, T. Miller, and M. Lanzone. 2012. Golden eagle home range, habitat use, demography, and renewable energy development in the California desert. An interim report submitted to the: Bureau of Land Management, California State Office (CASO). BLM Solicitation L11PS01121.

Kochert, M. N. and K. Steenhof. 2012. Frequency of nest use by Golden Eagles in Southwestern Idaho. J. Raptor Res. 46(3):239-247.

_____. 2002. Golden Eagles in the U.S. and Canada; status, trends conservation challenges. J. Raptor Res. 36(supplement):33-41.

Kochert, M. N., K. Steenhof, C. L. Mcintyre and E. H. Craig. 2007. Golden Eagle (Aquila chrysaetos), The Birds of North America Online (A. Poole, Ed.). Ithaca: Cornell Lab of Ornithology; Retrieved from the Birds of North America Online: http://bna.birds.cornell.edu/bna/species/684doi:10.2173/bna.684

L. B. Carpenter, and J. M. Marzluff. 1999. Effects of fire on Golden Eagle territory occupancy and reproductive success. Jour. Wildlife Management 63:773-780.

Lehman, R.N., P.L. Kennedy, and J.A. Savidge. 2007. The state of the art in raptor electrocution research: a global review. Biological Conservation 136:159-174.

Lockie, J.D. and D.A. Radcliffe. 1964. Insecticides and Scottish Golden Eagles. British Birds 57:89-102.

Marzluff, J. M., S. T. Knick, M. S. Vekasy, L. S. Schueck, and T. J. Zarriello. 1997. Spatial use and habitat selection of Golden Eagles in southwestern Idaho. Auk 114:673-687.

McGahan, J. 1968. Ecology of the Golden Eagle. Auk 85: 1-12.

Mcintyre, C. L. and L. G. Adams. 1999. Reproductive characteristics of migratory Golden Eagles in Denali National Park, Alaska. Condor 101:115-123.

Miller, J.D., and H. Safford. 2012. Trends in wildfire severity: 1984 to 2010 in the Sierra Nevada, Modoc Plateau, and southern Cascades, California, USA. Fire Ecology 8(3): 41-57.

Millsap, B.A., G.S. Zimmerman, J.R. Sauer, R.M. Nielson, M. Otto, E. Bjerre, and R. Murphy. 2013. Golden eagle population trends in the western United States: 1968-2010. Journal of Wildlife Management, 77(7):1436-1448. Doi: 10.1002/jwmg.588.

Nevada Department of Wildlife (NDOW). Unpublished. Results of Hycroft-area golden eagle aerial nest survey. Provided to JBR Environmental Consultants, 2011.

Newmont North America. 2012. *Twin Creeks Mine Golden Eagle (Aquila chrysaetos) Conservation Plan, Draft v1.0.* 50pp.

Page, J.L. and D.L. Siebert. 1973. Inventory of golden eagle nests in Elko County, Nevada. Transactions of California-Nevada Wildlife. 8pp.

Pagel, J.E., D.M. Whittington, and G.T. Allen. 2010. Interim golden eagle technical guidance: Inventory and monitoring protocols; and other recommendations in support of golden eagle management and permit issuance. Division of Migratory Bird Management. U.S. Fish and Wildlife Service. 26pp.

Platt, S. W. 1984. Energy development and raptor populations on and adjacent to the Black Butte Coal Co. mine permit area. Unpubl. Prog. Rep. Black Butte Coal Co. Point of Rocks, WY.

Reynolds III, H. V. 1969. Population status of the Golden Eagle in south-central Montana. Master's Thesis. Univ. of Montana, Missoula.

Rich, T. D., C. J. Beardmore, H. Berlanga, P. J. Blancher, M. S. W. Bradstreet, G. S. Butcher, D. W. Demarest, E. H. Dunn, W. C. Hunter, E. E. Iñigo-Elias, J. A. Kennedy, A. M. Martell, A. O. Panjabi, D. N. Pashley, K. V. Rosenberg, C. M. Rustay, J. S. Wendt, T. C. Will. 2004. Partners in Flight North American Landbird Conservation Plan. Cornell Lab of Ornithology. Ithaca, NY. Partners in Flight website. http://www.partnersinflight.org/cont_plan/ (VERSION: March 2005).

Ryser, F. A. 1985. *Birds of the Great Basin, A Natural History.* University of Nevada Press. 604pp.

Sacramento County. 2010. *South Sacramento Habitat Conservation Plan Working Draft.* Available online at: http://www.per.saccounty.net/PlansandProjectsIn-Progress/ Pages/SSHCPTablesofContent.aspx

Slater, S. J., W. Frye Christensen, R. N. Knight, K. Keller, and R. MacDuff. 2013. Great Basin bird species-at-risk and invasive species management partnership final report-phase 3. Department of Defense, Legacy Resources Management Program (Project #10-102).

Smith, D. G. and J. R. Murphy. 1979. Breeding responses of raptors to jackrabbit density in the eastern Great Basin Desert of Utah. Raptor Res. 13:1-14.

Steenhof, K., M. N. Kochert, and T. L. McDonald. 1997. Interactive effects of prey and weather on Golden Eagle reproduction. J. Anim. Ecol. 66:350-362.

Steenhof, K., M. N. Kochert, and M. Q. Moritsch. 1984. Dispersal and migration of southwestern Idaho raptors. J. Field Ornithol. 55:357-368.

United States Fish and Wildlife Service (USFWS). 2016. Programmatic Environmental Impact Statement for the Eagle Rule Revision. Division of Migratory Bird Management, 5275 Leesburg Pike, Falls Church, VA 22041-3803

_____. 2013. Eagle Conservation Plan Guidance. Module 1 – Land-based Wind Energy, Version 2. 103pp.

_____. 2012. Eagle Conservation Plan Guidance Module 1 – Land-based Wind Energy Technical Appendix. (Draft under review) 77pp.

_____. 2011. Draft Eagle Conservation Plan Guidance. 105pp.

_____. 2009a. Final environmental assessment. Proposal to permit take provided under the Bald and Golden Eagle Protection Act. U.S. Fish and Wildlife Service, Division of Migratory Bird Management, Washington D.C., USA.

_____. 2009b. Eagle permits; take necessary to protect interests in particular localities. Federal Register 74(175):46836-46879.

_____. Protection of eagles; definition of “Disturb.” Federal Register 72(107): 31132-31140.Utah Legacy Raptor Project. 2013. Utah west desert golden eagle management recommendations. Department of Defense, Legacy Resources Management Program (Project #10-102).

United States Geological Survey (USGS). 2011. National Gap Analysis Program. Southwest Regional GAP Analysis Project—Land Cover Descriptions. RS/GIS Laboratory, College of Natural Resources, Utah State University. http://gapanalysis.usgs.gov.

Watson, J. 1997. The Golden Eagle. 1st ed. T and A. D. Poyser, London, U.K.

Wildlife Resource Consultants, LLC. Unpublished. Hycroft Mine 2017 Raptor Nesting Surveys and Golden Eagle Monitoring Report. Prepared for Hycroft Resources and Development, Inc. September 6, 2017.

_____. Unpublished. Hycroft Golden Eagle Mitigation Opportunties. Technical Memorandum. Prepared for Hycroft Resources and Development, Inc. August 11, 2017.

_____. Unpublished. Hycroft Mine 2016 Raptor Nesting Surveys and Golden Eagle Monitoring Report. Prepared for Hycroft Resources and Development, Inc. January 19, 2017.

_____. Unpublished. Hycroft Mine 2015 Raptor Nesting Surveys and Golden Eagle Monitoring Report. Prepared for Hycroft Resources and Development, Inc. September 28, 2015.

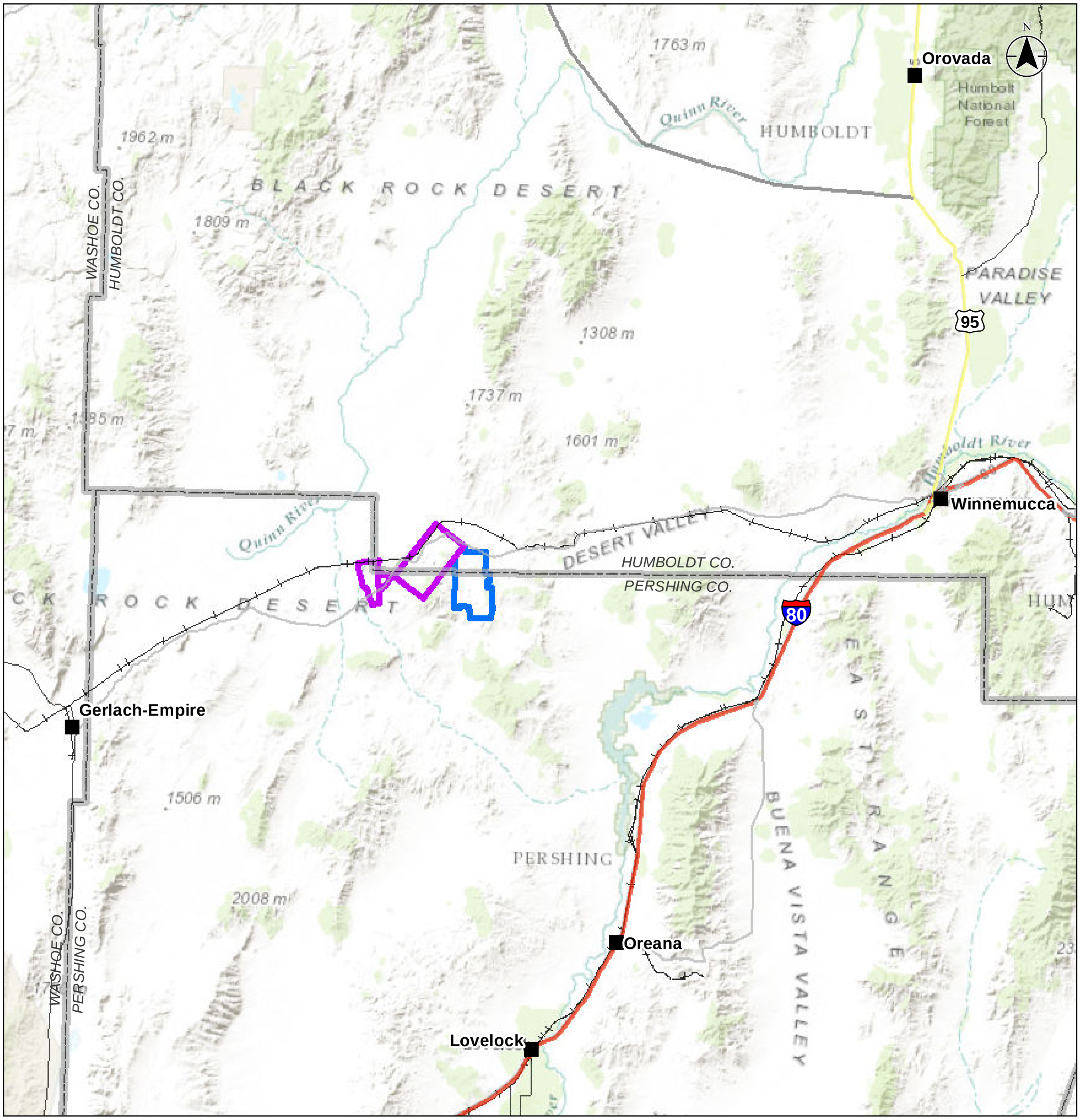
_____. Unpublished. Hycroft Mine 2014 Raptor Nesting Surveys and Golden Eagle Monitoring Report. Prepared Hycroft Resources and Development, Inc.

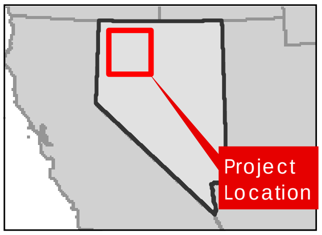
Worley, D.K. 1984. Raptor breeding biology and responses to transmission lines in northern Nevada. Master’s Thesis. University of Nevada, Reno. 414pp.

APPENDIX A

Figures

X:\NV\Clients\Allied\Hycroft\Hycroft Mine Phase II Expansion 203703039\MXDs\WorkingMXDs\Biological\ECP\Fig 1 Project Location.mxd Revised: 2015-09-11 By: cjohnson





☐ Authorized Project Area

☐ Proposed Phase II Expansion Plan Area

0 7.5 15 miles

1:950,400 (at original document size of 8.5x11)

Project Location Humboldt & Pershing Co. NV	Project No.: 203703039 Prepared by CJ on 9/11/2015 Review by NK on 9/11/2015

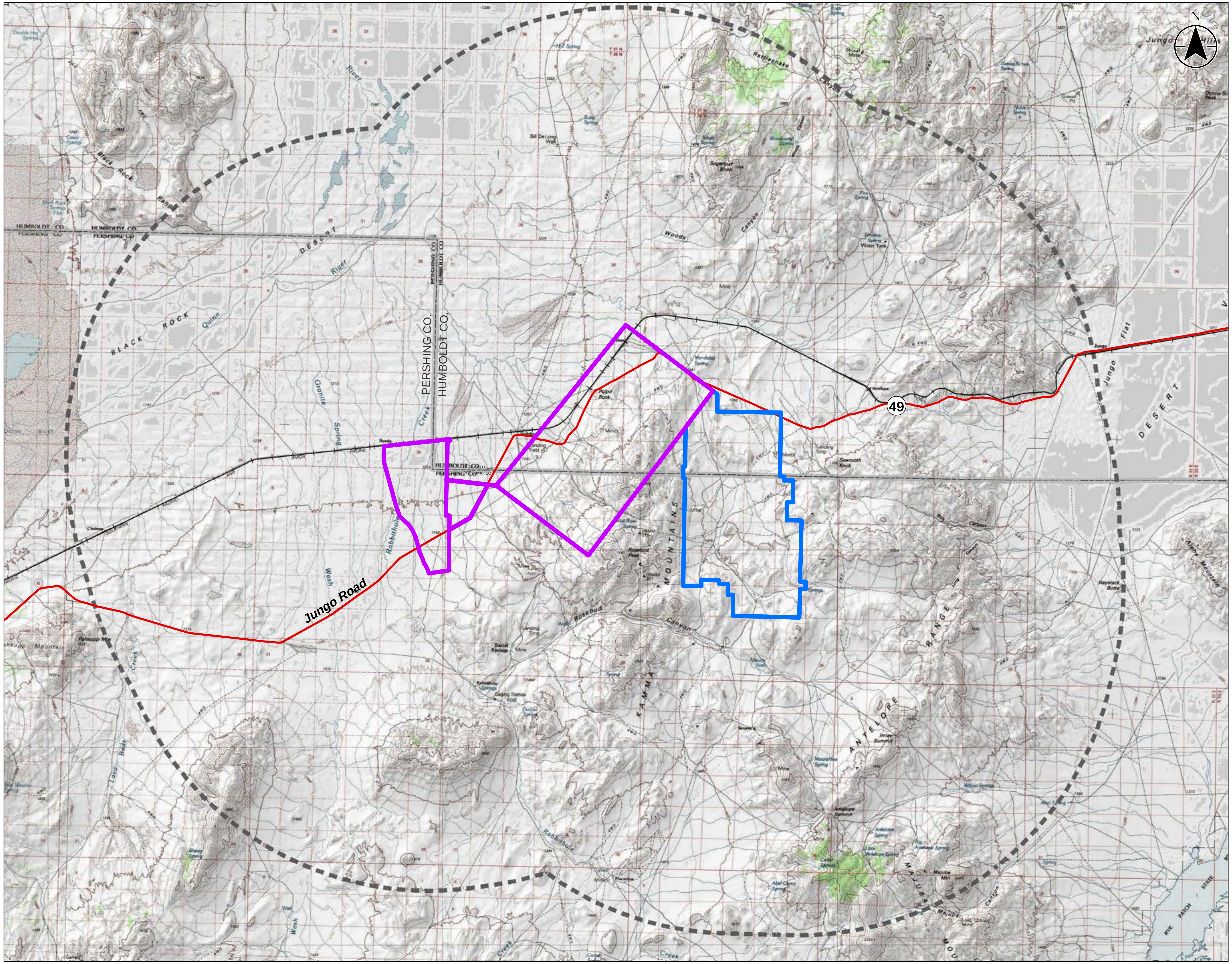
Client/Project

Hycroft Resources and Development, Inc.
Eagle Conservation Plan

Figure No./Title

Figure 1
Project Location

Notes
1. Coordinate System: NAD 1983 UTM Zone 11N
2. Base features produced under license with the Ontario Ministry of Natural Resources © Queen's Printer for Ontario, 2013.
3. Orthoimagery © First Base Solutions, 20xx.



▭ Authorized Project Area

▭ Proposed Phase II Expansion Plan Area

▭ 10-mile Buffer around POO Area and Phase II Expansion Area

0 3½ 7 Miles

1 in = 17,000 feet (At original document size of 11x17)

Notes
1. Coordinate System: NAD 1983 UTM Zone 11N
2. Basemap: Copyright:© 2013 National Geographic Society, i-cubed

Project Location
Humboldt &
Pershing Counties, NV

Project No.: 203703039
Prepared by JT on 9/14/2015
Tech. Review by NK on 9/14/2015

Client/Project
Hycroft Resources and Development, Inc.
Eagle Conservation Plan

Figure Number/Title

Figure 2
Study Area

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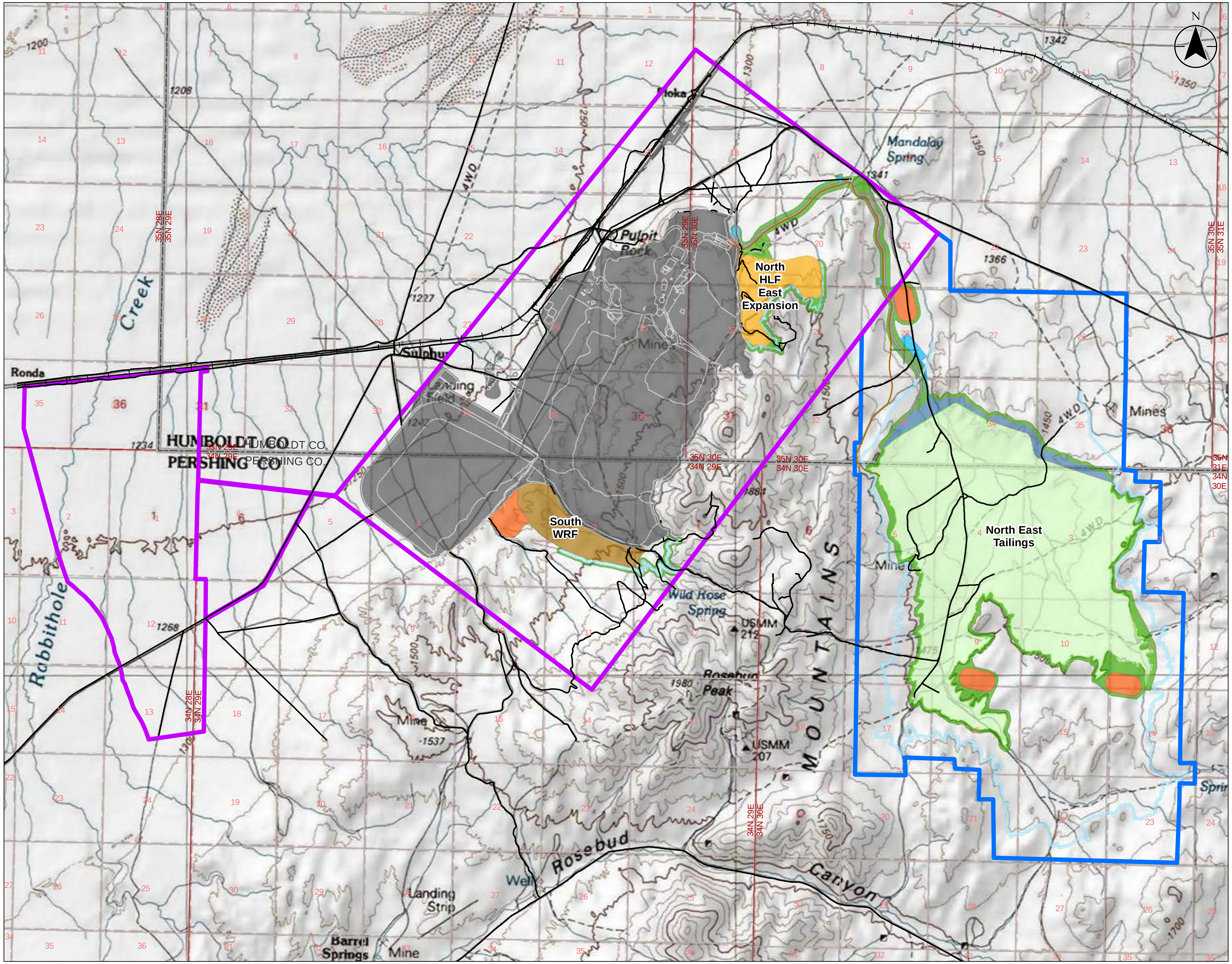


■ Authorized Project Area
■ Proposed Phase II Expansion Plan Area
— Road
┼ Railroad
— Proposed Conveyance Ditch
■ Pre-2015 Surface Disturbance (Existing/Authorized/Pending Authorization)

Phase II Proposed Disturbance and Facilities

■ Growth Media Stockpile
■ Haul Road
■ Leach Pad
■ Light Duty Road
■ Miscellaneous
■ Pond
■ Stormwater Diversion
■ Tailings
■ Tailings Dam
■ Waste Rock Dump

0 6,000 12,000 Feet

1 in = 6,000 feet (At original document size of 11x17)

Notes
1. Coordinate System: NAD 1983 UTM Zone 11N
2. Basemap: Copyright:© 2013 National Geographic Society, i-cubed

Project Location
Humboldt &
Pershing Counties, NV

Project No.: 203703039
Prepared by JT on 9/14/2015
Tech. Review by NK on 9/14/2015

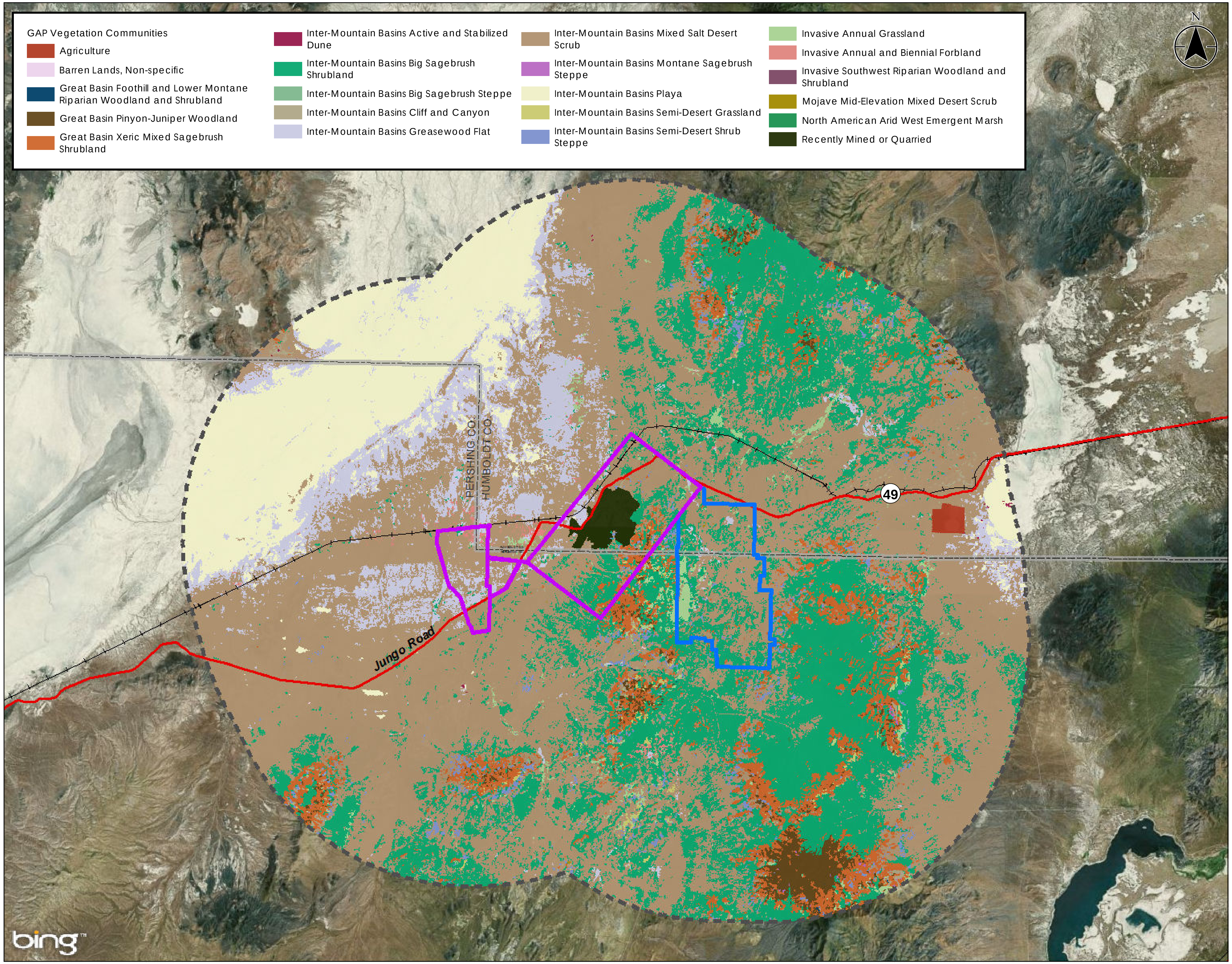
Client/Project

Hycroft Resources and Development, Inc.
Eagle Conservation Plan

Figure Number/Title

Figure 3
Project Surface

X:\NV\Clients\Allied\Hycroft_Mine_Phase_II_Expansion_203703039\MXDs\WorkingMXDs\Biological\ECP\Fig_3_Proposed New_and_Existing_Facilities.mxd Revised: 2015-09-14 By: jtrook



🟪 Authorized Project Area

🟦 Proposed Phase II Expansion Plan Area

▭ 10-mile Buffer around POO Area and Phase II Expansion Area

0 3½ 7 Miles

1 in = 21,000 feet (At original document size of 11x17)

Notes
1. Coordinate System: NAD 1983 UTM Zone 11N
2. Basemap: NAIP 2013 Image

Project Location
Humboldt &
Pershing Counties, NV

Project No.: 203703039
Prepared by JT on 9/11/2015
Tech. Review by NK on 9/11/2015

Client/Project

Hycroft Resources and Development, Inc.
Eagle Conservation Plan

Figure Number/Title

Figure 4
Hycroft Mine Expansion Buffer Area Southwest ReGAP Vegetation

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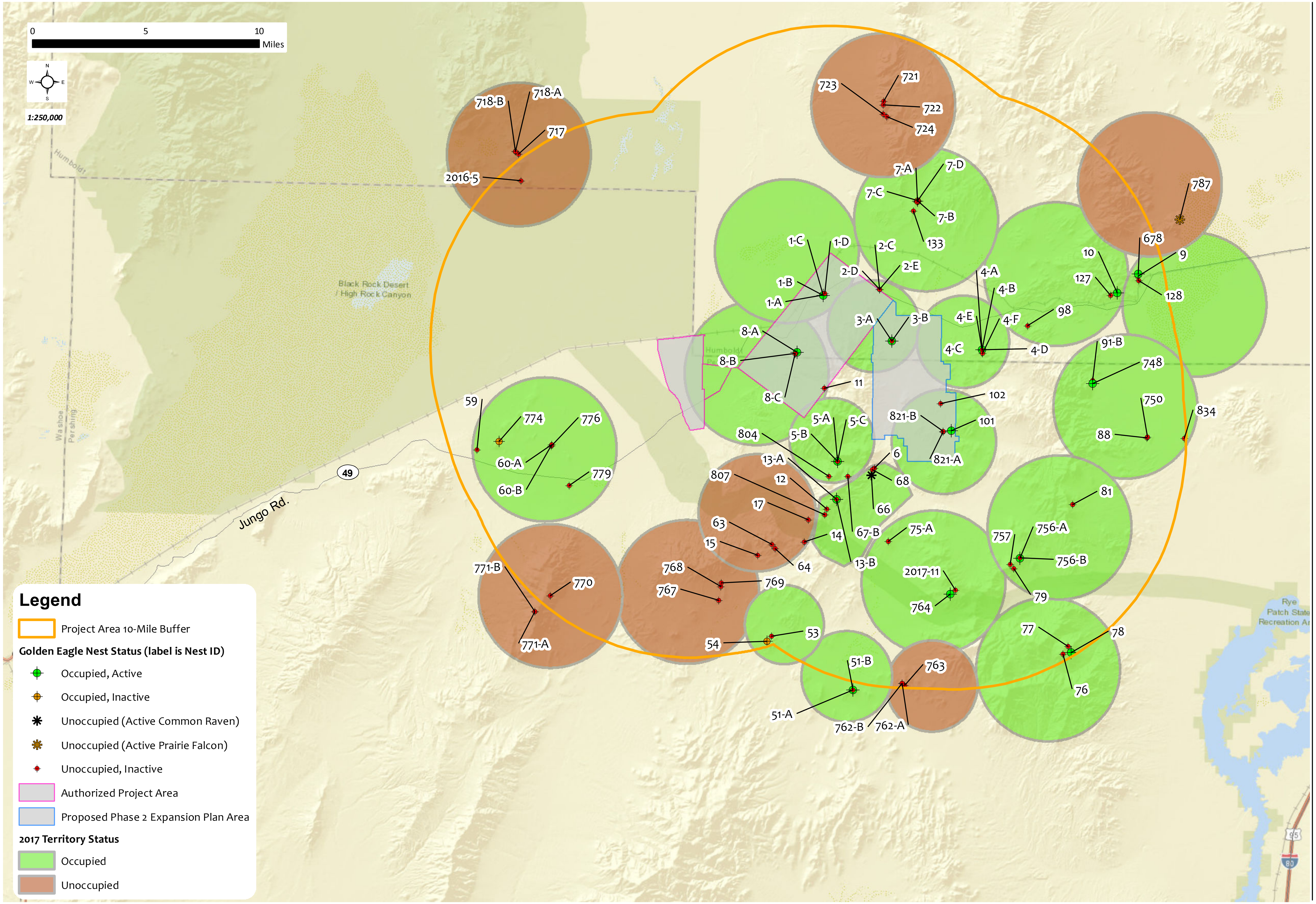

Hycroft Mine Eagle Conservation Plan

**Figure 5.
2017
Golden Eagle
Nest Status and
Estimated
Territories
and Occupancy**

Base data ESRI and National Geographic Society.
Other data provided by Allied and Stantec.
Projection UTM NAD 83.

This map contains confidential information.

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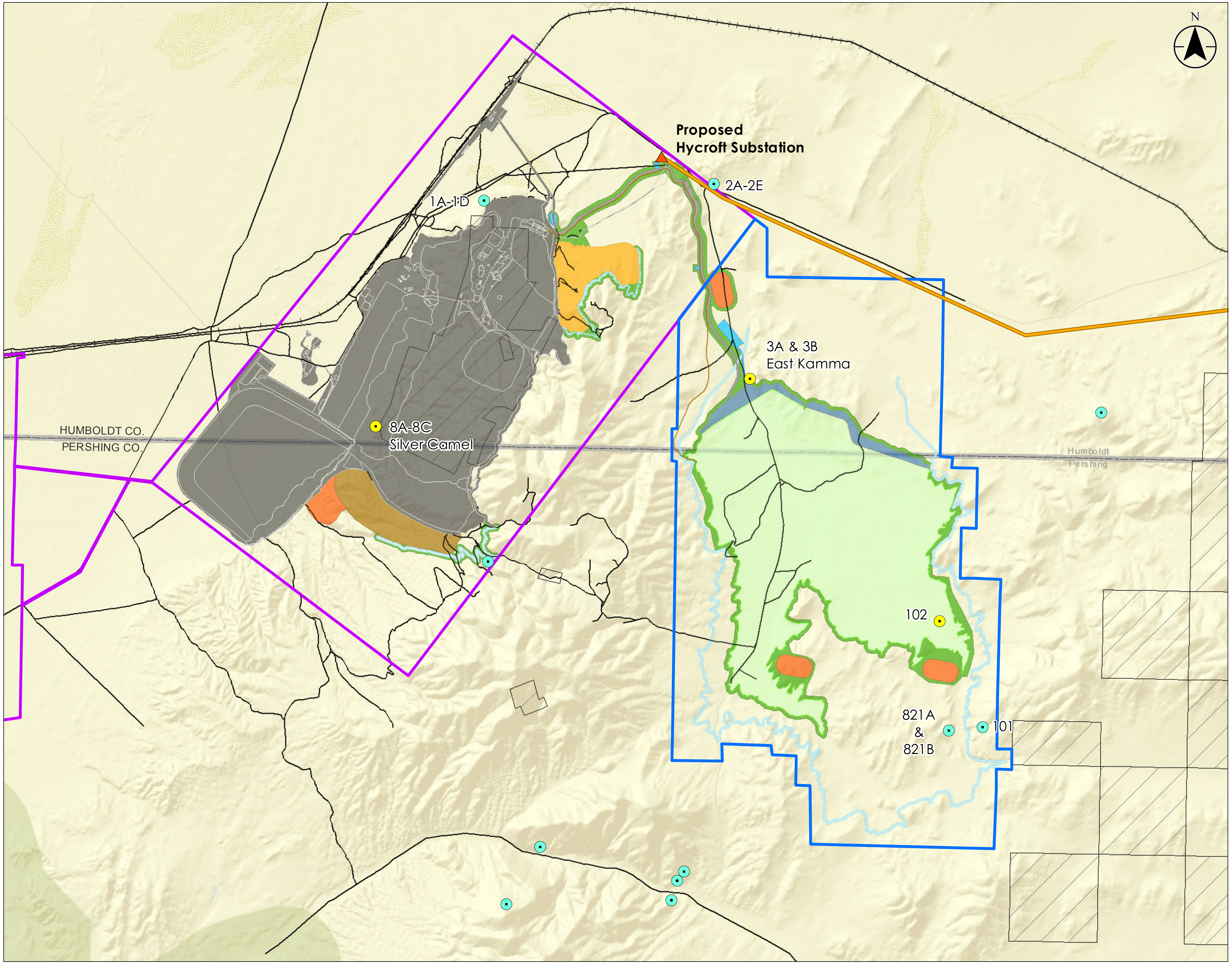
Wildlife Resource Consultants LLC
P. O. Box 68
Cedarville, CA 96104



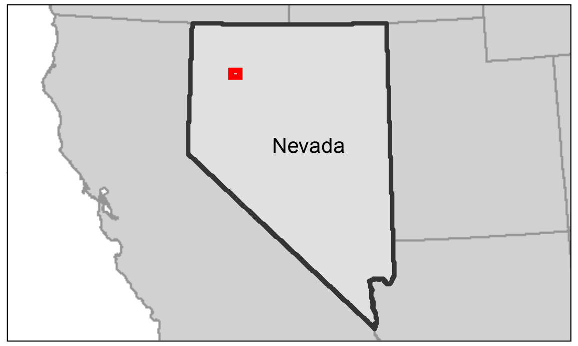
● Golden Eagle Nests
● Golden Eagle Nests Proposed For Take
▭ Authorized Project Area
▭ Proposed Phase II Expansion Plan Area
▨ Private
— Proposed 345 kV Transmission Line
— Road
—+— Railroad
— Proposed Conveyance Ditch
■ Existing and Authorized Disturbance

Proposed Disturbance and Facilities

■ Growth Media Stockpile
■ Haul Road
■ Leach Pad
■ Light Duty Road
■ Miscellaneous
■ Pond
■ Stormwater Diversion
■ Tailings
■ Tailings Dam
■ Waste Rock Dump

0 3,000 6,000
Feet
1 in = 6,000 feet (At original document size of 11x17)

Notes
1. Coordinate System: NAD 1983 UTM Zone 11N
2. Basemap: 2015 National Agriculture Imagery Program (NAIP)



Project Location
Humboldt &
Pershing Counties, NV

Client/Project
Hycroft Resources and Development, Inc.
Eagle Conservation Plan

Figure Number/Title

Figure 6
Golden Eagle Nests Proposed For Take

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APPENDIX B

Golden Eagle Summary of Nest Data 2010 to 2017

Table A-1 Summary of Nest Data 2010 to 2017
Taken from Wildlife Resource Consultants 2017 Raptor Nesting Surveys and Golden Eagle Monitoring Report

Notes: This database created by WRC 2017. Represents all potential raptor nests identified in 2017 surveys.
Prior nest status from several sources, including JBR GIS databases and reports (2010-2013) and WRC databases and reports (2014-2016)
* NS represents not surveyed

Site_ID	E_UTM_83	N_UTM_83	type_	last_act	goea_terr	nest_size	nest_cond	nest_prot	nest_ht	sub_ht	occ_2010	act_2010	occ_2011	act_2011	occ_2012	act_2012	occ_2013	act_2013	occ_2014	act_2014	occ_2015	act_2015	occ_2016	act_2016	occ_2017	act_2017	2017_1ad	2017_1adsp	2017_1adbeh	2017_1recus	2017_1egg	2017_1yo	2017_1age	2017_1ph	2017_1no	2017_2ad	2017_2adsp	2017_2adbe	2017_2recus	2017_2young	2017_2age	2017_2ph	2017_2no
6			GOEA	goea	24	3	I	CB	40	50	goea	act	goea	act	goea	act	unocc	inact	goea	inact	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	30-31	nest 6 changed to occupied, inactive in 201	0	0	0	0	0	0	none	
9			GOEA	goea	5	3	I	CB	30	35	ns	ns	goea	act	unocc	inact	goea	inact	unocc	inact	goea	act	unocc	inact	unocc	inact	0	0	0	0	0	0	0	191		0	0	0	0	0	0	none	
10			GOEA	goea	4	3	I	CO/CB	20	30	ns	ns	goea	act	ns	ns	unocc	inact	unocc	inact	unocc	inact	goea	inact	goea	act	1	goea	f	0	0	0	0	186-187		1	goea	p	0	1	5-6	75-77	
11			GOEA	none	1	3	D	CB	15	40	ns	ns	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	90		1	prfa	b	0	3	?	99-105	
12			GOEA	goea	24	3	I	CB	20	25	ns	ns	unocc	inact	unocc	inact	goea	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	1	goea	P	0	0	0	0	24-25	1 adult perched on rock above nest	0	0	0	0	0	0	none	
14			GOEA	goea	23	3	I	CB	15	25	ns	ns	unocc	inact	unocc	inact	unocc	inact	unocc	inact	goea	inact	goea	inact	unocc	inact	0	0	0	0	0	0	0	22		0	0	0	0	0	0	none	
15			GOEA	goea	23	3	D	CB	75	125	ns	ns	goea	act	ns	ns	unocc	inact	goea	act	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0		40-42		0	0	0	0	0	0	none	
17			GOEA	none	23	3	I	CB	40	45	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	23		0	0	0	0	0	0	none	
52-A			SR	none		1	D	CO/CB	5	20	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	9	crashed	0	0	0	0	0	0	none	
52-B			CORA	none		1	I	CB	15	30	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	10		0	0	0	0	0	0	none	
53			GOEA	goea	22	3	I	CB	5	10	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	goea	act	goea	act	unocc	inact	0	0	0	0	0	0	0	12		0	0	0	0	0	0	none	
54			GOEA	none	22	2	I	CB	5		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	goea	inact	1	goea	b/i	0	0	0	0	11	1 adult on nest	0	0	0	g	0	0	none	
55			CORA	none		0	I	CH	8	40	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	13		0	0	0	0	0	0	none	
56			CORA	none		0	I	CH	80	200+	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	14		0	0	0	0	0	0	none	
57			SR	none		0	D	CB	30	80	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	none		0	0	0	0	0	0	none	
58			LR	cora		2	I	CB	5	10	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	cora	act	cora	act	0	0	0	0	0	0	0	52		1	cora	i/b	0	0	0	none	
59			GOEA	none	12	3	D	CB	15	30	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	none	nest gone, land slide	0	0	0	0	0	0	none	
61			FEHA	none		3	I	O	20	30	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	55		0	0	0	0	0	0	none	
62			CORA	cora		0	I	CB	10	20	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	cora	act	unocc	inact	unocc	inact	0	0	0	0	0	0	0	60		0	0	0	0	0	0	none	
63			GOEA	goea	23	2	I	CB	10	20	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	goea	act	unocc	inact	0	0	0	0	0	0	0	158		0	0	0	0	0	0	none	
64			GOEA	none	23	3	D	CB	50	60	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	159-160		0	0	0	0	0	0	none	
65			LR	cora		2	I	CO/CB	10	15	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	cora	act	unocc	inact	unocc	inact	0	0	0	0	0	0	0	21		0	0	0	0	0	0	none	
66			GOEA	cora	24	3	I	CB	20	25	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	goea	act	goea	act	cora	act	0	0	0	g	0	0	0	26-28		1	cora	b	0	1	?	none	
67-A			CORA	cora		0	I	CB	50	120	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	cora	act	unocc	inact	unocc	inact	0	0	0	0	0	0	0	31		0	0	0	0	0	0	none	
67-B			GOEA	none	21	3	I	CB	50	75	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	0	0	0	0	0	0	0	32		0	0	0	0	0	0	none	
68			GOEA	none	24	3	I	CB	10	20	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	29		0	0	0	0	0	0	none	
74			SR	cora		1	I	CO/CB	5	15	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	cora	act	unocc	inact	0	0	0	0	0	0	0	64-65		0	0	0	0	0	0	none	
75-A			GOEA	none	8		D				ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	138-139		0	0	0	0	0	0	none	
75-B			CORA	cora		1	I	CO/CB	10	15	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	cora	act	cora	act	unocc	inact	0	0	0	0	0	0	0	138-139		0	0	0	0	0	0	none	
75-C			CORA	none		0	I	CO/CB	10	15	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	138-139		0	0	0	0	0	0	none	
76			GOEA	none	14	3	I	CB	40	80	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	167		0	0	0	0	0	0	none	
77			GOEA	none	14	3	I	CB	30	50	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	169-170		0	0	0	0	0	0	none	
78			GOEA	goea	14	3	I	CB	40	50	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	goea	act	goea	inact	goea	act	0	0	0	0	0	0	0	168		1	goea	feed	0	2	7-8	141-145	
79			GOEA	goea	15	3	I	CB	30	50	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	goea	act	unocc	inact	unocc	inact	0	0	0	0	0	0	0	161		0	0	0	0	0	0	none	
81			GOEA	none	15	3	I	CB	20	40	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	goea	inact	goea	inact	unocc	inact	0	0	0	0	0	0	0	173		0	0	0	0	0	0	none	
82			CORA	prfa		0	I	CB	50	70	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	cora	act	prfa	act	unocc	inact	0	0	0	0	0	0	0	174-175		0	0	0	0	0	0	none	
83			SR	none		1	I	CB	30	35	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	176		0	0	0	0	0	0	none	
84			SR	cora		1	I	CO/CB	15	60+	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	cora	act	unocc	inact	0	0	0	0	0	0	0	178		0	0	0	0	0	0	none	
85-A			CORA	cora		0	I	CH	15	40	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	cora	act	unocc	inact	unocc	inact	0	0	0	0	0	0	0	179		0	0	0	0	0	0	none	
85-B			CORA	none		0	I	CH	15	40	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	179		0	0	0	0	0	0	none	
86			SR	none		0	DET	CB	3	10	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	214-216		0	0	0	0	0	0	none	
88			GOEA	goea	7	3	I	CB	10	15	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	goea	act	unocc	inact	0	0	0	0	0	0	0	212		0	0	0	0	0	0	none	
89			SR	none		1	I	CB	15	25	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	180		0	0	0	0	0	0	none	
90			SR	prfa		0	I	CO/CB	20	25	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	prfa	act	unocc	inact	0	0	0	0	0	0	0	181		0	0	0	0	0	0	none	
91-A			SR	none		1	I	CO/CB	15	20	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	205		0	0	0	0	0	0	none	
91-B			GOEA	none	7		D				ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	0	0	0	0	0	0	0	205	destroyed	0	0	0	0	0	0	none	
92			FEHA	feha		3	I	O	25	25	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	feha	act	0	0	0	0	0	0	0	156		0	0	0	0	1	?	132-133	
93			FEHA	none		3	I	O	8	8	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	157		0	0	0	0	0	0	none	
94			FEHA	none		3	I	O	25	25	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	155		0	0	0	0	0	0	none	
95			CORA	cora		0	I	CO/CB	20	22	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	cora	act	unocc	inact	unocc	inact	0	0	0	0	0	0	0	152		0	0	0	0	0	0	none	
96			LR	none		2	I	CH	5	10	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	none	crashed and rat looking sticks	1	cora	i/b	0	0	0	none	
97			FEHA	feha		3	I	O	4	4	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	feha	act	unocc	inact	0	0	0	0	0	0	0	150		0	0	0	0	0	0	none	
98			GOEA	none	4	3	I	CB	90	100+	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	149		0	0	0	0	0	0	none	
99			CORA	none		0	I	CB	10	14	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	146-148		0	0	0	0	0	0	none	
100			CORA	none		0	D	CB	10	15	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	none	nest gone	0	0	0	0	0	0	none	
101			GOEA	goea	16	3	I	CB	10	20	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	goea	act	1	goea	i/b	0	0	0	0	136		0	0	0	0	2	10-11	123-126	
102			GOEA	none	16	3	D	CO/CB	4	8	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	133	prairie falcon flying in vicinity	0	0	0	0	0	0	none	
103			SR	prfa		0	I	CH	15	20	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	prfa	act	prfa	act	unocc	inact	0	0	0	0	0	0	0	132	prairie falcon flying in vicinity	0	0	0	0	0	0	none	
104			CORA	cora		0	D	PPOLE	60	60	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	cora	act	unocc	inact	unocc	inact	0	0	0	0	0	0	0	none		0	0	0	0	0	0	none	
105			CORA	cora		0	D	PPOLE	60	60	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	cora	act	unocc	inact	unocc	inact	0	0	0	0	0	0	0	none		0	0	0	0	0	0	none	
106			CORA	none		0	I	CO/CB	20	40	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	none		0	0	0	0	0	0	none	
107			CORA	none		1	I	CO/CB	6	8	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	none		0	0	0	0	0	0	none	
109			CORA	none		0	D				ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	63		0	0	0	0	0	0	none	
110			FEHA	feha		3	I	O	30	30	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	feha	act	0	0	0	0	0	0	0	none		1	feha	b	0	2	?	117-118	
111			SR	prfa		0	I	CO/CB	25	40	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	prfa	act	prfa	act	prfa	act	0	0	0	0	0	0	0	114	prairie falcon	0	prfa	0	0	3	?	none	
112			SR	none		1	DET	CB	10	30	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	none		0	0	0	0	0	0	none	landslide took out nest
113			LR	none		2	I	CB	5	30	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	116		0	0	0	0	0	0	none	landslide took out nest
114			LR	none		2	I	CH	15	20	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	71	prairie falcon on ledge above nest	0	0	0	0	0	0	none	
115			SR	none		0	D	CH	30	45	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	prfa	act	unocc	inact	unocc	inact	0	0	0	0	0	0	0	none	nest not found; one adult stooped down fa	0	0	0	0	0	0	none	
117			SR	cora		1	I	CH	40	45	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	cora	act	0	0	0	0	0	0	0	76		1	cora	i/b	0	0	0	none	
118			SR	none		1	I	CH	60	65	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	77		0	0	0	0	0	0	none	
119			SR	none		1	DET	CO/CB	10	15	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	none		0	0	0	0	0	0	none	
120			SR	prfa		1	I	CO/CB	10	15	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	prfa	act	unocc	inact	0	0	0	0	0	0	0	89		0	0	0	0	0	0	none	
121			SR	none		1	I	CH	10	15	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	87-88		0	0	0	0	0	0	none	
122			SR	prfa		0	I	CB	50	70	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	prfa	act	prfa	act	unocc	inact	0	0	0	0	0	0	0	91	lots snow on nest	0	0	0	0	0	0	none	
123			SR	none		1	DET	CB	50	70	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	92		0	0	0	0	0	0	none	
124			LR	none		2	D	CH	100+	200+	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	104		0	0	0	0	0	0	none	
125			CORA	none		0	I	CH	20	30	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	95		0	0	0	0	0	0	none	
126			CORA	none		0	I	CH	190+	200+	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	101		0	0	0	0	0	0	none	
127			GOEA	none	4	3	I	CB	25	30	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	185		0	0	0	0	0	0	none	
128			GOEA	none	5	3	I	CO/CB	15	30	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	goea	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	188		0	0	0	0	0	0	none	
129			LR	prfa		2	I	CH	20	40	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	prfa	act	unocc	inact	0	0	0	0	0	0	0	184		1	cora	i/b	0	0	0	none	
131			FEHA			3	I	O	10	10	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	204	two eagles seen flying in the vicinity, but n	0	0	0	0	0	0	none	
132			LR	none		3	I	CB/O	10	13	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	198		0	0	0	0	0	0	none	
133			GOEA	none	9	3	DET	CB	40	45	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	118		0	0	0	0	0	0	none	
134			CORA	prfa		0	I	CO/CB	10	25	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	prfa	act	unocc	inact	0	0	0	0	0	0	0	119-120	small pile of sticks above and left of nest,	0	0	0	0	0	0	none	
138			FEHA	none		3	I	O	40	40	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	115		0	0	0	0	0	0	none	
678			GOEA	goea	5	3	I	CB	30	50	ns	ns	ns	ns	ns	ns	goea	act	unocc	inact	unocc	inact	unocc	inact	goea	act	1	goea	i/b	0	0	0	0	192-194		0	goea	0	0	2	9-10	78-81	
717			GOEA	goea	10	3	I	CB	40	100	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	goea	act	unocc	inact	0	0	0	0	0	0	0	105-106		0	0	0	0	0	0	none	
721			GOEA	goea	13	3	I	CB	20	100	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	goea	act	unocc	inact	0	0	0	0	0	0	0	111		0	0	0	0	0	0	none	
722			GOEA	goea	13	3	I	CO/CB	40	80	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	goea	act	unocc	inact	unocc	inact	0	0	0	0	0	0	0	112		0	0	0	0	0	0	none	
723			GOEA	none	13	3	I	CO/CB	80	90	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	113		0	0	0	0	0	0	none	
724			GOEA	goea	13	3	DET	CB	150+	200+	ns	ns	ns	ns	ns	ns	unocc	inact	goea	act	unocc	inact	unocc	inact	unocc	inact	ns	ns	ns	ns	ns	ns	ns	none	not found first flight, but surveyed second	0	0	0	0	0	0	none	
731			LR	none		3	I	CO/CB	30	40	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	203		0	0	0	0	0	0	none	
748			GOEA	goea	7	3	I	CB	25	100+	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	goea	act	goea	inact	goea	act	0	0	0	0	0	0	0	206-208		0	0	0	0	2	8	127-131	
749			FEHA	none		3	I	O	15	15	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	209-211		0	0	0	0	0	0	none	
750			GOEA	none	7	3	I	CB	15	20	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	213		0	0	0	0	0	0	none	
751-A			FEHA	none		3	I	O	10	10	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	none	crashed, not rebuilt	0	0	0	0	0	0	none	
751-B			FEHA	none		3	D				ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	none		0	0	0	0	0	0	none	
757			GOEA	none	15	3	I	O	8	8	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	goea	inact	unocc	inact	0	0	0	0	0	0	0	162		0	0	0	0	0	0	none	

763		GOEA	none	17	3	I	CH	60	65	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	6		0	0	0	0	0	0	none	
764		GOEA	goea	8	3	I	CB	20	40	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	unocc	inact	goea	act	1	goea	i/b	0	0	0	0	144-145	saw 1 goea perched ~0.5 miles from nest	0	0	0	0	2	8-9	85-87	
767		GOEA	goea	3	3	I	CO/CB	6	10	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	goea	inact	goea	act	unocc	inact	0	0	0	0	0	0	0	44-45	small pile of sticks above and left of nest, c	0	0	0	0	0	0	none	
768		GOEA	none	3	3	I	CO/CB	6	10	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	46		0	0	0	0	0	0	none	
769		GOEA	none	3	3	I	CB/CH	10	14	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0		47		0	0	0	0	0	0	none	
770		GOEA	none	11	3	I	CB	20	30	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	48-49		0	0	0	0	0	0	none	
774		GOEA	none	12	2	I	CB	10	15	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	unocc	inact	goea	inact	2	goea	F	0	0	0	0	53-54	one of the two goea has white dorsal wing	0	0	0	0	0	0	none	
776		GOEA	none	12	3	I	CB	20	40	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	ns	ns	ns	ns	ns	ns	ns	none		0	0	0	0	0	0	none	
779		GOEA	none	12	3	I	CB	25	30	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	prfa	act	unocc	inact	unocc	inact	0	0	0	0	0	0	0	59		0	0	0	0	0	0	none	
787		GOEA	prfa	6	3	DET	CB	30	35	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	unocc	inact	prfa	act	0	0	0	0	0	0	0	202		0	0	0	0	3	?	73-74	
804		GOEA	none	21	3	I	CB	40	100+	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	33		0	0	0	0	0	0	none	
807		GOEA	none	24	3	D	CB	30	45	ns	ns	ns	ns	ns	ns	unocc	inact	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	none	fallen or missing	0	0	0	0	0	0	none	
809-A		FEHA	none		3	I	O	20	20	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	19-20		0	0	0	0	0	0	none	
809-B		FEHA	none		3	I	O	20	20	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	19-20		0	0	0	0	0	0	none	
817-A		FEHA	none		3	I	O	20	20	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	140		1	feha	f	0	0	0	none	
817-B		CORA	none		1	I	CO	20	20	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	140		0	0	0	0	0	0	none	
817-C		FEHA	none		3	I	O	10	10	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	141		0	0	0	0	0	0	none	
834		GOEA	none	7	3	I	CB	30	50	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	217-218		0	0	0	0	0	0	none	
11-A		SR	prfa		1	I	CB	15	40	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	prfa	act	unocc	inact	prfa	act	0	0	0	0	0	0	0	none		1	prfa	f	0	3	?	99-105	
13-A		GOEA	goea	24	3	I	CB	70	80	ns	ns	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	goea	act	0	0	0	0	0	0	0	none		0	0	0	0	2	8	92-95	
13-B		GOEA	prfa	24	2	I	CO/CB	60	80	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	prfa	act	prfa	act	unocc	inact	0	0	0	0	0	0	0	none		0	0	0	0	0	0	none	
1-A		GOEA	none	2	3	I	CB	60	100	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	73		0	0	0	0	0	0	none	
1-B		GOEA	goea	2	3	I	CB	60	100	goea	act	unocc	inact	unocc	inact	goea	act	goea	act	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	74		0	0	0	0	0	0	none	
1-C		GOEA	goea	2	3	I	CO/CB	40	100	unocc	inact	unocc	inact	goea	act	unocc	inact	unocc	inact	unocc	inact	unocc	inact	goea	act	0	0	0	0	0	0	0	75		0	0	0	0	2	3-4	111-116	
1-D		GOEA	none	2	3	DET	CO	50	100	unocc	inact	goea	act	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	72		0	0	0	0	0	0	none	
2-A		FEHA	feha		3	I	O	25	25	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	feha	act	feha	act	feha	act	0	0	0	0	0	0	0	70		1	feha	b	0	?	?	none	tated so did not stick around for count of young or photo
2-B		FEHA	none		3	I	O	30	30	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	69		0	0	0	0	0	0	none	
2-C		GOEA	none	19	3	I	CB	75	80	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	69		0	0	0	0	0	0	none	
2-D		GOEA	none	19	3	I	CB	75	85	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	68		0	0	0	0	0	0	none	
2-E		GOEA	none	19	3	I	CB	30	85	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	67		0	0	0	0	0	0	none	
2-F		SR	prfa		1	I	CO/CB	25	30	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	prfa	act	unocc	inact	unocc	inact	0	0	0	0	0	0	0	66		0	0	0	0	0	0	none	
2-G		SR	none		1	I	CB	80	80	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	66		0	0	0	0	0	0	none	
3-A		GOEA	goea	19	3	I	CB	60	120+	goea	act	goea	act	unocc	inact	goea	act	goea	act	goea	inact	goea	inact	goea	act	1	goea	i/b	0	0	0	0	61-62		0	0	0	0	1	9-10	119-122	
3-B		GOEA	none	19	1	I	CB	30	120	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	61-62		0	0	0	0	0	0	none	
4-A		GOEA	goea	20	3	D	CB	70	100	ns	ns	unocc	inact	unocc	inact	unocc	inact	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	127-131		0	0	0	0	0	0	none	
4-B		GOEA	goea	20	3	I	CB	20	100	ns	ns	goea	act	goea	act	goea	inact	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	127-131		0	0	0	0	0	0	none	
4-C		GOEA	none	20	3	I	CB	40	100	ns	ns	unocc	inact	unocc	inact	unocc	inact	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	127-131		0	0	0	0	0	0	none	
4-D		GOEA	goea	20	3	I	CB	50	100	ns	ns	unocc	inact	unocc	inact	unocc	inact	ns	ns	unocc	inact	unocc	inact	goea	act	1	goea	i/b	0	0	0	0	127-131		0	0	0	0	2	8-9	134-137	
4-E		GOEA	none	20	3	I	CB	50	100	ns	ns	unocc	inact	unocc	inact	unocc	inact	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	127-131		0	0	0	0	0	0	none	
4-F		GOEA	rtha	20	3	I	CB	30	130	ns	ns	unocc	inact	rtha	act	unocc	inact	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	127-131		0	0	0	0	0	0	none	
51-A		GOEA	goea	18	3	DET	CB	20	40	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	goea	act	1	goea	p	0	0	0	0	7	1 adult perched ~200 feet west on top of rc	1	goea	f	0	1	9-10	82-84	
51-B		GOEA	goea	18	3	I	CO	20	40	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	goea	act	unocc	inact	0	0	0	0	0	0	0	8		0	0	0	0	0	0	none	
5-A		GOEA	goea	21	3	I	CB	40	100	goea	inact	unocc	inact	unocc	inact	goea	inact	goea	act	unocc	inact	unocc	inact	goea	act	1	goea	b/i	0	0	0	0	36-39		0	0	0	0	2	9-10	96-98	
5-B		GOEA	goea	21	3	I	CB	40	100	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	goea	act	goea	act	unocc	inact	0	0	0	0	0	0	0	36-39		0	0	0	0	0	0	none	
5-C		GOEA	none	21	2	I	CB	40	100	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	36-39		0	0	0	0	0	0	none	
60-A		GOEA	goea	12	3	I	CB	40	60	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	goea	inact	goea	act	unocc	inact	0	0	0	0	0	0	0	56		0	0	0	0	0	0	none	
60-B		GOEA	none	12	1	I	CB	40	60	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	57-58		0	0	0	0	0	0	none	
718-A		GOEA	none	10	3	I	CB	60	100+	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	107	only one nest found	0	0	0	0	0	0	none	
718-B		GOEA	none	10	3	D	CB	60	100+	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	goea	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	none	nest not located in 2017; destroyed	0	0	0	0	0	0	none	
756-A		GOEA	goea	15	3	I	CB/O	15	20	ns	ns	ns	ns	ns	ns	unocc	inact	goea	act	unocc	inact	unocc	inact	goea	act	1	goea	i/b	0	0	0	0	163-165		0	0	0	0	1	10	138-140	
756-B		GOEA	none	15	3	I	CB/O	8	12	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	166		0	0	0	0	0	0	none	
761-A		LR	none		2	I	CB	10	20	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	1		0	0	0	0	0	0	none	
761-B		LR	none		2	D	CB	10	20	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	2	nest fell	0	0	0	0	0	0	none	
762-A		GOEA	none	17	3	I	CB/CH	17	20	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	4-5		0	0	0	0	0	0	none	
762-B		GOEA	goea	17	3	I	CB/CH	15	20	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	goea	act	unocc	inact	0	0	0	0	0	0	0	4-5		0	0	0	0	0	0	none	
771-A		GOEA	none	11	3	I	CB	10	25	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	50-51		0	0	0	0	0	0	none	
771-B		GOEA	goea	11	3	I	CB	14	25	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	goea	act	unocc	inact	0	0	0	0	0	0	0	50-51		0	0	0	0	0	0	none	
7-A		GOEA	goea	9	3	I	CB	25	80	unocc	inact	unocc	inact	ns	ns	unocc	inact	goea	act	unocc	inact	unocc	inact	goea	inact	2	goea	i/b; f	0	0	0	0	125-126	one on nest; another flying nearby	0	0	0	0	0	0	none	
7-B		GOEA	goea	9	3	I	CO/CB	30	50	ns	ns	unocc	inact	unocc	inact	unocc	inact	unocc	inact	goea	act	goea	act	unocc	inact	0	0	0	0	0	0	0	123-124		0	0	0	0	0	0	none	
7-C		GOEA	none	9	2	I	CO/CB	15	50	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	125-126		0	0	0	0	0	0	none	
7-D		GOEA	none	9	3	I	CO/CB	10	30	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	125-126		0	0	0	0	0	0	none	
821-A		GOEA	none	16	3	I	CB	5	15	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	134		0	0	0	0	0	0	none	
821-B		GOEA	goea	16	3	I	CB	2	15	ns	ns	ns	ns	ns	ns	unocc	inact	goea	act	unocc	inact	goea	act	unocc	inact	0	0	0	0	0	0	0	135		0	0	0	0	0	0	none	
8-A		GOEA	goea	1	3	I	CO/CB	15	25	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	goea	act	1	goea	P	0	0	0	0	78-84	perched on topmost part of rock above ne	0	0	0	0	1	7-8	106-110	
8-B		GOEA	goea	1	3	I	CO/CB	20	30	ns	ns	goea	inact	goea	inact	goea	inact	goea	inact	goea	act	goea	act	unocc	inact	0	0	0	0	0	0	0	85-86		0	0	0	0	0	0	none	
8-C		GOEA	none	1	3	I	CB	15	30	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	unocc	inact	unocc	inact	0	0	0	0	0	0	0	85-86		0	0	0	0	0	0	none	
2016-1		LR	none		3	I	O	30	30	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	0	0	0	0	0	0	0	15	El Aero WPT 138, new nest in 2016	0	0	0	0	0	0	none	
2016-2		CORA	none		1	I	CB	5	10	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	0	0	0	0	0	0	0	199	El Aero WPT 139, new nest in 2016; looks ra	0	0	0	0	0	0	none	
2016-3		LR	none		2	I	O	20	50	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	0	0	0	0	0	0	0	121	El Aero WPT 140, new nest in 2016	0	0	0	0	0	0	none	
2016-4		FEHA	feha		3	I	O	5	5	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	feha	act	unocc	inact	0	0	0	0	0	0	0	117	El Aero WPT 141, new nest in 2016	0	0	0	0	0	0	none	
2016-5		GOEA	none	10	3	DET				ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	unocc	inact	0	0	0	0	0	0	0	102-103		0	0	0	0	0	0	none	
2017-1		CORA	none		0	I	CH	15	20	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	0	0	0	0	0	0	0	3	looks ratty	1	cora	i/b	0	0	0	none	
2017-2A		CORA	none		1	I	CH	10	12	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	0	0	0	0	0	0	0	16-18		0	0	0	0	0	0	none	
2017-2B		FEHA	none		3	I	O	12	12	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	0	0	0	0	0	0	0	16-18		0	0	0	0	0	0	none	
2017-8		SR	none		2	I	CH	50	80	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	0	0	0	0	0	0	0	108-110		0	0	0	0	0	0	none	
2017-9		LR	none		3	I	CB	30	50	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	0	0	0	0	0	0	0	122		0	0	0	0	0	0	none	
2017-11		GOEA	none	8	3	I	CB	10	15	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	0	0	0	0	0	0	0	142-143		0	0	0	0	0	0	none	
2017-15		SR	none		1	I	CB	10	30	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	0	0	0	0	0	0	0	171-172		0	0	0	0	0	0	none	
2017-16		LR	none			D				ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	0	0	0	0	0	0	0	177	fallen on ground	0	0	0	0	0	0	none	
2017-17		LR	none		3	I	CB	40	50	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	0	0	0	0	0	0	0	182-183		0	0	0	0	0	0	none	
2017-18		LR	none		3	I	CB	90	120	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	0	0	0	0	0	0	0	189-190		0	0	0	0	0	0	none	
2017-19		SR	none		1	I	CB	60	90	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	0	0	0	0	0	0	0	196-197		0	0	0	0	0	0	none	
2017-20		SR	none		2	I	CB	20	40	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	unocc	inact	0	0	0	0	0	0	0	198-201		0	0	0	0	0	0	none	

Table A-2 Summary of Nesting Data 2010 to 2017
Taken from Wildlife Resource Consultants *2017 Raptor Nesting Surveys and Golden Eagle Monitoring Report*

(Ns—Not Surveyed; Nd-- Not Determined)

	Year															
	2010		2011		2012		2013		2014		2015		2016		2017	
Territory (Nests)	Active	No. of Young	Active	No. Fledged	Active	No. of Young	Active	No. Fledged	Active	No. Fledged	Active	No. Fledged	Active	No. Fledged	Active	No. Fledged
North Cliffs (1-A, B, C, D)	yes	ND	yes	2	yes	ND	yes	1	yes	1	no	0	no	0	yes	1
East Kamma (3-A, B)	yes	1	yes	1	no	0	yes	1	yes	1	no	0	no	0	yes	1
Sawtooth Knob (4-A, B, C, D, E, F)	NS	NS	yes	1	yes	ND	no	0	no	0	no	0	no	0	yes	2
West Rosebud Canyon (5-A, B, C)	yes	ND	no	0	no	0	no	0	yes	0	yes	1	yes	2	yes	2
East Rosebud Canyon (6, 66, 68, 12, 13-A, B, 807)	yes	ND	yes	2	yes	ND	no	0	no	0	yes	1	yes	1	yes	2
Wood Canyon (7-A, B C, D)	no	0	no	0	no	0	no	0	yes	2	yes	1	yes	1	no	0
Silver Camel (8-A, B, C, 11)	NS	NS	no	0	no	0	no	0	no	0	yes	1	yes	1	yes	1
West Jungo Flats #1 (9, 128, 678)	NS	NS	yes	2	NS	NS	yes	1	no	0	yes	2	no	0	yes	2
West Jungo Flats #2 (10, 127, 98)	NS	NS	yes	1	NS	NS	no	0	no	0	no	0	no	0	yes	0.5
Rabbithole Creek (14, 15, 17, 63, 64)	NS	NS	yes	1	no	0	no	0	yes	2	no	0	yes	2	no	0
Cow Creek (53, 54)	NS	NS	no	0	NS	NS	NS	NS	NS	NS	yes	1	yes	2	no	0
Majuba Mountain (76, 77, 78)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	yes	2	no	0	yes	2
Antelope Range (79, 81, 756-A, B, 757)	NS	NS	no	0	NS	NS	no	0	yes	1	yes	1	no	0	yes	1
West Jackson Mountains (721, 722, 723, 724)	NS	NS	NS	NS	NS	NS	no	0	yes	1	yes	2	yes	0	no	0
Haystack Mine (88, 91-B, 748, 750, 834)	NS	NS	NS	NS	NS	NS	no	0	no	0	yes	2	yes	1	yes	2
South of Sawtooth (821-A, B, 101, 102)	NS	NS	no	0	NS	NS	no	0	yes	0	no	0	yes	2	yes	2
Black Rock Point (717, 718-A, B, 2016-5)	NS	NS	NS	NS	NS	NS	no	0	no	0	no	0	yes	1	no	0
Abel Camp Spring (762-A, B, 763)	NS	NS	no	0	NS	NS	no	0	no	0	no	0	yes	1	no	0
Rabbithole Peak (767, 768, 769)	NS	NS	no	0	NS	NS	no	0	no	0	no	0	yes	3	no	0
Sheep Spring (770, 771-A, B)	NS	NS	no	0	NS	NS	no	0	no	0	no	0	yes	0	no	0
Placerites (51-A, B)	NS	NS	no	0	NS	NS	NS	NS	NS	NS	no	0	yes	1	yes	1
Lava Beds Creek (59, 60-A, B, 774, 776, 779)	NS	NS	no	0	NS	NS	NS	NS	NS	NS	no	0	yes	2	no	0
Alkali Flats (787)	NS	NS	NS	NS	NS	NS	no	0	no	0	no	0	no	0	no	0
Moonshine Spring (75-A, 764, 2017-11)	NS	NS	NS	NS	NS	NS	no	0	no	0	no	0	no	0	yes	1
Total Active Territories	ND		ND		ND		ND		ND		10		15		14	
Total Occupied Territories	ND		ND		ND		ND		ND		13		22		17	
Successful Nests	ND		7		ND		3		6		10		13		14	
Total Fledged Young	ND		10		ND		3		8		14		20		20.5	
Nest Success (no. of successful nests/ no. occupied territories, %)	ND		ND		ND		ND		ND		76.92%		59.09%		82.35%	
Mean Brood Size (no. of young fledged/no. of successful nests)	ND		1.43		ND		1.00		1.33		1.40		1.54		1.46	
Productivity (no. of young fledged/no. of occupied territories)	ND		ND		ND		ND		ND		1.08		0.91		1.21	

[1] Flight conducted in late May, and therefore represents a reasonable estimate of number fledged.

[2] Number of young undetermined; this is a minimum estimate of fledglings.

[3] Only one flight was conducted this year; no estimate of early breeding area occupancy available.