

2016

Influence of Disturbance on Greater Sage-Grouse Habitat Selection in Southern Utah

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INFLUENCE OF DISTURBANCE ON GREATER SAGE-GROUSE HABITAT
SELECTION IN SOUTHERN UTAH

by

Erica P. Hansen

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

of

MASTER OF SCIENCE

in

Wildlife Biology

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2016

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ABSTRACT

Influence of Disturbance on Greater Sage-Grouse

Habitat Selection in Southern Utah

by

Erica P. Hansen, Master of Science

Utah State University, 2016

Major Professor: S. Nicole Frey
Department: Wildland Resources

The greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) is a species of conservation concern that occupies sagebrush-dominated (*Artemisia spp.*) landscapes across the western United States and southern Canada. In September 2015, as the result of a historic collaboration between many stakeholders, the U.S. Fish and Wildlife Service (USFWS) determined that the sage-grouse did not warrant protection under the Endangered Species Act. However, this decision hinged on federal and state commitments to continue informed management of sagebrush habitats, a commitment which is complicated by increasing landscape disturbance. I tested the effects of two types of disturbance (wildfire and transmission line construction) on seasonal sage-grouse habitat selection in southern Utah.

I deployed Global Positioning System (GPS) transmitters on n=21 male and n=5 female sage-grouse in the Bald Hills Sage-Grouse Management Area of southern Utah in 2014 and 2015. I modeled seasonal sage-grouse habitat use using a resource selection

function framework, based on when the population was most likely to be impacted by each type of disturbance. My summer model examined the influence of wildfire, and suggested that sage-grouse selected for areas that had been burned and reclaimed within the last 10 years. I suggest that this may be occurring due to vegetation present as a result of post-fire restoration efforts implemented by the Bureau of Land Management.

My winter model examined the influence of transmission line construction within an existing energy corridor using one season of pre-construction data to two seasons of post-construction data. Modeling predicted a 3% decrease in probability of use for winter habitat in the immediate vicinity of the transmission line corridor after construction. However, I did not observe increased avoidance by sage-grouse when comparing spatial distributions using Minimum Convex Polygons (MCPs). This may be because the line was sited within an existing energy corridor, adjacent to an area of low probability of use. However, I caution that the transmission line could have long-term impacts outside the scope of my analysis. Thus, I recommend continued monitoring of sage-grouse habitat use in the area, as well as an assessment of indirect impacts such as presence of avian predators.

PUBLIC ABSTRACT

Influence of Disturbance on Greater Sage-Grouse

Habitat Selection in Southern Utah

Erica P. Hansen

The greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) is a species of conservation concern that occupies sagebrush-dominated (*Artemisia spp.*) landscapes across the western United States and southern Canada. The U. S. Fish and Wildlife Service (USFWS) reviewed the status of the sage-grouse in September 2015 and determined that it did not warrant protection under the Endangered Species Act due to collaborative efforts between numerous public and private stakeholders. However, this decision hinged on federal and state commitments to continue science-based management of sagebrush habitats. As human development increases across the west, there is an increasing need for understanding the impacts of disturbance on sage-grouse. Filling this knowledge gap is important because it will allow us to predict how sage-grouse populations may respond to changes in the future. I assessed how two types of disturbance (wildfire and transmission line construction) influenced habitat use of a population of sage-grouse in southern Utah. I deployed Global Positioning System (GPS) transmitters on 26 (21 male and 5 female) sage-grouse in the Bald Hills Sage-Grouse Management Area in 2014 and 2015 to record what habitat sage-grouse were using during the summer and winter seasons. I compared these used locations to habitat that was seasonally available to the birds using resource selection functions. My models showed that in the summer, birds showed preference for areas burned and reclaimed

within the last 10 years. I suggest that this may be occurring because the birds are seeking out vegetation that was seeded by the Bureau of Land Management (BLM) during wildfire reclamation. In the winter, my models showed an overall 3% decrease in predicted probability of use for winter habitat in the vicinity of the transmission line corridor, but this change did not immediately result in increased avoidance by sage-grouse when comparing spatial distributions for sage-grouse locations within winter habitat near the transmission line. I suggest that this is because the new transmission line was paired with a preexisting line which was already avoided by sage-grouse. However, the construction of the new line could have long-term consequences outside the two year scope of my study. These impacts could be delayed because sage-grouse are strongly tied to historic habitats and may not change habitat use immediately in spite of landscape changes. Additionally, the presence of the new line could cause indirect landscape changes which may only manifest over longer time periods such as increasing human activity in the area or changing the distribution of avian predators of sage-grouse that use the transmission line for perching. I recommend continued monitoring of sage-grouse in the area to determine if any changes in habitat use manifest in future years.

ACKNOWLEDGMENTS

I would like to thank my advisor, Dr. Nicki Frey, for her time and patience in helping to make this project a reality. Her positivity and flexibility allowed me to take ownership of my research while knowing I had strong support whenever it was needed. I would especially like to thank my committee members, Drs. Terry Messmer and Joe Wheaton, for their support and assistance through-out the entire process. The team of biologists and rangeland specialists in southern Utah are an incredible group of people. Jason Nicholes and Jake Selby (UDWR) as well as Jason Bradshaw (NRCS) provided invaluable local knowledge and sacrificed many nights of sleep to help me trap sage-grouse each spring. I am so thankful that Melanie Mendenhall and Vicki Tyler (BLM) took the time to patiently explain methods of habitat treatment and wildfire reclamation to me. Devin Monroe provided much needed field support during times I was unable to be in the field myself. I would also like to thank Rocky Mountain Power for the gracious funding which facilitated this research. Susan Durham provided extensive statistical input, and patiently worked with me through my endless questions.

I would like to give special thanks to my dear family and friends. I could not have done it without all of you. You have instilled in me a love of wild places from the very beginning, and encouraged me to pursue my passion in spite of any challenge that arose along the way. Particularly, I would like to thank my partner in adventure, Alex, for his absolutely unwavering support and belief in me through this entire process. You guys are the best.

Erica P. Hansen

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

GREATER SAGE-GROUSE ECOLOGY AND SEASONAL HABITAT USE

The greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) is a sagebrush (*Artemisia* spp.) obligate bird found in open rangelands across the western United States and southern Canada (Schroeder et al. 2004). It is the largest grouse species in North America, and is widely recognized for its unique courtship displays during the spring breeding season. Concern for the persistence of the species has been growing steadily since the mid-1990's (Stiver 2011) due to population declines in conjunction with sagebrush habitat loss and degradation. As a result, the U. S. Fish and Wildlife Service (USFWS) received multiple petitions to list the species under the Endangered Species Act from 1999 through 2005. In 2005, the USFWS determined sage-grouse warranted protection under the Endangered Species Act (U.S. Fish and Wildlife Service [USFWS] 2010), but this decision was precluded to prioritize species of more immediate concern. The final listing decision was revisited in September 2015, when USFWS determined that the sage-grouse was not warranted for listing. However, this decision depended on commitments from many stakeholders to continue conservation efforts into the future. Thus, additional research was required to assess how sage-grouse populations were persisting across the landscape and how to best implement conservation actions. The species currently occupies an estimated 56% of its distribution prior to the settlement of western North America, the effects of which have been compounded by increasing fragmentation within the species range (Schroeder et al. 2004). An analysis by Beck et al. (2003) estimated that sage-grouse in Utah occupy 41.3% of their historic distribution.

Sage-grouse are ground-dwelling birds that exhibit seasonal use of different sagebrush habitats. Connelly et al. (2000a) characterized sage-grouse populations into three categories: non-migratory, 1-stage migratory (grouse move between two distinct seasonal ranges), or 2-stage migratory (grouse move between three distinct seasonal ranges). A migration refers to any movement greater than 10 km in one direction (Connelly et al. 2000a). Whether or not a bird is migratory is dependent on its utilization of different habitats throughout the year. Migratory patterns may vary within a single breeding population, with some birds remaining non-migratory while others may exhibit 1- or 2- stage migrations. This can complicate efforts to characterize the movements of a particular group of birds (Connelly et al. 2000a).

The regions where sage-grouse breed, nest, and initially raise their broods are classified as breeding habitats (Connelly et al. 2004). In the spring, sage-grouse males gather in open areas known as leks to initiate breeding displays. Males perform their courtship display on leks for several hours during the early morning in the springtime, generally from late February through mid-May (Martin 1970, Schroeder et al. 1999). Leks may be located in areas of sparse vegetation such as old lakebeds, low sagebrush flats and ridge tops, roads, cropland, and burned areas (Connelly et al. 1981). They generally form in areas opportunistically located near good quality nesting sites and surrounded by sagebrush habitat. For example, one study showed that 64% of nests occurred within 5 km of a lek in Wyoming (Holloran and Anderson 2005). Average distance traveled from nearest lek to nesting location averaged 2.20 km for sage-grouse in Utah from 1998-2013 (Dahlgren et al. 2016).

After breeding, hens select an appropriate nest site in the sagebrush habitat surrounding the lek. Although hens have been observed nesting under multiple shrub species, Connelly et al. (1991) showed that they predominantly nest under sagebrush and also experience the highest nest success when nesting under sagebrush (53% successful under sagebrush versus 22% successful under other shrub species). Another crucial component of nesting habitat is close proximity to appropriate early brood-rearing habitats. These are generally located in open stands of upland sagebrush (about 14% canopy cover; Wallestad 1971) with a percentage of cover by grasses and forbs greater than or equal to 15% (Sveum et al. 1998). This grass and forb understory promotes the presence of small invertebrates that form a critical dietary component in the early life stage of new chicks (Klebenow and Gray 1968).

By June or July, the upland sagebrush habitats used for early brood-rearing begin to desiccate. At this point, sage-grouse often migrate to more mesic summer and late brood-rearing habitats which may or may not have sagebrush present (Martin 1970, Connelly et al. 1988). These regions may include meadows, riparian zones, agricultural land, higher elevation areas where plants reach maturity later in the year, and a variety of sagebrush microclimates which provide suitable abundance of grasses, forbs, and insects for food throughout the summer (Schroeder et al. 1999, Connelly et al. 2004). Both females that did not successfully nest and males may move to these varied summer habitats prior to hens with broods, which remain in breeding areas until chicks are old enough to move between habitats (Connelly et al. 1988, Gregg et al. 1993). These movements can vary temporally depending on annual precipitation and temperature (Fischer et al. 1996).

As early as late-August, sage-grouse begin making movements towards transitional, autumn habitats. They can remain in these areas until as late as December (Connelly et al. 1988). Movements during this time are largely dependent on the timing of vegetation desiccation, hard frost, temperature, weather, water, topography, and distance between summer and winter habitats (Connelly et al. 2004). As forb and grass resources become less abundant, sage-grouse begin to increasingly rely on sagebrush as a major component in their diet as they move into their winter ranges (Patterson 1952).

Sage-grouse rely nearly exclusively on sagebrush for resources through the winter months. The location of their preferred habitats varies based on snow quality, topography, and vegetation height, species and cover (Beck 1977). Because the distribution of sage-grouse populations in the winter is closely related to snow depth, the use of winter habitat can vary annually based on precipitation, wind, and temperature (Crawford et al. 2004). One Utah study showed that winter ranges were characterized by medium to tall (40-60 cm) shrubs and moderate shrub canopy cover (20-30%; Homer et al. 1993, Connelly et al. 2004). The broad range of seasonal habitats required by sage-grouse throughout the year has resulted in the bird generally being referred to as an “umbrella species”. This need for many different types of habitat, in conjunction with sometimes large-scale movement patterns, has necessitated unique collaborations between private landowners, conservation groups, and state and federal agencies to implement actions that will mitigate threats to the persistence of the species.

DISTURBANCE IN SAGEBRUSH ECOSYSTEMS

The sagebrush ecosystem on which sage-grouse depend has undergone extensive alteration and loss since settlement in the early 1900’s as a result of habitat conversion,

degradation, and fragmentation (Schroeder et al. 1999, Connelly et al. 2004). Crawford et al. (2004) estimated 4 million ha of habitat suitable for sage-grouse has been converted to other uses over the past 50 years. Habitat loss has occurred as a result of agriculture, mining and energy development, development of ranches and farm sites, reservoirs, roads and highways, and the growth of towns and urban sites (Braun 1998, Connelly et al. 2004). The anthropogenic conversion of native landscapes not only directly replaces habitat, but may functionally fragment habitat for sage-grouse use (Connelly et al. 2004). Habitat quality has also been impacted through alteration of native grass and forb communities and the invasion of exotic species.

Wildfire

It is thought that fire severity, intensity, and frequency have been altered as a result of European settlement in sagebrush ecosystems (Bukowski and Baker 2013). It has historically been accepted that fire frequency was suppressed overall since the settlement of the west due to irrigation and rangeland management (e.g. Miller and Rose 1990). However, recent research has shown that fire rotations may currently be more frequent than those in pre-settlement times as a result of changes in rangeland forb and grass species (Bukowski and Baker 2013). A primary concern is the invasion of cheatgrass, an exotic annual grass species. Communities consisting of Wyoming big sagebrush (*A. tridentata* var. *wyomingensis*) and basin big sagebrush (*A. tridentata* var. *tridentate*) are particularly susceptible to invasion (Miller and Eddleman 2001). This extremely flammable grass can increase fire homogeneity and severity in sagebrush landscapes, and may ultimately convert these communities to steady-state annual

grasslands by increasing the frequency of fire (Miller and Eddleman 2001, Baker 2006). Once this change has taken place, it can be difficult to restore an ecosystem back to its native state (Pedersen et al. 2003, Bukowski and Baker 2013).

Most studies designed to investigate the influence of wildfire on sage-grouse have found no effect or a net negative impact on populations associated with burned areas (e.g. Coates et al. 2015, Fischer et al. 1996, 1997). In southern Idaho, lek attendance declines were exacerbated by the introduction of prescribed burning treatments (Connelly et al. 2000*b*). Similarly, a recent large-scale analysis assessing 30 years of lek count data collected throughout the Great Basin indicated that wildfire has resulted in persistent lek population declines in spite of cyclic periods of favorable precipitation which would traditionally be associated with population growth (Coates et al. 2015). Studies focusing on wildfire in sage-grouse nesting and brood-rearing habitat in southern Idaho indicated that wildfire did not disrupt seasonal migrations from brood-rearing to summer habitat and that sage-grouse did not select differently between burned and unburned patches within brood-rearing habitat (Fischer et al. 1996, 1997). Byrne (2002) observed that nesting, brood-rearing, and broodless females preferentially avoided burned habitat in Oregon. Arkle et al. (2014) compared restoration success in randomly located plots across the Great Basin. They found that post-burn overstory vegetative components did not meet habitat requirements necessary for sage-grouse use, particularly during the winter months when shrubs are an essential component of sage-grouse habitat. In spite of documented neutral or negative impacts of wildfire on sage-grouse in nesting, brood-rearing, and winter habitat, studies have suggested that sage-grouse can be attracted to burned areas during the summer months (Klebenow and Beall 1978, Martin 1990), when

individuals are less dependent on sagebrush as a main dietary staple. Additionally, fire has been attributed as a mechanism that may have naturally limited the expansion of Pinyon (*Pinus* spp.) and juniper (*Juniperus* spp.; pinyon-juniper) communities into sagebrush ecosystems (Knick et al. 2005). Pinyon-juniper encroachment has been identified as a major threat to sage-grouse habitat preservation (Baruch-Mordo et al. 2013), although prescribed burning is only cautiously utilized as a habitat treatment to reduce tree densities due to the significant potential for invasion by cheatgrass (Knick et al. 2005). These varying conclusions indicate that the complex impacts of fire and post-fire habitat restoration on sage-grouse populations are not fully understood, and highlight the need for research to determine the response of sage-grouse to wildfire rehabilitation efforts currently in practice in the Great Basin.

Energy Development and Tall Structures

Connelly et al. (2004) suggested that structures associated with energy transmission and development in sage-grouse habitat may functionally fragment sage-grouse habitat. Due to these concerns, the USFWS recommended the use of buffers between tall structures and occupied sage-grouse habitats to mitigate potential impacts of development (U.S. Fish and Wildlife Service [USFWS] 2003). Likewise, many state agency sage-grouse plans identify varying buffer distances from anthropogenic activities (Manier et al. 2014). Tall structures are typically defined as power lines, communication towers, wind turbines, and other installations (U.S. Fish and Wildlife Service [USFWS] 2010). Management guidelines for mitigating the impacts of tall structures are largely based on the logic that the introduction of new vertical structures and associated

infrastructure in a sagebrush landscape may increase perching by avian predators, fragment sage-grouse habitat, increase hunting ease for terrestrial predators, or promote human traffic in otherwise undisturbed areas (Messmer et al. 2013). In a landscape-scale analysis, Wisdom et al. (2011) compared multiple variables between current and extirpated sage-grouse habitat. They found that, among multiple other factors, distance to transmission line and distance to cellular towers were strongly associated with sage-grouse extirpation. However, they concluded that the mechanism of this relationship was unknown at a regional scale. Gillian et al. (2013) showed that sage-grouse in Idaho avoided transmission lines by 600 m when comparing telemetry locations to a random null model.

Increased perching substrate for avian predators of sage-grouse is a major concern related to power line development. Coates et al. (2014) showed that common raven presence was greater within 2.2 km of a transmission line corridor in southern Idaho. To mitigate this threat, perch deterrents have been used to discourage avian predator use of transmission line poles. Prather and Messmer (2010) studied the effectiveness of varying types of perch deterrents using a randomized block treatment design. They did not detect a difference in perching frequency between any type of perch deterrent and control poles with no perch deterrents. Slater and Smith (2010) compared a transmission line fitted with perch deterrents to a nearby control line. Although they found that predator activity was significantly lower on the line with deterrents, the deterrents did not entirely discourage perching. An increase in avian predator activity, whether nesting or perching, can influence how sage-grouse select and use sagebrush habitats. Sage-grouse hens in Wyoming were shown to select different habitats depending on their breeding stage based

on risk of predation from avian predators and food availability (Dinkins et al. 2014), while another study showed that sage-grouse nest and brood locations had lower densities of avian predators than random locations (Dinkins et al. 2012).

Messmer et al. (2013) conducted a literature review designed to evaluate whether the concerns regarding tall structures were supported by empirical evidence in scientific literature. This review was then utilized in a series of stakeholder focus groups to identify current knowledge regarding the impacts of tall structures on sage-grouse and to identify existing knowledge gaps. They concluded that “professional opinions, personal observations, unpublished data, anecdotal references, and modeling efforts, as well as peer-reviewed studies on the cumulative effects of oil and gas development and associated infrastructures on sage-grouse, were used to implicate tall structures as potential causal agents” of sage-grouse population decline. However, they emphasized that any cumulative effects studies regarding the impacts of oil and gas infrastructure were unable to specifically address tall structures themselves as drivers of negative impacts (Messmer et al. 2013). Although it appears that sage-grouse may select habitat to avoid transmission lines and/or avian predators in some situations, the mechanism of this phenomena is not understood and warrants additional research (Messmer et al. 2013).

BALD HILLS SAGE-GROUSE MANAGEMENT AREA

The Bald Hills Sage-Grouse Management Area (Bald Hills SGMA) is located in the Bald Hills region of Beaver and Iron counties in Utah, and is at the southern edge of the current sage-grouse distribution. Although in the early 1900s sage-grouse were recorded as far south as northern Arizona, Schroeder et al. (2004) noted that recent data

has shown that populations appeared to be receding northward. This has resulted in an increased focus on sage-grouse research in the southern Utah region. Populations on the periphery of their species distribution may have local adaptations that result in increased conservation importance (Hunter and Hutchinson 1994). The Bald Hills sage-grouse are an isolated population at the southern edge of the sage-grouse distribution, and thus their conservation may be significant to the persistence of the species (Burnett 2013).

Potential threats to sage-grouse in southern Utah include development of human infrastructure, drought and poor weather conditions, altered wildfire regimes, increased levels of human recreational activity, and establishment of invasive vegetation species (Frey et al. 2006). However, Frey et al. (2006) conceded that specific threats to sage-grouse in southern Utah were difficult to quantify due to a lack of empirical data supporting the current status of sage-grouse habitat use and population demographics in the area.

In response to this need for research, a study of the Bald Hills region was initiated in 2010 by Utah State University to quantify seasonal habitat use and movement patterns of the Bald Hills sage-grouse and to compare those with habitat guidelines derived from studies conducted in the center of the species range (Burnett 2013). The results from the 2010-2013 study indicated strongly that the Bald Hills population exhibited unique habitat preferences and that local management guidelines should be adjusted appropriately. For example, 1.41% of summer, 43.65% of winter, and 7.84% of nesting/brood-rearing locations were collected outside of predicted seasonal boundaries delineated within the SGMA (Burnett 2013, State of Utah 2013). This information is of particular importance due to the history of disturbance in the Bald Hills and the high

potential for future development in the area. The Bald Hills region contains a mosaic of areas affected by wildfires of varying ages, including four significant wildfires in the last ten years: the Greenville Bench, Wrangler, Black Mountain, and Baboon Wildfires.

Portions of areas impacted by these fires have been treated and reseeded to support the establishment of forbs and perennial grasses (BLM, unpublished data; Burnett 2013).

The Utah Renewable Energy Zone (UREZ) Task Force has identified a resource zone for future development (Milford) that overlaps with a large portion of the Bald Hills region (Black and Veatch Corporation 2010, Burnett 2013). This region will continue to be investigated as a potential source of renewable energy for the state of Utah.

Additionally, several large transmission lines pass through the Bald Hills SGMA. They are part of a Section 368 West-Wide Energy Corridor that has the potential for continued expansion as development in the region increases (Bureau of Land Management [BLM] 2009). In the fall of 2014, Rocky Mountain Power constructed the Sigurd-Red Butte transmission line, a new 345 kV transmission line in the Bald Hills region. This project passed within a 6.4 km (4 mile) Bureau of Land Management (BLM) designated lek buffer surrounding an active sage-grouse lek on the western portion of the Bald Hills, and crossed both critical brood-rearing and winter habitat (Bureau of Land Management [BLM] 2012).

STUDY PURPOSE AND RESEARCH OBJECTIVES

The Bald-Hills sage-grouse occupy marginal habitat and, as such, have adapted unique seasonal habitat preferences (Burnett 2013). Consequently, this necessitates a locally specific management strategy to ensure that conservation measures implemented

in the region are appropriate and effective. The Bald Hills SGMA is primarily located on Bureau of Land Management (BLM) land which is impacted by many small dirt roads, multiple wildfires, current transmission line construction, cattle grazing, and potential renewable energy development in the future (Bureau of Land Management [BLM] 2009, Black and Veatch Corporation 2010). Due to the high level of altered habitat and the known unique attributes of sage-grouse in this region, understanding how this population responds to disturbance is of heightened conservation importance.

To collect detailed habitat use data of birds in the region, I deployed 20 Solar Platform Transmitting Terminal (PTT)/Global Positioning System (GPS) transmitters on birds from two leks: Mud Springs and Little Horse Valley. These were the two leks nearest to the Sigurd-Red Butte 345kV transmission line, which was constructed in the fall of 2014, and were two of the largest leks within the SGMA. This spatial data was used to model how seasonal habitat use was related to two types of landscape disturbance: wildfire (Chapter 2) and transmission line construction (Chapter 3). I also collected supplementary information to quantify changes in the relative abundance of avian predators and vehicular traffic along the Sigurd-Red Butte transmission line corridor (Appendix B). The goals of this project were: 1) to assess whether sage-grouse in the Bald Hills preferentially use or avoid areas impacted by wildfire in the summer; and 2) to determine if the construction of the new transmission line spatially displaces sage-grouse that overwinter in the vicinity of the transmission line corridor. These components are addressed specifically below.

Question 1: Does recent wildfire influence summer habitat selection by sage-grouse?

Hypothesis: Greater sage-grouse show preference for areas that have burned within the last 20 years.

Question 2: Does the addition of a transmission line to a preexisting West-Wide energy corridor impact sage-grouse winter habitat use?

Hypothesis: At times of the year when greater sage-grouse are in the Mud Springs vicinity, habitat use will shift to increase distance from the transmission line.

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CHAPTER 2

FIRE INFLUENCES SUMMER HABITAT SELECTION OF NON-REPRODUCTIVE
SAGE-GROUSE IN SOUTHERN UTAH**ABSTRACT**

In the state of Utah, wildfire has been identified as the most significant threat to existing greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) populations. Wildfire can result in both direct loss of habitat as well as functional habitat loss through the replacement of native vegetation in burned areas by exotic species such as cheatgrass (*Bromus tectorum*). The Bald Hills Sage-Grouse Management Area (SGMA) in southern Utah contained a mosaic of different areas burned by wildfire within the last two decades which occurred primarily in, or adjacent to, pinyon-juniper forests. Nearly all wildfires within the last 20 years (93% of total area burned in major fires) were subsequently reseeded by the Bureau of Land Management (BLM; mean time from burn to initial revegetation effort <1 year). Wildfires may assist in limiting pinyon-juniper encroachment, but concerns have been raised about establishing suitable sage-grouse habitat post-fire. I used Resource Selection Functions (RSFs) to evaluate the influence of burned and reclaimed patches on summer habitat selection of 21 non-reproductive (male and non-nesting/broodless hen) sage-grouse in the Bald Hills SGMA. I found that, following agricultural areas, areas that had burned recently (within the last 20 years) were selected for more strongly than any other landcover type, with greater preference being shown for burned areas less than 10 years old. I suggest that burned areas may be attractive to non-reproductive birds because they were reseeded by the Bureau of Land Management, and could be offering vegetation components (forbs and grasses included in

seed mixes) that are limited elsewhere within the SGMA. This confirms that burned areas within Utah SGMAs which are promptly restored can retain their classification as sage-grouse habitat, and can be utilized by non-reproductive sage-grouse in the summer months. Additional field data collection regarding the particular habitat characteristics which may be attracting sage-grouse to these areas would yield additional information for managers interested in successfully rehabilitating burned areas following wildfire.

INTRODUCTION

The greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse) is a sagebrush (*Artemisia* spp.) obligate bird found in sagebrush-dominated regions across the western United States and southern Canada (Schroeder et al. 2004). Concern for the persistence of the species has been growing steadily since the mid-1990's (Connelly et al. 2004) due to population declines in conjunction with sagebrush habitat loss and degradation. The species currently occupies an estimated 56% of its original distribution in North America; and 41.3% of its historic range in Utah (Beck et al. 2003). The sagebrush ecosystem on which sage-grouse depend has undergone extensive alteration since European settlement in the early 1900's as a result of habitat conversion, degradation, and fragmentation (Connelly et al. 2004, Schroeder et al. 2004). Habitat loss has occurred as a result of agriculture, mining and energy development, development of ranches and farm sites, reservoirs, roads and highways, and the growth of towns and urban sites (Braun 1998). These anthropogenic conversions of the western landscape not only directly replace habitat, but may effectively fragment habitat for sage-grouse use (Connelly et al. 2004). The quality of remaining habitat has also been altered

dramatically; for example, by the invasion of exotic grasses and forbs. These non-native species are particularly prevalent in areas impacted by disturbance such as wildfire.

Historically, scientific consensus held that naturally occurring fire cycles were suppressed overall since the settlement of the west due to agricultural irrigation and rangeland management (e.g. Miller and Rose 1990). However, recent research suggests that current fire rotations may actually be more frequent than those in pre-settlement times (Bukowski and Baker 2013). Wildfires may result in the permanent loss of sagebrush when an area is subsequently invaded by non-native vegetation such as cheatgrass (*Bromus tectorum*), an exotic annual grass species. Comparisons of burned and unburned habitat of varying ages in southern Idaho found that sagebrush did not return in 20 years, resulting in a net loss of sage-grouse nesting habitat (Nelle et al. 2000). Communities consisting of Wyoming big sagebrush (*A. tridentata* var. *wyomingensis*) and basin big sagebrush (*A. tridentata* var. *tridentate*) show heightened susceptibility to cheatgrass invasion (Miller and Eddleman 2001).

Most studies designed to investigate the influence of wildfire on sage-grouse have found no effect or a net negative impact on populations associated with burn zones (e.g. Connelly et al. 2000a, Coates et al. 2015, Byrne 2002). In southern Idaho, lek attendance declines were exacerbated by the introduction of prescribed burning treatments (Connelly et al. 2000a). Similarly, a recent large-scale analysis assessing 30 years of lek count data collected throughout the Great Basin indicated that wildfire has resulted in persistent lek population declines in spite of cyclic periods of favorable precipitation which would traditionally be associated with population growth (Coates et al. 2015). Studies focusing on wildfire in sage-grouse nesting and brood-rearing habitat in southern Idaho indicated

that wildfire did not disrupt seasonal migrations from brood-rearing to summer habitat and that sage-grouse did not select differently between burned and unburned patches within brood-rearing habitat (Fischer et al. 1996, 1997). Byrne (2002) observed that nesting, brood-rearing, and broodless females preferentially avoided burned habitat in Oregon. In spite of documented neutral or negative impacts of wildfire on sage-grouse in nesting and brood-rearing habitats, some studies have suggested that sage-grouse can be attracted to burned areas during the summer months (Klebenow and Beall 1978, Martin 1990), when individuals are less dependent on sagebrush as a main dietary component.

Additionally, fire has been attributed as a mechanism that may have naturally limited the expansion of Pinyon (*Pinus* spp.) and juniper (*Juniperus* spp.; pinyon-juniper) communities into sagebrush ecosystems (Knick et al. 2005). Pinyon-juniper encroachment has been identified as a major threat to sage-grouse habitat preservation (e.g. Baruch-Mordo et al. 2013). However, prescribed burning is only cautiously utilized as a habitat treatment to reduce tree densities due to the significant potential for invasion by cheatgrass (Knick et al. 2005). These varying conclusions indicate that the complex impacts of fire and post-fire habitat restoration on sage-grouse populations are not fully understood, and highlight the need for research to determine the response of sage-grouse to wildfire rehabilitation efforts currently in practice across western North America. The State of Utah sage-grouse management plan (Plan; State of Utah 2013) provides for a 5-year window within which habitat may be restored prior to reclassifying disturbed areas as non-habitat. I tested whether areas burned by wildfire and subsequently reclaimed influenced predicted probability of sage-grouse habitat use, to determine if burned

patches warranted inclusion as designated habitat within a Sage-Grouse Management Area (SGMA) in southern Utah (State of Utah 2013).

STUDY AREA

The Bald Hills SGMA was 1 of 11 sage-grouse management areas located within the state of Utah (State of Utah 2013). It covered 1343 km², spanned across Beaver and Iron counties, and was located at the southern periphery of the entire sage-grouse range (Fig. 2-1, Utah Division of Wildlife Resources [UDWR] 2014, State of Utah 2013). Habitat within the SGMA boundary was primarily managed by the Bureau of Land Management (BLM) as well as private stakeholders and state agencies (State of Utah 2013). The SGMA contained 14 leks that were active during the study (Fig. 2-1), and had a maximum lek count of 148 males in 2015 (J. Nicholes, Utah Division of Wildlife Resources, unpublished data). The Bald Hills SGMA was a mountainous area which ranged from 1596 m in elevation in the southwest corner, at the Mud Springs lek, to 2314 m in the northwest portion of the study area. The average annual precipitation, recorded in the town of Minersville, was 26.5 cm. The study area was located in the Great Basin sagebrush ecosystem as defined by West and Young (2000), and differed notably from the sagebrush-steppe habitat that sage-grouse occupy in the central and northern parts of their range. Great Basin sagebrush regions are generally arid and desert-like. Specifically, shrubs are generally <1m in height, are less densely spaced, and are interspersed with loamy surface soils, microphytic crusts, and sparsely distributed grasses (West and Young 2000).

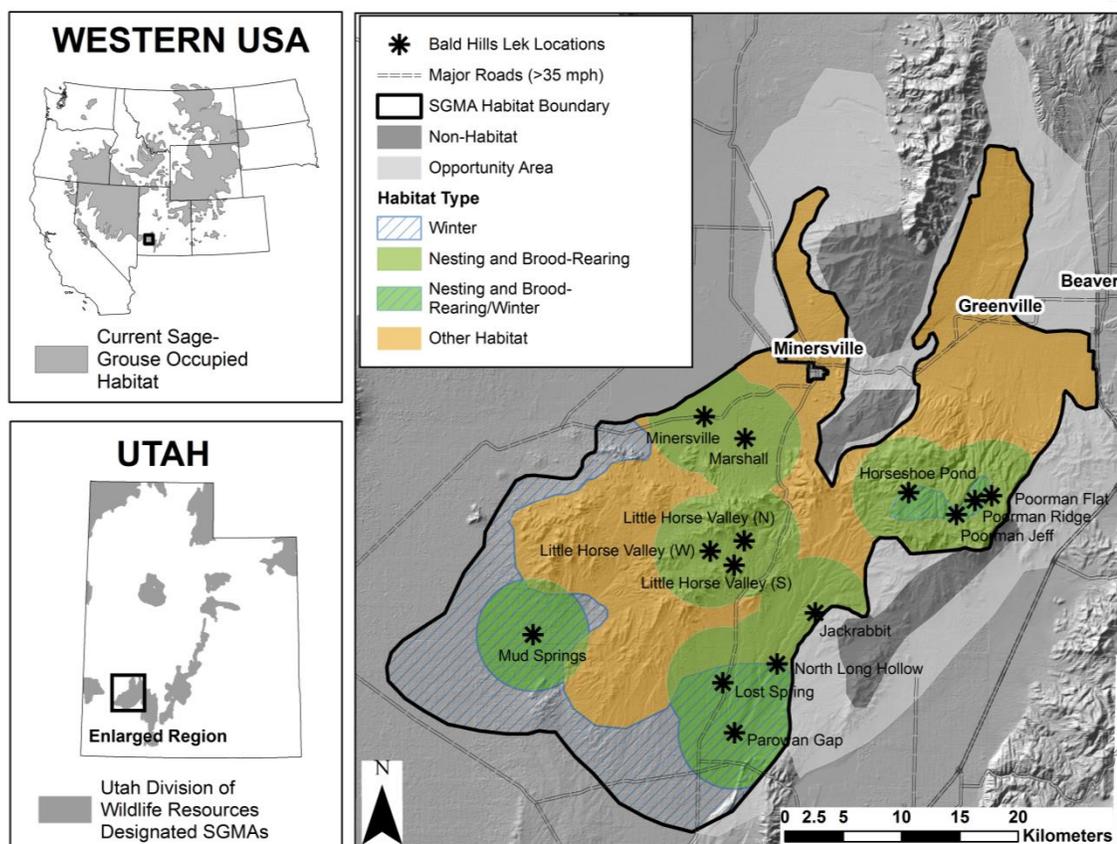


Figure 2-1. Location of the Bald Hills Sage-Grouse Management Area (SGMA) in southwestern Utah, USA, 2014-2016.

Sagebrush species in the Bald Hills consisted of mountain big sagebrush (*A. tridentata vaseyana*) at upper elevations and black sagebrush (*A. nova*) at lower elevations, with Wyoming big sagebrush (*A. tridentata wyomingensis*) present at moderate elevations and mixing with the other two species (Burnett 2013). Sand sagebrush (*A. fillifolia*) was also present in small quantities in the northwestern portion of the study area. In addition to sagebrush habitat, the study site contained large patches of pinyon-juniper forest; salt-desert shrub (dominant species included *Artiplex confertifolia*, *Krascheninnikovia lanata*, and *Salicornia* spp.); agricultural fields consisting of alfalfa

(*Medicago sativa*), and corn (*Zea* spp.); and disturbed areas that were characterized by native and non-native forbs and grasses.

The study area contained multiple sources of natural and anthropogenic landscape disturbance. Domestic cattle (*Bos* spp.) and sheep (*Ovis* spp.) grazing were common across the SGMA, and agricultural development was present in the northern portion of the site near the town of Minersville (pop. 907, U.S. Census Bureau 2012) and the unincorporated community of Greenville. Two 2-lane highways bisected the study area in the north-south and east-west directions (Fig. 2-1).

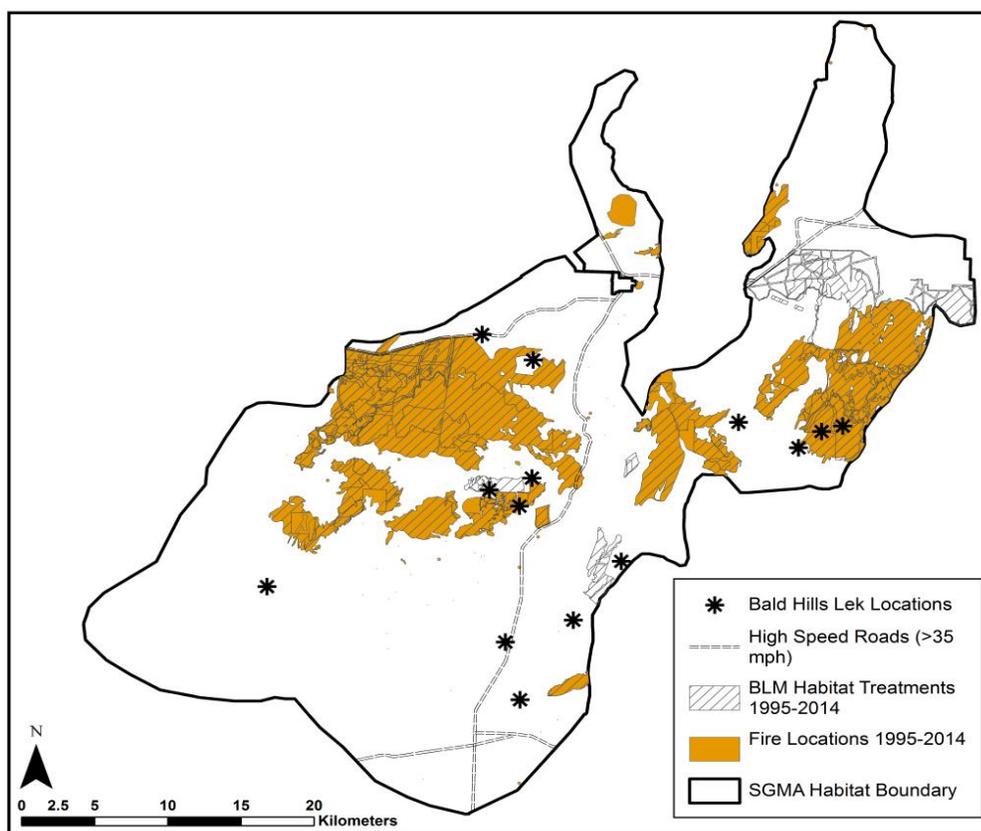


Figure 2-2. Locations of fires and Bureau of Land Management habitat treatments in the Bald Hills Sage-Grouse Management Area (SGMA), Utah, USA from 1995-2014. Habitat treatments overlapping fire zones indicate fire rehabilitation efforts such as reseeding or seed incorporation procedures via chaining (M. Mendenhall, Bureau of Land Management, unpublished data, 2015).

The study area also contained a mosaic of areas affected by wildfires of varying ages (Fig. 2-2), including four major wildfires in the last ten years: the Greenville Bench, Wrangler, Black Mountain, and Baboon Wildfires (Table 2-1, Bureau of Land Management [BLM] 2014).

Table 2-1. Fires with areas $>0.03 \text{ km}^2$ in the Bald Hills SGMA, Utah, USA from 1995 through 2014. Year Reclaimed indicates the year reclamation was first initiated, and Years to Reclamation indicates the temporal gap between the fire occurrence and initial reclamation implementation.

Fire Name ¹	Fire Year	Area (km^2) ²	Year Reclaimed	Years to Reclamation
Lowe	1997	1.98	1999	2
Mahagony	1998	1.16	1998	0
Pdog Tebbs Rx ³	1998	1.39	1998	0
Maple Spring	2002	10.17	2002	0
Mound	2005	1.08	2012	7
Neck	2005	19.96	2005	0
Baboon	2006	5.33	2009	3
Baboon 2	2006	9.26	2006	0
Chipman	2006	1.54	2006	0
Badjer	2006	30.95	2006	0
Narrows	2008	2.55	2008	0
RX Phase I ³	2009	50.83	2009	0
Greenville	2010	15.98	2010	0
Badger Fire	2010	1.42	2010	0
Hot Springs	2010	1.30	2010	0
Wrangler	2011	33.52	2011	0
Baboon	2012	80.04	2012	0
Round About	2012	9.95	2014	2
Black Mountain	2013	16.38	2013	0
Gap	2013	2.37	2013	0
Pioneer	2013	1.40	2013	0

¹Fire perimeter data obtained from Utah BLM Fire History Data.

http://www.blm.gov/ut/st/en/prog/more/geographic_information/gis_data_and_maps.html

²Area reflects surface area of fire perimeter located in habitat considered available to sage-grouse within the Bald Hills SGMA

³Prescribed burn conducted by the Bureau of Land Management [BLM]

Most (93%) of areas impacted by these fires had been treated and reseeded by the BLM (Fig. 2-2, Table 2-1) to support the establishment of forbs, perennial grasses, and shrubs (M. Mendenhall, Bureau of Land Management, unpublished data; Burnett 2013). Comparison with LANDFIRE Existing Vegetation Type data from 2001 (LANDFIRE 2001) indicated that 41% of the total study area burned since 2001 occurred in pinyon-juniper forest, 43% occurred in sagebrush, and 16% occurred in other habitats. Of the sagebrush and other habitats that burned, many were in direct proximity to pinyon-juniper forest, with the average distance of each burned patch to pinyon-juniper forest ranging from 0 km - 1.59 km.

METHODS

Sage-Grouse Capture and Data Collection

I deployed Global Positioning System (GPS)/Platform Transmitting Terminal (PTT) transmitters (22g Model PTT-100, Microwave Telemetry Inc., Columbia, MD) on male and female sage-grouse in the springs of 2014 and 2015. Transmitters were programmed to record 4 GPS locations/day for download once weekly through the Argos satellite data collection system (Argos System, CLS America, Lanham, MD). Locations were recorded at 0200, 0700, 1300, and 2100 daily, local time, to ensure habitat use was accurately represented throughout each 24-hour period. Sage-grouse were captured using standard spotlight methodology (Wakkinen et al. 1992). Individuals were captured in the vicinity of the Mud Springs lek and the Little Horse Valley lek complex. These 2 areas had the highest numbers of breeding individuals within the study area (J. Nicholes, UDWR, unpublished data, 2015), and were the 2 closest lekking areas to the West-Wide

Energy Corridor containing the SRB and IPP transmission lines. The PTT-100 transmitters used in this study recorded GPS locations as well as additional locations derived from the position of the transmitter in relation to the Argos receiving satellites (Microwave Telemetry, Inc. 2016). The Argos location data were qualified by an assigned location class indicating the reliability of each data point. The highest quality locations were assigned a value of LC3, which indicated that the location was accurate to ± 250 m (Collecte Localisation Satellites 2014). Visual examination of these locations in comparison to GPS location data collected at similar times indicated that this error radius was typically much smaller than 250 m. Thus, the GPS data for an individual was supplemented with the highest-quality Argos data (LC3) for analysis in the rare event of a GPS component malfunction.

Spatial and Temporal Extents of Analysis

I defined the summer season as ranging from May 31 – October 21 for both years. These seasonal dates were chosen because they corresponded with dates found through previous research in the area (Burnett 2013) and were slightly more conservative than movement patterns observed in the summers of 2014 and 2015 (i.e. the last bird arrived in summer habitat just prior to May 31 and the first bird left summer habitat just after October 21). Another recent study in Utah defined the summer season as ranging from June 15 – August 31 for all populations across the state from 1998-2013 (Dahlgren et al. 2016). However, my definition of the summer season was utilized for this analysis because it most accurately reflected specific habitat use for the Bald Hills population across the years in question. Data were pooled from both years to increase the number of

locations per bird, but bird identity information was retained to allow for variation in habitat selection between individuals.

Post-priori, based on the data collected through both summer seasons, I updated the SGMA boundary for analysis to more accurately represent the spatial extent of habitat available to sage-grouse in the Bald Hills. No sage-grouse locations were detected north of HWY 21 during the course of the study, so I clipped the sage-grouse habitat polygon to only include habitat south of HWY 21 using the Split Polygons with Lines tool in ArcGIS Desktop version 10.3 (Environmental Systems Research Institute, Redlands, CA software). This resulted in 1243.8 km² of available habitat located south of HWY 21 and within the SGMA boundary.

Predictor Variables

To analyze sage-grouse habitat use within the study area, I selected multiple spatial covariates shown to be biologically related to sage-grouse habitat use (Burnett 2013, Arkle et al. 2014; Table 2-2). These included landcover, distance to high speed roads, distance to low speed roads, distance to water, elevation, slope, aspect, (Burnett 2013), and mean July normalized difference vegetation index (NDVI; Aldridge and Boyce 2007, Dinkins et al. 2014). To produce my final landcover layer, I combined LANDFIRE 2012 Existing Vegetation Type data (LANDFIRE 2012) with spatial data showing landscape disturbance in the Bald Hills using ArcGIS Desktop (Version 10.3, Environmental Systems Research Institute, Redlands, CA).

Table 2-2. Predictor variables selected *a priori* and allowed to compete in final resource selection function model development for summer habitat selection of greater sage-grouse (*Centrocercus urophasianus*) in the Bald Hills Sage-Grouse Management Area, Utah, USA.

Variable	Type	Resolution	Description (units)
Landcover (<i>evt.f</i>) ¹	Categorical	30 m	LANDFIRE 2012 Existing Vegetation Type updated to include burned and treated patches
Aspect (<i>asp.f</i>)	Categorical	30 m	calculated from 30 m DEM (km)
Slope (<i>slope_rad</i>)	Continuous	30 m	calculated from 30 m DEM (radians)
Elevation (<i>DEM</i>)	Continuous	30 m	30 m DEM (km)
Elevation ² (<i>DEM</i> ²)	Continuous	30 m	squared term for elevation
Mean July NDVI (<i>ndvi</i>)	Continuous	250 m	averaged 2014/2015 Normalized Difference Vegetation Index values for 12 July in each year
Distance to Water (<i>dist_water</i>)	Continuous	30 m	distance to nearest water source
Distance to Low Speed Roads (<i>dist_rdlow</i>)	Continuous	30 m	distance to ≤ 56.33 km/hr (≤ 35 mph) roads (km)
Distance to Low Speed Roads ² (<i>dist_rdlow</i> ²)	Continuous	30 m	squared term for distance to low speed roads
Distance to High Speed Roads (<i>dist_rdhi</i>)	Continuous	30 m	distance to > 56.33 /hr (> 35 mph) roads (km)

¹Landcover categories included NonHabitat (not considered available), Forest, Developed, Grass, OtherShrub (non-sage shrub), Juniper, Agriculture, SaltDesert, Treated (treatment other than wildfire reclamation), OldBurn (11-20 years ago), and NewBurn (0-10 years ago). Refer to Appendix Table A-1

²Squared term, indicating a non-linear relationship with response variable

³Aspect categories represented the compass direction of the downslope topography, partitioned by direction into categories including North ($337.5^\circ - 22.5^\circ$), Northeast ($22.5^\circ - 67.5^\circ$), East ($67.5^\circ - 112.5^\circ$), Southeast ($112.5^\circ - 157.5^\circ$), South ($157.5^\circ - 202.5^\circ$), Southwest ($202.5^\circ - 247.5^\circ$), West ($247.5^\circ - 292.5^\circ$), and Northwest ($292.5^\circ - 337.5^\circ$).

I obtained detailed spatial polygon data representing habitat treatments and wildfires that occurred in the Bald Hills from 1995-2014 (M. Mendenhall, Bureau of Land Management, unpublished data, 2015; Bureau of Land Management [BLM] 2014) and converted them to raster data using the Polygon to Raster tool. Because nearly all of

the burned areas were covered by treatment polygons (Fig. 2-2), I generalized that all burned areas within the Bald Hills had undergone some type of rehabilitation treatment. The rasterized treatment and wildfire layer represented areas burned 0-10 years ago and had been rehabilitated (NewBurn), 11-20 years ago and had been rehabilitated (OldBurn), and areas that were treated for purposes other than wildfire reclamation (Treated). New Burns were given the highest priority, so that if an area was historically treated but then subsequently burned, it was classified in the NewBurn group. Prescribed burns were included in the Burn category corresponding with the year they were conducted. They were excluded from the Treated category because they were more likely to represent post-wildfire landscape conditions than mechanical or chemical habitat treatments. When all raster cells were appropriately classified in my wildfire and treatment layer, I used the Raster Calculator to update the LANDFIRE raster to reflect NewBurn, OldBurn, and Treated patches. I then collapsed the habitat categories provided by the LANDFIRE 2012 data to produce 12 final habitat categories (Appendix Table A-1, Fig. 2-3).

I obtained 30-m Digital Elevation Model data (DEM; Utah Automated Geographic Reference Center [AGRC], www.gis.utah.gov, accessed 16 March 2014) and used it to derive Slope (radians) and Aspect (categorical, 8 categories) layers for my analysis in ArcGIS 10.2.2. I calculated distance to roads (Road Centerlines; Utah AGRC, accessed 16 March 2014) and distance to water (Lakes, Streams, and Springs layers; Utah AGRC, accessed 17 March 2014) by creating rasters reflecting Euclidean distance from these features by using the Euclidean Distance tool in ArcGIS 10.2.2. Roads were categorized into 1) high speed and 2) low speed.

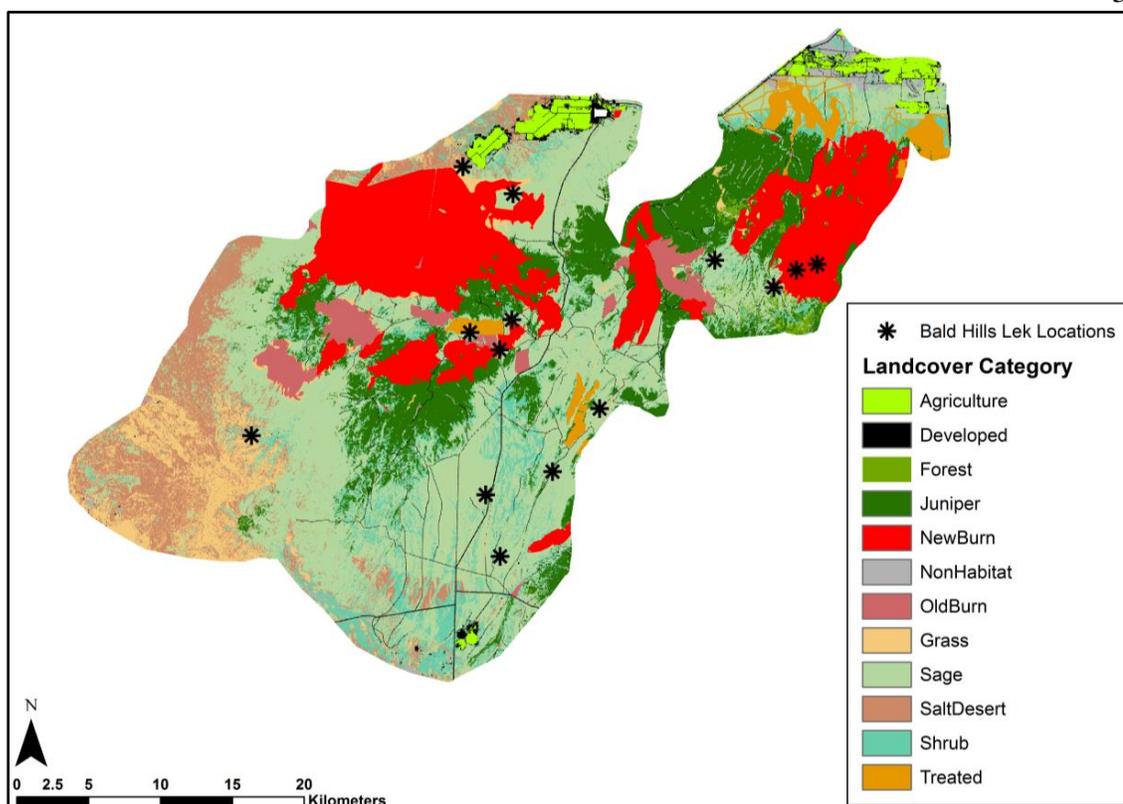


Figure 2-3. Landcover categories present within the available habitat boundary used in resource selection function modeling for summer greater sage-grouse (*Centrocercus urophasianus*) habitat use in the Bald Hills Sage-Grouse Management Area, Utah, USA, 2014-2015.

High speed roads were roads with posted speeds >35 mph, and included paved, 2-lane highways. Low speed roads were roads with posted speeds ≤ 35 mph, and included single-lane paved roads, dirt roads, and two-tracks. I only included streams identified as “major” in my distance to water category because location checks of several smaller streams indicated that these were ephemeral and therefore could not be reliably included as a spatial predictor of sage-grouse presence. For my NDVI covariate, I obtained Moderate Resolution Imaging Spectroradiometer [MODIS] MOD13Q1 16-day 250m NDVI tiles (Land Processes Distributed Active Archive Center (LP DAAC), accessed 1 Nov 2016) for Julian day 193 (12 July) for the summers of 2014 and 2015. I used data

from 12 July because it was likely that most types of vegetation were at heightened productivity around that time period, and similar data had been included in other studies of sage-grouse habitat selection (Aldridge and Boyce 2007). This data was projected from sinusoidal (SIN) to North American Datum 83 (NAD83) using the Modis Reprojection Tool (<https://lpdaac.usgs.gov/tools/modis_reprojection_tool>, accessed 1 Nov 2016). The two tiles were then averaged using the Cell Statistics tool in ArcGIS 10.2.2 to produce a raster representing mean July NDVI values across the two summer seasons.

Resource Selection Function Analysis

I used a resource selection function (RSF) framework to compare second-order selection (Johnson 1980) of habitat used by sage-grouse in the summer months to available habitat within the Bald Hills SGMA under a used-available design (Manly et al. 2002). Resource selection functions are a form of habitat suitability index (HSI) that incorporates statistical rigor to predict the relative probability of use for locations within an area of interest (Boyce et al. 2002). RSFs are generally estimated using logistic regression (regression modeling with a specified logit-link function) to approximate the relative probability of use within a specified area (Manly et al. 2002, Hosmer et al. 2013). The regression in this context compares used habitat to available habitat (as opposed to truly unused habitat), because GPS location data collected at specified time intervals cannot represent with certainty where animals were between data collection periods. Thus, this results in a *relative* probability of use rather than a *true* probability of use, but is still a useful representation to predict selection across a landscape (Manly et al. 2002).

Recently, advances in GPS transmitter technology have exponentially increased the amount of data available regarding animal space use. However, this has resulted concerns about spatial and temporal autocorrelation between points collected repeatedly within an individual, which can bias habitat use estimates (Nielsen et al. 2006), particularly when large differences exist between sample sizes per individual. To adjust for this, Gillies et al. (2006) recommended including a random intercept for each individual into the model. I incorporated this into my final RSF structure, which took the form of a generalized linear mixed-model (GLMM; Bolker et al. 2009). The logit form of my final RSF ($g(x)$) was calculated as follows for location i of individual j where γ_{0j} is the random intercept for individual j (Gillies et al. 2006):

$$g(x) = \beta_0 + \beta_1 x_{1ij} + \beta_2 x_{2ij} + \dots + \beta_n x_{nij} + \gamma_{0j}$$

In the context of a use-availability design, β_0 is meaningless and is conventionally dropped, however it still affects the estimates for fixed-effects coefficients (Manly et al. 2002, Gillies et al. 2006). Points to represent available habitat were randomly generated within the available habitat boundary at a 1:1 ratio with used points. Because no used points occurred in the non-habitat landcover category, I assumed that these areas were unavailable to birds for selection and no random points were generated in non-habitat. This resulted in 11 landcover categories included in the landcover covariate for the final analysis. Points representing available habitat were joined with used sage-grouse locations into a single data set within ArcGIS, and values for all predictor variables were extracted using the Extract Multi Values to Points tool.

Each variable was initially checked for outliers and nonlinearities. Variables were then screened for collinearity by calculating Pearson's correlations between all

continuous variable pairs (Hosmer et al. 2013). No variables were collinear (Pearson's correlation coefficient >0.6) so all variables were considered for final model development. All continuous variables were mean-centered prior to analysis. Preliminary investigation of the data set indicated that some predictors (distance to low speed roads and elevation) may have a non-linear relationship to probability of use, so a set of candidate models was developed *a priori* using the lme4 package in R (R version 3.1.3, www.r-project.org, accessed 12 Dec 2015) and allowed to compete within a hierarchical information-theoretic framework corrected for small sample sizes (AIC_c; Boyce et al. 2002, Burnham and Anderson 2002) to determine the best fit model. I used Sage as the reference category for my landcover covariate, as the relationship between sage-grouse and sagebrush is well-documented and this aided in interpretation of the other vegetation coefficients. I used East as the reference category for Aspect because I expected that perceived heat exposure would differ between cardinal directions, as north-facing slopes would be cooler, while south slopes would be warmer and west-facing slopes would be of moderate temperature.

Model Validation

The ultimate test of the reliability of an RSF is how well it predicts species use of landscapes across space and time (Johnson et al. 2006). To assess model fit, the final RSF was validated both internally through k-fold cross-validation (Boyce et al. 2002), and externally by remapping the RSF using older landcover and NDVI predictor variables and comparing model fit with independently collected very high-frequency (VHF) data from the Bald Hills in 2011-2012 (Burnett 2013). I divided the individuals

from the main (2014-2016) data set into 5 randomly assigned folds, thus preserving the random effect for individual included in the GLMM model structure. The top RSF model was then refit 5 times, each time withholding a different fold of test data. The refit RSFs were mapped across available habitat in the Bald Hills using ArcGIS 10.3, and divided into 10 quantile (equal-area) bins of increasing rank (1 = very low quality habitat, 10=very high quality habitat). I extracted the frequency of test fold data points that fell in each bin for all 5 refit RSF models. I then calculated Spearman rank correlations to test the correlation between frequency of use by the withheld test fold locations and increasing bin ranks of habitat quality (Boyce et al. 2002, Aldridge and Boyce 2007) expecting that as bin rank increased, frequency of use should also increase.

Although internal validation of an RSF provides insight on its' effectiveness, the best test of an RSF is independent validation with an external data set (Boyce et al. 2002). I obtained VHF data collected from sage-grouse in the Bald Hills from 2011-2012 (Burnett 2013) to assess how well my model performed across different individuals and differing temporal scales in the Bald Hills. Individuals from the 2011-2012 study were caught at all active leks in the Bald Hills during the 2011 and 2012 seasons, which differed from my 2014-2015 study which only included birds from two lek complexes. I used the same seasonal cutoff dates that were applied for the 2014-2016 model. However, in the summer of 2012, VHF locations were only collected through 16 Aug so the summer season extended from 31 May to 16 Aug for that year.

To ensure that temporally dynamic covariates were appropriately applied to this model, I used NDVI, vegetation type, and wildfire/treatment data that better reflected landscape characteristics during the summers of 2011 and 2012 to update predictor

variables accordingly. I used Julian day 193 (12 July) NDVI tiles from 2011 and 2012 and combined them to generate a mean July NDVI layer in the same manner as the NDVI predictor for the original model. I combined wildfire, treatment, and 2010 LANDFIRE existing vegetation type data in the same method as the original model, but reflecting a time frame of 1993-2012. Two large wildfires occurred in the end of 2012 (Baboon, 80 km², ignited 13 July 2012 and contained 22 July 2012; Roundabout, 10 km², ignited 1 Oct 2012, and contained Oct 5 2012, Bureau of Land Management [BLM] 2014) but they were not included in the landcover layer for the 2011/2012 validation because the Baboon fire occurred near the end of the study when no birds were in the vicinity (Burnett 2013), and the Roundabout fire occurred after the conclusion of summer data collection for that year.

RESULTS

Sage-Grouse Location Data Collection

In the initial trapping event (Spring 2014) I deployed 10 transmitters on birds from the Mud Springs lek (n = 7 adult males, n = 3 juvenile males) and 10 transmitters on birds from the Little Horse Valley lek complex (n = 5 juvenile females, n = 3 adult males, n = 1 juvenile male, and n = 1 male of unknown age). I did not capture any female sage-grouse at Mud Springs, so transmitters were only deployed on males at that location. As individuals died or transmitters fell off, they were refurbished by Microwave Telemetry and deployed on new individuals. I redeployed 4 transmitters at the Mud Springs lek in February of 2015, just prior to the initiation of lekking (n = 4 adult males). In the final trapping event in the spring of 2015, I redeployed 2 more transmitters on adult males in

the Little Horse Valley area. Thus, in total, my sample for the entire study across all seasons consisted of 26 individual sage-grouse (n = 5 juvenile females, n = 16 adult males, n = 4 juvenile males, and n = 1 male of unknown age).

Table 2-3. Individual sage-grouse location data collected from the summers of 2014 and 2015 and used for final resource selection function modeling of summer habitat selection for greater sage-grouse (*Centrocercus urophasianus*) in the Bald Hills Sage-Grouse Management Area, Utah, USA.

Bird_ID	Capture Lek	Sex	Number of Locations
LH10	Little Horse Valley	Female	489
LH12	Little Horse Valley	Male	557
LH13	Little Horse Valley	Male	551
LH14	Little Horse Valley	Male	85
LH2	Little Horse Valley	Male	60
LH4	Little Horse Valley	Male	1087
LH5	Little Horse Valley	Male	106
LH7	Little Horse Valley	Female	971
LH8	Little Horse Valley	Female	560
LH9	Little Horse Valley	Female	566
MS1	Mud Springs	Male	1132
MS10	Mud Springs	Male	905
MS11	Mud Springs	Male	881
MS12	Mud Springs	Male	406
MS13	Mud Springs	Male	541
MS14	Mud Springs	Male	548
MS15	Mud Springs	Male	561
MS3	Mud Springs	Male	968
MS5	Mud Springs	Male	1100
MS8	Mud Springs	Male	378
MS9	Mud Springs	Male	1035

Because the number of females captured was small, and nesting and brood-rearing females select for habitat differently than non-reproductive birds (e.g. Connelly et al. 1988, Gregg et al. 1993), I focused on males and broodless hens for modeling of summer seasonal habitat selection. The RSF analysis for the summers of 2014 and 2015 utilized data from 21 non-reproductive individuals and included 13487 locations. Number of locations per bird ranged from 60 to 1132, depending on the length of transmitter deployment for that particular bird (Table 2-3). The VHF data set from 2011 and 2012 used for validation contained 604 locations from 54 male and non-nesting and broodless female sage-grouse collected from the summers of 2011 and 2012.

Summer Seasonal Resource Selection

I used 13487 sage-grouse locations (Table 2-3) to assess habitat use across 1243.8 km² of available habitat within the Bald Hills SGMA. All covariates selected *a priori* were significant in univariate model analyses ($p < 0.05$), so all were included in the final model selection process. Comparison of models indicated that a full model which included quadratic terms for both elevation and distance to low speed roads performed much better ($>2 \Delta AIC_c$, Table 2-4) than all other models, so this model was selected as the final model for the RSF analysis. The overall top model included landcover (*evt.f*), aspect (*asp.f*), elevation ($DEM_km + DEM_km^2$), slope (*slope_rad*), distance to water (*water_km*), distance to roads >35 mph (*roadhi_km*), and distance to roads ≤ 35 mph ($roadlow_km + roadlow_km^2$), and mean July NDVI (*ndvi*). Within the landcover category, NewBurn was selected for most strongly (Table 2-5) followed by Treated areas, Agriculture, and OldBurn areas when compared to sage as a reference category.

Table 2-4. Akaike information criterion (AIC_c)-ranked candidate resource selection function models for summer greater sage-grouse (*Centrocercus urophasianus*) habitat selection in the Bald Hills Sage-Grouse Management Area, Utah, USA 2014-2015.

Model	AIC _c	ΔAIC _c	ω _i
<i>evt.f + asp.f + dem_km + dem_km² + slope_rad + water_km + roadhi_km + roadlow_km + roadlow_km² + ndvi</i>	20642.9	0	0.999
<i>evt.f + asp.f + dem_km + dem_km² + slope_rad + water_km + roadhi_km + roadlow_km + ndvi</i>	20657.6	14.63	0.001
<i>evt.f + asp.f + dem_km + slope_rad + water_km + roadhi_km + roadlow_km + roadlow_km² + ndvi</i>	21330.7	687.78	0.000
<i>evt.f + asp.f + dem_km + slope_rad + water_km + roadhi_km + roadlow_km + ndvi</i>	21344.1	701.13	0.000

Table 2-5. Beta coefficients (β_i) and standard errors (SE) for final resource selection function model describing summer habitat use by greater sage-grouse (*Centrocercus urophasianus*) in the Bald Hills Sage-Grouse Management Area, Utah, USA from 2014-2015. Non-significant (p < 0.05) variables within categorical predictors are delineated with dashes (-).

Landcover	β _i	SE	Aspect	β _i	SE	Continuous Predictors	β _i	SE
Forest	-1.88	0.31	Flat	-1.18	0.37	Elevation (km)	-0.69	0.17
Developed	0.87	0.13	N	0.36	0.08	Elevation ² (km)	9.57	0.38
Grass	-	-	NE	-0.24	0.09	Distance to Water	-0.96	0.03
Shrub	0.75	0.08	SE	-	-	Slope (radians)	-6.69	0.30
Juniper	-1.58	0.15	S	-0.28	0.09	Distance to Roads <35 mph (km)	1.96	0.06
Agriculture	1.17	0.13	SW	-0.26	0.09	Distance to Roads <35 mph ² (km)	-0.36	0.09
Salt Desert	0.49	0.08	W	0.32	0.08	Distance to Roads >35 mph (km)	-0.06	0.01
Treated	2.14	0.11	NW	0.86	0.07	Distance to Roads >35 mph (km)	-0.06	0.01
OldBurn	1.41	0.12				Distance to Roads >35 mph (km)	-0.06	0.01
NewBurn	2.84	0.06				Mean July NDVI	3.50	0.26

Sage-grouse also showed selection for north, northwest, and west aspects, lower angle slopes, and high mean July NDVI values. Probability of use was negatively associated with juniper and forest habitats, and northeast, south, southwest, and flat aspects. Birds also selected for high and low elevations while avoiding moderate elevations. Distance to low speed roads, high speed roads, and water are all classified as “distance to” categories, thus the direction of their coefficients needs to be reversed when interpreting selection or avoidance. For example, $\beta_{\text{water_km}} = -0.96$ indicates that as distance to water goes up, probability of use goes down. Thus, sage-grouse selected for areas closer to water, moderate distances from low speed roads, and show a weak effect of selecting for areas closer to high speed roads.

Model Validation

The model performed well in both internal (k-fold) and external validation tests (Table 2-6).

Table 2-6. Spearman-rank correlations (r_s) for internal k-fold cross-validation of final resource selection function model and external validation using 2011-2012 Very High Frequency data collected within the Bald Hills Sage-Grouse Management Area, Utah, USA from 2014-2015.

Test Fold	r_s	p-value
1	0.988	< 0.001
2	0.902	<0.001
3	0.952	< 0.001
4	0.960	<0.001
5	0.927	<0.001
Mean r_s across folds	0.946	-
External 2011-2012 Validation	0.900	0.004

Four folds contained four individuals and the fifth fold contained 5 individuals. The average Spearman rank correlation coefficient (r_s) for the k-fold cross-validation was 0.96 across all 5 folds, while external validation resulted in $r_s = 0.900$ ($p < 0.005$). The mapped RSF exhibited strong predictive capacities across available habitat in the Bald Hills SGMA for the 2014-2015 and 2011-2012 studies (Figs 2-4 and 2-5).

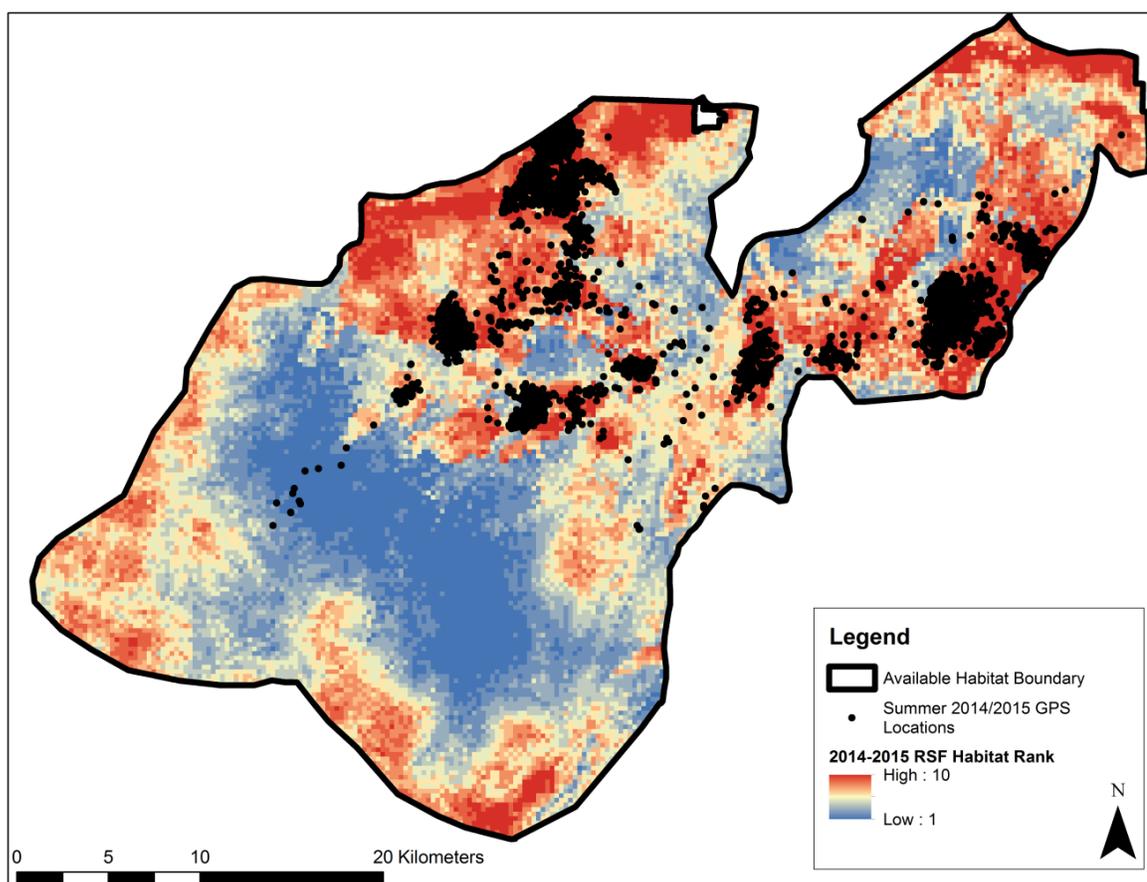


Figure 2-4. Mapped resource selection function model for available habitat within the Bald Hills Sage-Grouse Management Area, Utah, USA. Habitat is split into 10 equal-area bins indicating relative probability of use for non-reproductive sage-grouse during the summer months (1 = low, 10 = high). Black points indicate locations used by greater sage-grouse (*Centrocercus urophasianus*) in the summers 2014 and 2015.

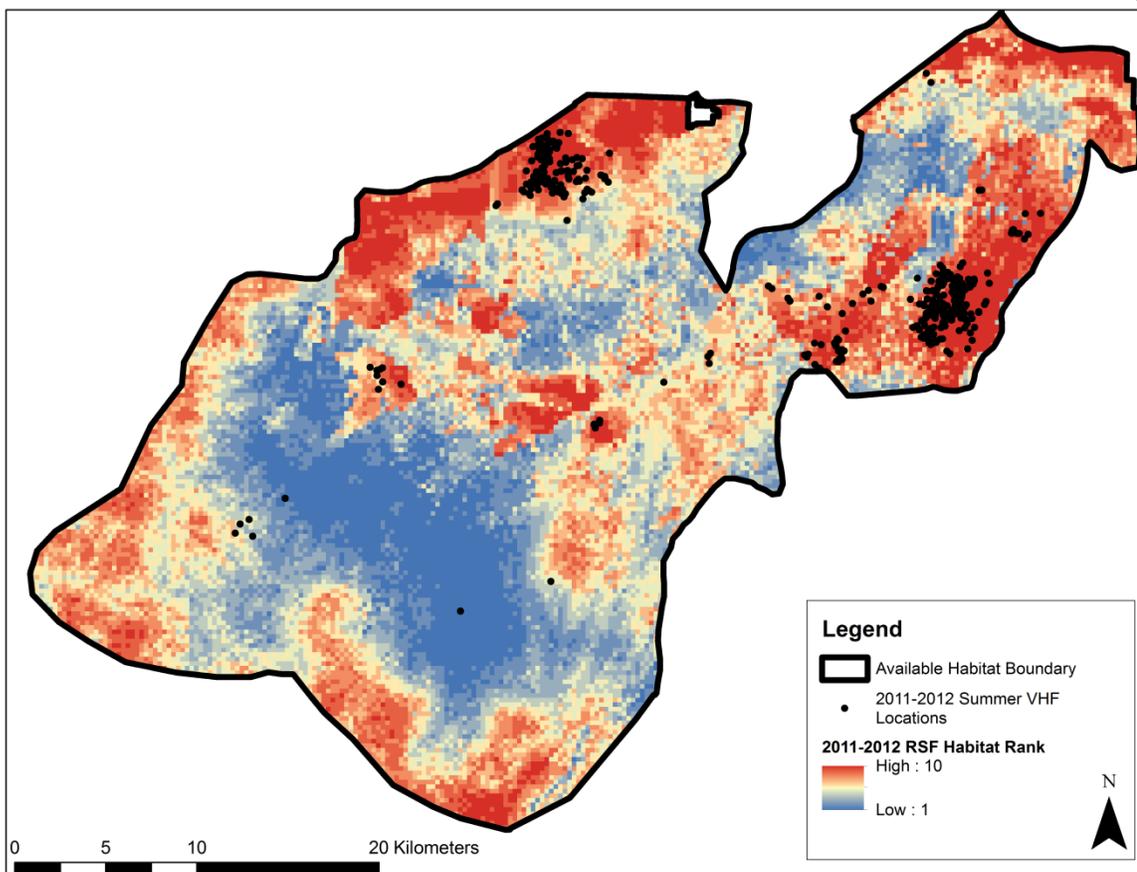


Figure 2-5. Resource selection function model mapped for available habitat within the Bald Hills Sage-Grouse Management Area using 2010 LANDFIRE data, wildfires and habitat treatments from 1993-2012, and mean July Normalized Difference Vegetation Index (NDVI) from July of 2011 and 2012. Habitat is split into 10 equal-area bins indicating relative probability of use (1 = low through 10 = high). Independently collected greater sage-grouse (*Centrocercus urophasianus*) locations from the summers of 2011 and 2012 are displayed in black.

Examination of frequency histograms (Figs. 2-6 and 2-7) displaying RSF-predicted habitat rank for used locations in both the 2014-2015 and 2011-2012 time periods also suggested that the model accurately predicted used locations, with most used locations falling in bin 10, or the bin with the highest ranked probability of use.

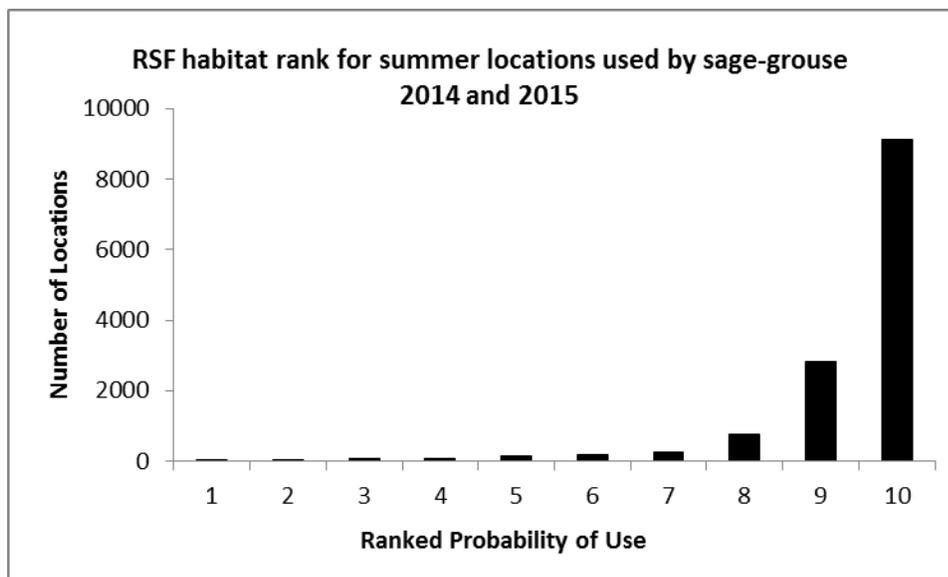


Figure 2-6. Frequency histogram of resource selection function (RSF)-derived habitat ranks for greater sage-grouse (*Centrocercus urophasianus*) locations collected from the summers of 2014 and 2015 in the Bald Hills Sage-Grouse Management Area, Utah, USA. Ranks were derived by mapping the RSF and dividing into 10 equal-area bins of increasing predicted probability of use (bin 1 = low through 10 = high).

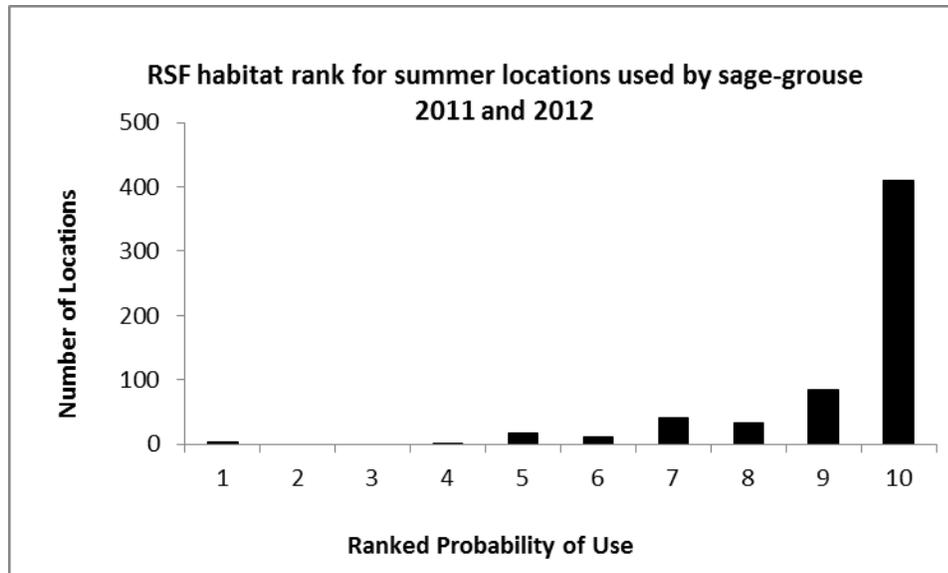


Figure 2-7. Frequency histogram of resource selection function (RSF)-derived habitat ranks for greater sage-grouse (*Centrocercus urophasianus*) locations collected from the summers of 2011 and 2012 in the Bald Hills Sage-Grouse Management Area, Utah, USA. Ranks were derived by mapping the RSF using landscape covariates representative of that time period and dividing into 10 equal-area bins of increasing predicted probability of use (bin 1 = low through 10 = high).

DISCUSSION

Sage-grouse in the Bald Hills showed preference for areas that had been burned in the last two decades, with stronger predicted probability of use for areas burned in the last 10 years. NewBurn patches were selected for more strongly than any landcover category with the exception of agricultural areas. The 2011-2012 validation confirmed that this model performed well across varying temporal scales, indicating that it could be useful for predicting the influence of wildfire on non-reproductive sage-grouse in the Bald Hills in future years. Additionally, because the birds for the 2011-2012 study were captured from all leks in the SGMA, these results indicate that the 2014-2016 model (which was developed for birds from two of the leks) is also applicable to birds captured from other locations within the Bald Hills. Because nearly all of the major wildfires included in my analysis underwent reclamation efforts within a year of disturbance (Table 2-1), it was not possible to test the influence of delay of wildfire reclamation on likelihood of habitat use. However, my results show that areas that were reclaimed within one year of wildfire were used by non-reproductive sage-grouse in the summer months. This is exemplified by the Baboon wildfire, which took place in 2012, was reclaimed in 2012, and was actively used by sage-grouse when I began collecting data in the summer of 2014 (Fig. 2-8).

I could not determine the mechanism driving this selection from my RSF model alone. However, it is possible that areas burned by wildfire had an altered vegetative community structure or increased levels of grasses or forbs (Nelle et al. 2000, Davis and Crawford 2015) when compared to other areas throughout the Bald Hills.

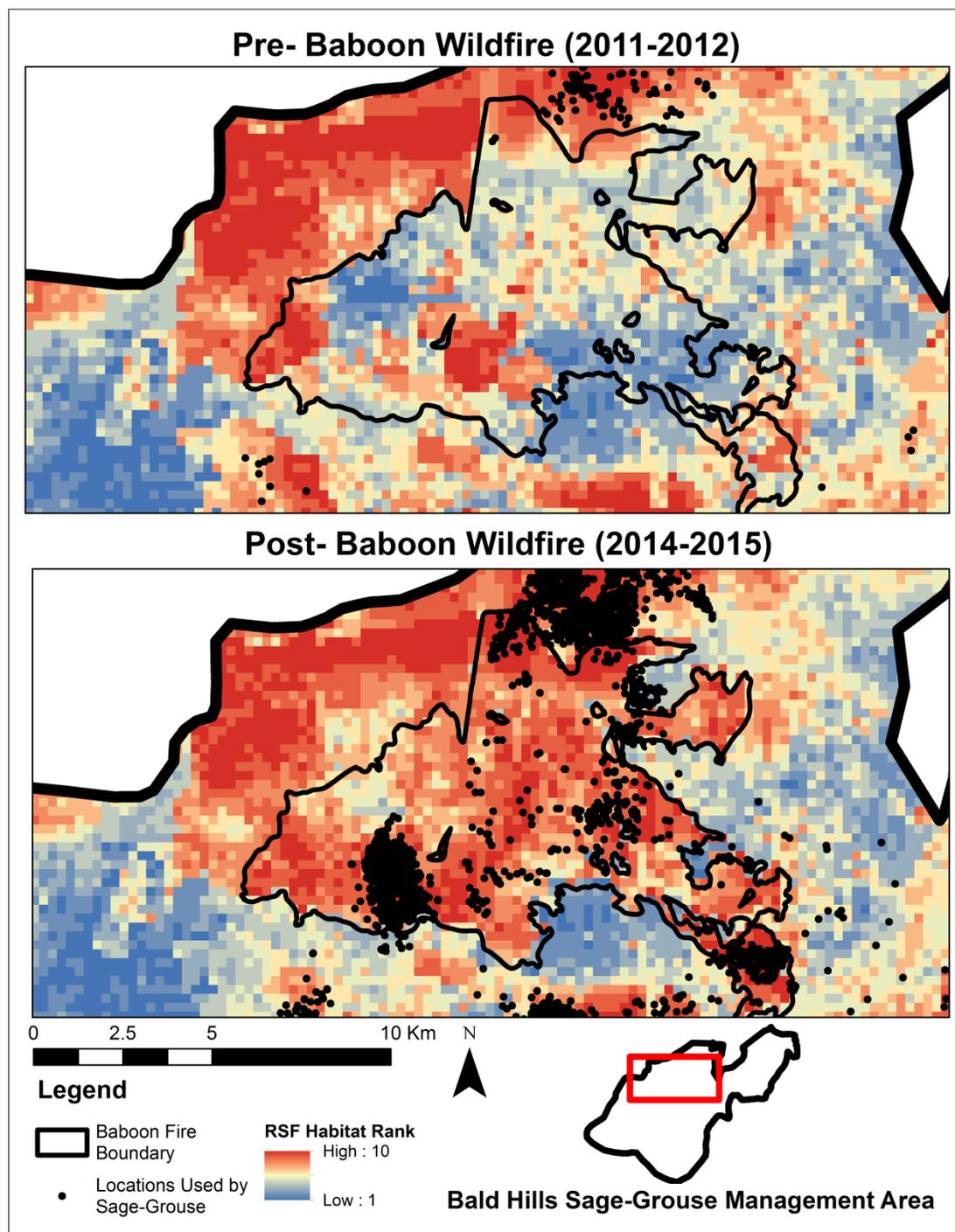


Figure 2-8. Non-reproductive greater sage-grouse (*Centrocercus urophasianus*) habitat use and ranked resource selection function (RSF)-predicted probability of summer use for the area burned by the 2012 Baboon wildfire in the Bald Hills Sage-Grouse Management Area (Utah, USA) both before and after the wildfire took place. Both RSF-predicted probability of use and actual use (proportion of recorded sage-grouse locations within the wildfire perimeter) were higher in the post-fire summers of 2014-2015.

Burnett (2013) conducted vegetation surveys at areas that were used by sage-grouse during the summer months and compared to randomly placed plots throughout the Bald Hills. She found that grass and forb canopy cover at used sites were within recommendations for productive sage-grouse habitat (Burnett 2013, Connelly et al. 2000b), while grass and forb canopy cover at randomly located sites was lower than recommended levels. Additionally, used sites had lower shrub canopy cover and less bare ground than randomly placed plots. This was supported by my visual observations of high-use areas that were recently burned in the Bald Hills, which were generally characterized by low shrub cover and a robust presence of native and non-native forbs and grasses (E. Hansen, personal observation, Fig. 2-9).



Figure 2-9. Area burned in the 2012 Baboon wildfire in the Bald Hills Sage-Grouse Management Area, Utah, USA. This area was used heavily by greater sage-grouse (*Centrocercus urophasianus*) during the summer months. This area was reclaimed post-fire by the Color Country Bureau of Land Management via reseeding with a mixture of native and non-native grasses and forbs (M. Mendenhall, Bureau of Land Management, unpublished data, 2015).

Although these areas appear to be fulfilling summer habitat requirements for non-reproductive birds that are not met by other areas within the SGMA, my RSF model did not incorporate any population demographic information, or specific information regarding vegetation community structure. Thus, I could not draw conclusions regarding the source-sink dynamics of burned areas on the landscape. It is possible that the reduction of cover from shrubs in burned zones could result in increased predation, and consequently, long-term population decline (Coates et al. 2015). Because these results only address habitat selection by non-reproductive birds, more research is required regarding survival and reproductive rates of the population within the SGMA to determine whether wildfire and subsequent reclamation efforts are beneficial or harmful to sage-grouse populations in the area across longer temporal scales.

Because non-reproductive individuals are not tied to broods, their habitat selection may be more reactive to current vegetative conditions. It is important to note that the seasonal variations in habitat required by sage-grouse are well-documented (e.g. Connelly et al. 2003), and that although these areas are selected for by non-reproductive individuals in the summer months, this change in available habitat could be occurring at the expense of winter or nesting and brood-rearing habitat needed during other times of the year. However, given that 41% of all wildfires in the Bald Hills since 2001 occurred in pinyon-juniper habitat, and pinyon-juniper habitat is avoided by sage-grouse across life stages (e.g. Baruch-Mordo et al. 2013) this factor is likely to only partially influence habitat dynamics of areas burned by wildfire within the Bald Hills.

The Utah Plan provides a 5-year window for the reclamation of sage-grouse habitat after disturbance (State of Utah 2013). If reclamation does not occur within that

time period, the habitat is re-designated as non-habitat. My results provide support for this guideline, because I observed sage-grouse utilizing habitat within two years of a major wildfire (Fig. 2-8), and there was a high RSF-predicted probability of habitat use in areas that had been burned and promptly reclaimed (Table 2-5). Although shrub cover can take many years to reestablish (Nelle et al. 2000), these results show that burned and reclaimed patches can be utilized by non-reproductive birds within just a few years, and highlights the need for a swift implementation of reclamation activities following wildfire in sage-grouse habitat.

MANAGEMENT IMPLICATIONS

Defining specific predictors of habitat use is of heightened importance for peripheral populations, because they may occupy habitat that differs from population core areas. Thus, they may exhibit locally-specific seasonal habitat preferences and may respond in unique ways to environmental perturbations such as wildfire. Non-reproductive sage-grouse in the Bald Hills selected for areas that were recently burned and reclaimed during the summer months, and showed greater preference for areas that burned within the last 10 years. This highlights the effectiveness of, and importance of continuing, wildfire reclamation efforts in the Bald Hills. The burned zones that sage-grouse utilized in the Bald Hills: 1) primarily occurred directly within, or in habitat adjacent to, pinyon-juniper communities, and 2) had nearly all undergone some type of reclamation activity. 93% of the patches burned by major wildfires in the last 20 years were reclaimed by the Color Country BLM Field Office (Bureau of Land Management [BLM] 2014, M. Mendenhall, Bureau of Land Management, unpublished data, 2015),

with an average delay between wildfire and initial reclamation effort of less than one year. This supports guidelines in the Utah Plan which allow 5 years for reclamation efforts to take effect prior to reclassifying disturbed areas as non-habitat. My results suggest that areas burned by wildfire and reclaimed can be utilized by sage-grouse within two years post-fire, and that these patches can positively influence probability of habitat use for up to 20 years post-fire. Because these areas show potential to be utilized heavily by a portion of the Bald Hills population during the summer months, implementing restoration actions prior to cheatgrass invasion should be a continued priority for land managers.

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CHAPTER 3

INFLUENCE OF TRANSMISSION LINE CONSTRUCTION ON WINTER SAGE-GROUSE HABITAT USE IN SOUTHERN UTAH¹**ABSTRACT**

The construction and operation of electric power transmission lines (“power lines”) and their associated infrastructure has been identified as a conservation threat to the greater sage-grouse (*Centrocercus urophasianus*; sage-grouse). The conservation buffer zones recommended by state and federal agencies to avoid potential impacts on breeding populations differ because information regarding the effects of power lines on sage-grouse is lacking. Little information is available regarding sage-grouse responses to power lines placed in winter habitat. Hence, I evaluated sage-grouse habitat use before and after construction of the Sigurd-Red Butte (SRB) 345-kilovolt (kV) transmission line in winter habitat. The SRB line was constructed in the fall of 2014, and was sited parallel to a pre-existing 500-kV transmission line through salt-desert habitat on the western edge of what is now the Bald Hills Sage-Grouse Management Area (SGMA) in southern Utah. I deployed Global Positioning System (GPS) transmitters on 2 female and 16 male sage-grouse from 2014-2016 and compared collected locations to data independently acquired in the winter of 2011-2012 to determine if the construction of the SRB transmission line altered sage-grouse winter habitat use. Using the 2014-2016 data, I developed a resource selection function (RSF) model to quantify the influence of transmission line presence on sage-grouse movements while accounting for low-quality habitat (salt-desert) near the

¹ Erica P. Hansen, A. Cheyenne Stewart, and S. Nicole Frey

transmission line. Post-construction data were compared to the 2011-2012 data to evaluate whether RSF-predicted changes in relative probability of use were reflected in actual shifts in habitat use before and after construction. The top RSF model contained a significant negative interaction between distance to transmission line and average salt-desert coverage within a 1-km² moving window. Although a comparison of pre- and post-construction mapped RSFs predicted a decreased probability of winter habitat use in the vicinity of the transmission line corridor as a result of the new line, I did not detect increased avoidance by sage-grouse when comparing spatial distributions between winters using minimum convex polygons. This suggests that immediate negative effects of new transmission line construction can be eliminated by implementing best management practices such as co-locating the transmission line in a preexisting energy corridor where impacts on habitat selection have already occurred, and siting the line in poor-quality habitat that does not fragment existing habitat. However, I caution that there may be other long-term influences of transmission line installation that are outside the scope of my two-year post-construction study design, and more research is required to assess the influence of transmission lines on sage-grouse winter habitat use over longer timescales.

INTRODUCTION

The U.S. Fish and Wildlife Service (USFWS) attributed the historical range wide declines observed in greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) to continued loss and fragmentation of the sagebrush (*Artemisia* spp.) ecosystem in their 2010 decision to list the species as a candidate for protection under the Endangered

Species Act of 1973 (USFWS 2010). The sagebrush ecosystem on which sage-grouse depend has undergone extensive alteration since European settlement in the early 1900s as a result of habitat conversion, degradation, and fragmentation (Connelly et al. 2000, Schroeder et al. 2004). Connelly et al. (2004) suggested that ‘tall structures’ associated with energy production and transmission may functionally fragment sage-grouse habitat, and thus could have indirect impacts that are more pronounced than direct habitat loss. Tall structures are typically defined as power lines, communication towers, wind turbines, and other similar installations (USFWS 2010, Utah Wildlife in Need[©] 2010, Messmer et al. 2013).

The best management practices for mitigating the impacts of tall structures are largely based on the reasoning that introducing new vertical features and associated infrastructure in a sagebrush landscape where those features are typically rare may increase perching by avian predators, fragment sage-grouse habitat, or promote human traffic in otherwise undisturbed areas (Messmer et al. 2013). However, the extent of these impacts is not well understood (Utah Wildlife in Need[©] 2010, Walters et al. 2014). Conservation buffer zones recommended by state and federal agencies to avoid potential effects on breeding sage-grouse populations differ throughout the species’ range because information is lacking regarding the influence of power lines on sage-grouse (Messmer et al. 2013, Manier et al. 2014).

Wisdom et al. (2011) compared multiple variables between current and extirpated sage-grouse habitat. They found that, among other factors, distance to transmission lines and distance to cellular towers were strongly associated with sage-grouse extirpation. However, they concluded that the mechanism of this relationship was unknown at a

regional scale. Similarly, Gillian et al. (2013) showed that sage-grouse in Idaho avoided transmission lines by 600 m when comparing telemetry locations to a null model.

However, Johnson et al. (2011) did not detect an effect of power lines on sage-grouse lek trends between 1997 and 2007 across the species' range.

An empirical study conducted by Messmer et al. (2013) concluded that much of the available research addressing the impacts of tall structures on sage-grouse was related to oil and gas development, only quantified cumulative effects, or did not implicate tall structures themselves as causal agents of negative impacts. Specifically, the mechanism of avoidance and the timescale over which it may occur are not well understood (Utah Wildlife in Need[©] 2010, Messmer et al. 2013, Walters et al. 2014). One long-term study (Nonne et al. 2013) directly addressed the impact of transmission line presence on sage-grouse population demographics. They reported that habitat characteristics had a larger influence on nest success, brood success, and overall survival across time than distance to a transmission line. The authors were not able to describe how sage-grouse habitat use patterns may have been altered by the presence of the transmission line, however, because the study was conducted after the power line was built. Little information is available regarding sage-grouse responses to power lines placed in winter habitat.

In 2013, Utah published a state-wide plan (Plan; State of Utah 2013) to facilitate sage-grouse conservation by protecting all seasonal habitats (USFWS 2010, Dahlgren et al. 2016). Because sage-grouse use large landscapes, there is a need to understand seasonal movements and how these movements may be affected by anthropogenic land use such as the construction of power lines in winter range. Hence, I quantified how the

addition of a new transmission line to an existing energy corridor influenced sage-grouse winter habitat use before and after construction.

STUDY AREA

The Bald Hills Sage-Grouse Management Area (SGMA; study area) was 1 of 11 designated sage-grouse management areas within the state of Utah (State of Utah 2013). The Bald Hills SGMA consisted of 1343 km² and spanned across Beaver and Iron counties in the southwestern portion of the state. It was located at the southern periphery of the sage-grouse distribution in North America (State of Utah 2013, Utah Division of Wildlife Resources [UDWR] 2014; Fig. 3-1). The SGMA included land managed by the Bureau of Land Management (BLM) as well as private stakeholders and state agencies (State of Utah 2013). In 2015, a total maximum count of 148 male sage-grouse was obtained at 14 active leks (J. Nicholes, UDWR, unpublished data).

The Bald Hills SGMA was a mountainous area ranging from 1596 m elevation in the southwest corner, at the Mud Springs lek, to 2314 m elevation in the northwest portion. The average annual precipitation was 26 cm. The study area was located in the Great Basin sagebrush ecosystem (West and Young 2000), which was generally arid and desert-like. Specifically, shrubs were shorter (generally < 1m in height) than those in sagebrush-steppe, were less densely spaced, and were interspersed with loamy surface soils, microphytic crusts, and sparsely distributed grasses (West and Young 2000). Sagebrush species in the Bald Hills consisted of mountain big sagebrush (*Artemisia tridentata vaseyana*) at upper elevations, black sagebrush (*A. nova*) at lower elevations, and Wyoming big sagebrush (*A. tridentata wyomingensis*) present at moderate elevations

(Burnett 2013). Sand sagebrush (*A. fillifolia*) was also present in small quantities in the northwestern portion of the study area. The study area also contained significant patches of mixed pinyon (*Pinus spp.*) and juniper (*Juniperus spp.*) forest; salt-desert shrub (dominant species included *Artiplex confertifolia*, *Krascheninnikovia lanata*, and *Salicornia sp.*); agricultural fields consisting of alfalfa (*Medicago sativa*) and corn (*Zea sp.*); and disturbed areas that were characterized by both native and non-native forbs and grasses.

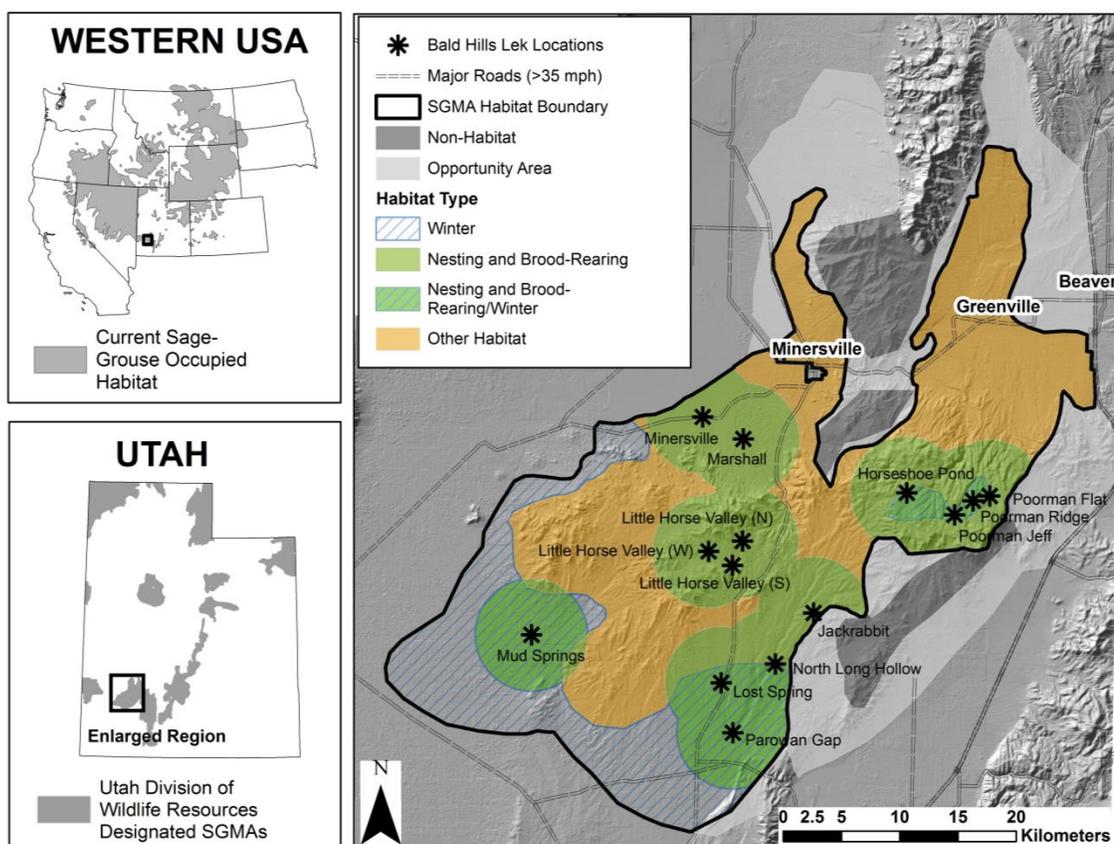


Figure 3-1. Location of the Bald Hills Sage-Grouse (*Centrocercus urophasianus*) Management Area (SGMA) in southwestern Utah, USA; 2014-2016. The SGMA is bordered by opportunity areas which could be converted to sage-grouse habitat through the implementation of habitat management actions.

The study area contained multiple sources of anthropogenic landscape disturbance (Fig. 3-2). Domestic cattle (*Bos* spp.) and sheep (*Ovis* spp.) grazing were common, and agricultural development was present in the northern portion of the study area near the town of Minersville (population 907, U.S. Census Bureau 2012) and the unincorporated community of Greenville. Two 2-lane, paved highways bisected the study area in the north-south and east-west directions. Additionally, many maintained and unmaintained dirt roads were present throughout the study area. The Bald Hills SGMA also overlapped the Milford Renewable Energy Development Zone, designated by the Utah Renewable Energy Task Force as a region that had high potential for wind and solar development (Black and Veatch Corporation 2010).

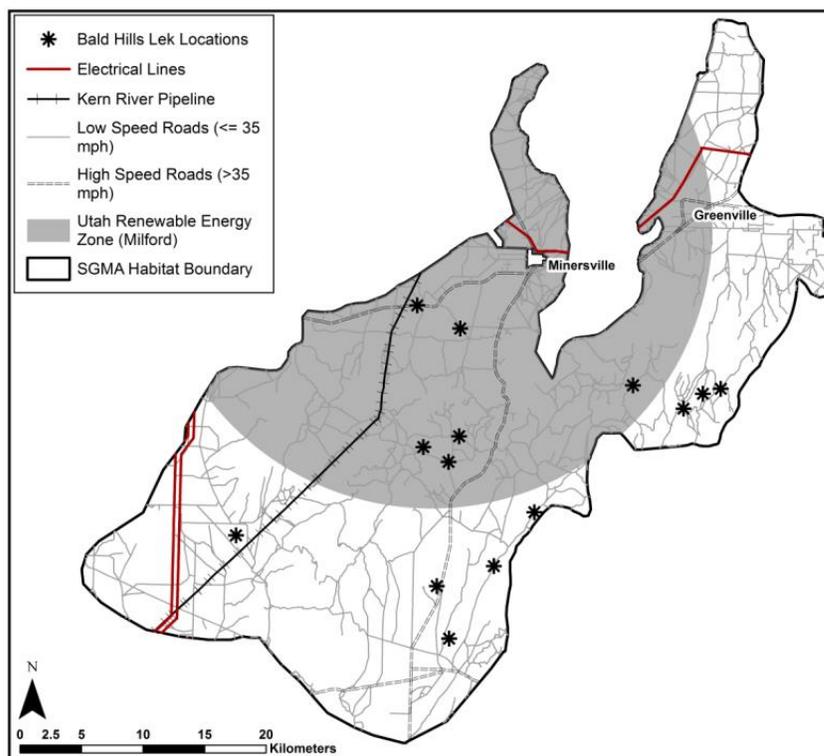


Figure 3-2. Current and potential sources of anthropogenic disturbance which could affect greater sage-grouse (*Centrocercus urophasianus*) habitat use within the study area, Bald Hills Sage-Grouse Management Area, Utah, 2014-2016.

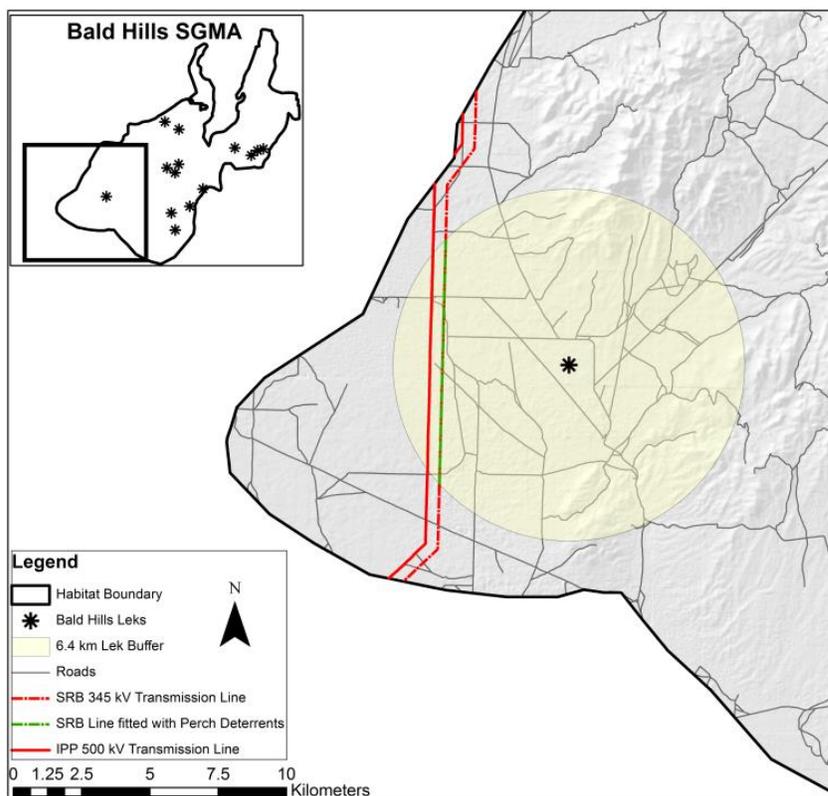


Figure 3-3. Transmission lines passing through greater sage-grouse (*Centrocercus urophasianus*) habitat west of the Mud Springs lek in the Bald Hills Sage-Grouse Management Area, southern Utah, 2014-2016. The Intermountain Power Project (IPP) 500-kV transmission line (pre-existing) and Sigurd-Red Butte (SRB) 345-kV transmission line (constructed fall 2014) both passed through a 6.4-km no-disturbance buffer surrounding the lek. SRB towers that were within the Mud Springs lek buffer were fitted with perch deterrents. The SRB line, upon completion, was located 4.7 km from the lek at its closest point. The area within the lek buffer was also used heavily by sage-grouse during the winter months.

A West-Wide Energy Corridor crossed the study site west of the Mud Springs lek (Bureau of Land Management [BLM] 2012a, Fig. 3-3). West-Wide Energy Corridors were designated under the Energy Policy Act of 2005 to delineate appropriate regions on federal land for the development of multiple oil, gas, and hydrogen pipelines and electricity transmission and distribution facilities (Barton 2005). At the start of the study in spring 2014, the corridor contained the 500-kV Intermountain Power Project (IPP) transmission line. In August 2014, construction of the Sigurd-Red Butte (SRB) 345-kV

transmission line was initiated, and construction was completed in fall of 2014. At the initiation of the scoping process for the SRB line, the proposed location was sited outside of the SGMA boundary. In 2010, however, the Mud Springs lek was discovered, and the SGMA boundary was subsequently adjusted. The lek discovery and boundary adjustment late in the scoping process caused the SRB line to violate a 6.4-km designated buffer of no disturbance around the Mud Springs lek, and pass through 18.8 km of designated sage-grouse habitat within the SGMA (Bureau of Land Management [BLM] 2012*b*). The SRB line was located to the east of the IPP line, with a separation distance of approximately 457 m (Fig. 3-3, Bureau of Land Management [BLM] 2012*a*). The Mud Springs lek was located 4.7 km from the SRB line at its closest point.



Figure 3-4. Typical H-frame, standard tower with installed perch deterrents (left) and latticed steel corner tower (right) of the Sigurd-Red Butte 345kV transmission line, constructed fall 2014. 6.1 km of standard towers that passed through the Mud Springs lek buffer were fitted with perch deterrents (Figure 3-3). Photos were taken approximately 9 months after initial revegetation of the Right of Way (ROW).

The access road under the SRB line was reseeded to promote vegetation growth and to discourage access by recreational vehicles. An established dirt road under the original IPP line was active throughout the study. SRB transmission line towers that were located within the 6.4-km buffer surrounding the Mud Springs lek were fitted with perch deterrents (Fig. 3-4). This corridor was a likely zone for siting additional transmission lines or pipelines in the region in future years.

METHODS

Sage-Grouse Capture and Data Collection

I deployed Global Positioning System (GPS)/Platform Transmitting Terminal (PTT) transmitters on male and female sage-grouse in the springs of 2014 and 2015 (22g Model PTT-100, Microwave Telemetry Inc., Columbia, MD). Transmitters were programmed to record 4 GPS locations/day for download once weekly through the Argos satellite data collection system (Argos System, CLS America, Lanham, MD). Locations were recorded at 0200, 0700, 1300, and 2100 daily, local time, to ensure habitat use was accurately represented throughout each 24-hour period. Sage-grouse were captured using standard spotlight methodology (Wakkinen et al. 1992). Individuals were captured in the vicinity of the Mud Springs lek and the Little Horse Valley lek complex. These 2 areas had the highest numbers of breeding individuals within the study area (J. Nicholes, UDWR, unpublished data, 2015), and were the 2 closest lekking areas to the West-Wide Energy Corridor containing the SRB and IPP transmission lines. The PTT-100 transmitters used in this study recorded GPS locations as well as additional locations derived from the position of the transmitter in relation to the Argos receiving satellites

(Microwave Telemetry, Inc. 2016). The Argos location data were qualified by an assigned location class indicating the reliability of each data point. The highest quality locations were assigned a value of LC3, which indicated that the location was accurate to ± 250 m (Collecte Localisation Satellites 2014). Visual examination of these locations in comparison to GPS location data collected at similar times indicated that this error radius was typically much smaller than 250 m. Thus, the GPS data for an individual was supplemented with the highest-quality Argos data (LC3) for analysis in the rare event of a GPS component malfunction.

Spatial and Temporal Extents of Analysis

Sage-grouse locations collected from the winters of 2014-2015 (first season after construction of the SRB line) and 2015-2016 (second season after construction of the SRB line) were used for model development. This was supplemented with Very High-Frequency (VHF) sage-grouse location data collected independently from the winter of 2011-2012 (pre-construction, Burnett 2013) for validation. Individuals from the 2011-2012 study were caught across all active leks in the Bald Hills. I assumed that potential avoidance of the transmission line was likely to occur within sage-grouse seasonal winter range (third-order selection, Johnson 1980), because sage-grouse exhibit strong seasonal site fidelity (Connelly et al. 2004). I believed that it was unlikely that construction of the new transmission line would result in dramatic shifts of winter home range placement within the SGMA as a whole (second-order selection) because the IPP line was already present. I defined the winter season as November 15 – February 25 for all years. These seasonal dates were chosen because they reflected seasonal movements to winter habitat

(i.e. the last bird arrived in winter habitat just prior to November 15 and birds began lekking after February 25).

We generated a 99% kernel density estimate (KDE) around all pooled 2014-2015 and 2015-2016 winter sage-grouse locations to delineate seasonally available habitat using package `adehabitatHR` in program R (R version 3.1.3, www.r-project.org, accessed 12 Dec 2015). I used a smoothing parameter of 0.8 times the reference bandwidth (h_{ref}), because the commonly used least-squares cross validation (h_{lscv}) bandwidth has been shown to be unreliable for the large numbers of clustered locations present in GPS data sets (Hemson et al. 2005), and 0.8 was the smallest multiplier of h_{ref} that still resulted in a single, continuous polygon (Kie 2013). A small portion of the KDE polygon extended outside delineated SGMA habitat boundaries into non-habitat, and no presence points were located in this area. To avoid including non-habitat in my assessment of availability, I clipped this portion of the KDE by the SGMA habitat boundary in ArcGIS 10.3 (Environmental Systems Research Institute, Redlands, CA software). This resulted in 355 km² of available winter habitat with the SGMA boundary. The final winter habitat polygon included >95% of all VHF locations collected from the 2011-2012 winter, and thus was determined to be a suitable delineation of available winter habitat for the pre-construction season as well.

Predictor Variables

We derived candidate predictor variables (Table 3-1) shown to be strongly associated with winter sage-grouse habitat selection (Carpenter et al. 2010, Burnett 2013,

Smith et al. 2014). Variables were divided into 3 categories: (1) vegetation, (2) topographic, and (3) anthropogenic.

Vegetation. Vegetation covariates were derived from LANDFIRE 2012 existing vegetation type and existing vegetation height data (LANDFIRE 2012) and assessed within a 1-km² (564-m radius) moving window because selection at this scale was detected in other studies of sage-grouse habitat use (e.g. Aldridge and Boyce 2007, Carpenter et al. 2010, Fedy et al. 2015). For sagebrush covariates, I extracted both mean and standard deviation of coverage within the 1-km² window, with the assumption that areas with a high standard deviation had more spatial heterogeneity or patchiness (Aldridge and Boyce 2007).

Topographic. I obtained 10-m Digital Elevation Model data (DEM; Utah Automated Geographic Reference Center [AGRC], www.gis.utah.gov, accessed 1 Feb 2016) and used it to derive slope (degrees), aspect (categorical, 8 categories) and topographic wetness index (TWI) layers in ArcGIS. TWI was calculated using Topography Tools for ArcGIS 10.3 and earlier (Dilts 2015), and is a steady-state wetness index based on upslope topography. TWI values for flat areas were rare, but extremely large, so TWI was capped at 2500; all values larger than 2500 (<5% of the total area) were reclassified as 2500 to assist with model convergence and increase ease of variable interpretation.

Anthropogenic. I included distance to roads (Road Centerlines; Utah AGRC, accessed 16 March 2014) because this was a strong predictor of winter sage-grouse habitat use in a previous study of this population (Burnett 2013). Roads were categorized into 2 classes; high-speed and low-speed. High-speed roads were roads with posted

speeds >35 mph, and included paved 2-lane highways. Low-speed roads were roads with posted speeds ≤ 35 mph, and included single-lane paved roads, dirt roads, and 2-tracks. I also derived an exponential decay covariate for distance to development (LANDFIRE 2012). Exponential decay was calculated as a function ($e^{-d/\alpha}$) where d was the distance to a feature and α was set to the radii for the chosen scale of selection (Smith et al. 2014). The value for α was set to 564 m, because that was the scale of selection chosen for other covariates included in the model. Assessing distance to development using an exponential decay function captures a non-linear relationship between the outcome and the predictor, where the predictor (i.e. effect of development) decreases to almost zero after a specified distance (Leu et al. 2011). An exponential decay function was used for distance to development because much of the development within the winter seasonal KDE was low-impact (water troughs, shoulders of dirt roads, and areas in the periphery of agricultural fields), and I assumed a linear distance measurement would likely overestimate the spatial influence of these features on the landscape. I anticipated that avoidance would occur at a localized scale with the influence of these features eventually decreasing to almost zero.

Because the scale at which the transmission line could influence habitat use was unknown, I developed multiple covariates describing distance to transmission line with varying strengths of exponential decay. Values chosen for α were 564 m, 1000 m, and 6400 m. These values were chosen because they were (1) the 564-m radius assessed for other covariates (Aldridge and Boyce 2007), (2) the 1000-m literature minimum recommended lek buffer radius for minimizing impacts of tall structures on sage-grouse based on observed effects (Howe et al. 2014, Manier et al. 2014), and (3) the radius of the

full 6400 m lek buffer distance applied to the Mud Springs lek (Bureau of Land Management 2012*b*).

Model Development

We used a resource selection function (RSF) framework to compare third-order selection (Johnson 1980) of habitat used by sage-grouse during the winters of 2014-2015 and 2015-2016 to available habitat within a 99% winter seasonal KDE under a used-available design (Manly et al. 2002). To ensure that small changes in the predicted probability of use with the construction of the new transmission line were appropriately captured, I randomly generated points to characterize available habitat at a rate of 100 points/km² within the winter habitat boundary, resulting in a total of 35,500 available points. RSF models were estimated using logistic regression to approximate relative probability of use within a specified area (Manly et al. 2002, Hosmer et al. 2013). I included a random intercept for individual in the model structure to accommodate potential spatial autocorrelation from high numbers of locations within an individual (Gillies et al. 2006). The final RSF took the form of a generalized linear mixed-model (GLMM; Bolker et al. 2009). I used a multi-step modeling approach to select a top model from all biologically relevant candidate covariates.

All continuous predictor variables were standardized ($\bar{x} = 0.0$, $SD = 1$) prior to analysis. Univariate analysis was conducted on each predictor individually to confirm predictive strength against a null model and to investigate the potential for including a quadratic term to accommodate nonlinearities. I then identified a top model in each of the 3 predictor categories using Akaike information criterion corrected for small sample

sizes (AICc) to select between any competing models (Hurvich and Tsai 1989, Burnham and Anderson 2002).

Table 3-1. Predictor variables considered for Resource Selection Function modeling for winter habitat use of greater sage-grouse (*Centrocercus urophasianus*) in the Bald Hills Sage-Grouse Management Area, Utah, USA 2014-2016.

Variable	Type (Resolution)	Description (units)
Vegetation		
<i>shrubheight_avg</i>	Continuous (30m)	Average shrub height derived from LANDFIRE Existing Vegetation Height layer (cm) ³
<i>shrubheight_sd</i>	Continuous (30m)	Standard deviation of shrub height derived from LANDFIRE Existing Vegetation Height layer (cm) ³
<i>sageall_avg</i>	Continuous (30m)	Average coverage of all sagebrush ^{1,3} (percent)
<i>sageall_sd</i>	Continuous (30m)	Standard deviation of all sagebrush ^{1,3}
<i>sagebig_avg</i>	Continuous (30m)	Average coverage of big sagebrush ^{1,3} (percent)
<i>sagebig_sd</i>	Continuous (30m)	Standard deviation of big sagebrush ^{1,3}
<i>sagelow_avg</i>	Continuous (30m)	Average coverage of low sagebrush ^{1,3} (percent)
<i>sagelow_sd</i>	Continuous (30m)	Standard deviation of low sagebrush ^{1,3}
<i>juniper_avg</i>	Continuous (30m)	Average coverage of pinyon-juniper forest ^{1,3} (percent)
<i>saltdesert_avg</i>	Continuous (30m)	Average coverage of salt desert ^{1,3} (percent)
Topographic		
<i>asp.f</i>	Categorical (10m)	Aspect calculated from 10m DEM (km) ²
<i>slope</i>	Continuous (10m)	Slope calculated from 10m DEM (degrees)
<i>dem</i>	Continuous (10m)	Elevation derived from 10m DEM (km)
<i>twi</i>	Continuous (10m)	Topographic wetness index
Anthropogenic		
<i>dist_rdlow</i>	Euclidean Distance (30m)	Distance to ≤ 56.33 km/hr (≤ 35 mph) roads (km)
<i>dist_rdhi</i>	Euclidean Distance (30m)	Distance to > 56.33 km/hr (> 35 mph) roads (km)
<i>dist_develop</i>	Exponential Decay (30m)	Distance to development ¹ defined by an exponential decay function with $a = 564\text{m}$
Transmission Line		
<i>SRBIPP_564</i>	Exponential Decay (10m)	Distance to SRB and IPP transmission lines defined by an exponential decay function with $a = 564\text{m}$
<i>SRBIPP_1000</i>	Exponential Decay (10m)	Distance to SRB and IPP transmission lines defined by an exponential decay function with $a = 1000\text{m}$
<i>SRBIPP_6400</i>	Exponential Decay (10m)	Distance to SRB and IPP transmission lines defined by an exponential decay function with $a = 6400\text{m}$
<i>IPP_564</i>	Exponential Decay (10m)	Distance to IPP transmission line defined by an exponential decay function with $a = 564\text{m}$

¹ Derived from 2012 LANDFIRE Existing Vegetation Type data. Refer to Appendix Table A-2 for LANDFIRE categories used to define each predictor

² Aspect categories represented the compass direction of the downslope topography, segmented by direction to include North (337.5° – 22.5°), Northeast (22.5° – 67.5°), East (67.5° – 112.5°), Southeast (112.5° – 157.5°), South (157.5° – 202.5°), Southwest (202.5° – 247.5°), West (247.5° – 292.5°), and Northwest (292.5° – 337.5°)

³ Assessed within 1-km² (564 m radius) moving window

No variables that were highly correlated (Pearson's correlation coefficient ≥ 0.70) were included in the same model at any stage. Because distance to transmission line was selected for inclusion *a priori*, it was excluded from covariate selection within the anthropogenic model, and only incorporated in the final step of the modeling process. The top models for each category were combined (i.e. anthropogenic + vegetation + topographic). The full model was compared against models for individual categories and a null model using AICc to select the best possible suite of covariates for predicting sage-grouse habitat selection within available winter habitat. Variables that became non-significant when top anthropogenic, vegetation, and topographic models were combined were removed if this improved model fit ($>2 \Delta AICc$).

Once an overall top model was selected from all candidate models, the covariates describing distance to transmission line were included at each scale of decay strength (*SRBIPP_564*, *SRBIPP_1000*, *SRBIPP_6400*) to determine which best described sage-grouse habitat use. Finally, because I suspected that any avoidance of the transmission line corridor may have been influenced by its placement in low-quality habitat (salt-desert) on the western side of the Bald Hills, I included an interaction between distance to transmission line and average salt-desert coverage (*SRBIPP*saltdesert_avg*) for each strength of transmission line decay to evaluate whether this improved model fit.

Model Validation

The ultimate test for the suitability of an RSF is how well it predicts species use of landscapes across space and time (Johnson et al. 2006). To assess model fit, the final RSF was validated both internally through k-fold cross-validation (Boyce et al. 2002),

and externally by mapping the RSF across a pre-construction landscape and validating with independently collected data from the winter of 2011-2012 (Burnett 2013). For k-fold validation, I divided the individuals from the main (2014-2015) data set into 5 randomly assigned folds. The top RSF model was then refit 5 times, each time withholding a different fold of test data. The refit RSFs were mapped across available habitat within the 99% winter KDE and divided into 10 quantiles (equal-area bins) of increasing rank (1 = low quality habitat, 10 = high quality habitat). I extracted the frequency of test fold data points that fell in each bin for all 5 refit RSF models and calculated Spearman rank correlations for each test fold to quantify the relationship between frequency of use by test locations and increasing bin ranks of habitat quality (Boyce et al. 2002, Aldridge and Boyce 2007). I expected that as bin rank increased, frequency of use should also increase.

Although internal validation of an RSF provides insight on its effectiveness, the best test of an RSF is independent validation with an external data set (Boyce et al. 2002). Because a previous study (Burnett 2013) had collected winter VHF data on sage-grouse locations from the winter of 2011-2012, this allowed us to evaluate model fit across years and compare how RSF-predicted habitat quality in the vicinity of the West-Wide Energy Corridor differed before and after construction of the SRB line. To ensure that temporally dynamic covariates were appropriately applied to this map, I used an input for distance to transmission line which included only the IPP line, because only that line was present in the West-Wide Energy Corridor at the time those locations were collected. I also updated vegetation predictor variables using LANDFIRE 2010 data (LANDFIRE 2010) to more accurately represent vegetation available during the winter of 2011-2012.

For external validation, the RSF was mapped across the pre-construction landscape within the same 99% winter seasonal KDE, divided into 10 equal-area bins, and frequencies of use were compared to bin rank using Spearman-rank correlations in a similar fashion as the validation for the post-construction RSF model.

Comparisons of Pre- and Post-Construction Data

The development of pre- and post-construction RSF models for winter habitat allowed us to compare how habitat quality may have changed with the construction of a new transmission line. This offered the most conservative estimate of differences between pre- and post-construction landscapes, because it assumed that the construction of the new SRB line did not change the strength of avoidance of the West-Wide Energy Corridor (β coefficient), only the spatial orientation of transmission lines on the landscape (i.e. the corridor was composed of 2 lines in the post-construction model and 1 line in the pre-construction model). If the addition of the new line was multiplicative (for example, doubled a negative effect), then the pre-construction map I derived would underestimate the probability of use near the single, original transmission line and the change in habitat would actually be greater than is reported here. However, because the effects of adding a new transmission line to a pre-existing transmission line corridor are not well documented, and the original patterns of habitat use prior to the construction of *any* transmission lines in the Bald Hills SGMA were unknown, I chose to estimate changes on the landscape in the most conservative manner possible.

We compared changes in RSF-predicted probability of habitat use and differences in the spatial distribution of sage-grouse locations within the vicinity of the transmission

line corridor between the pre- and post-construction data sets. I focused on these changes for winter habitat inside the 6.4-km Mud Springs lek buffer, because sage-grouse used this area heavily in the winter months and it was at a high risk of being negatively influenced by the construction of the new transmission line due to its close proximity. I quantified changes in RSF-predicted habitat use by calculating the difference between the pre- and post-construction mapped RSFs ($RSF_{post} - RSF_{pre} = \Delta RSF$). This resulted in a map layer that showed decreased RSF scores from pre-to post-construction as negative values, and increased RSF scores as positive values. To compare sage-grouse spatial distributions between winters, I generated minimum convex polygons (MCPs) for sage-grouse locations within the Mud Springs lek buffer for each winter (2011-2012, 2014-2015, and 2015-2016) and calculated the centroid for each MCP. I anticipated that if the RSF-predicted relative probability of use decreased within the boundaries of the lek buffer after the addition of the new transmission line, this would be reflected by a corresponding shift in MCP centroids further from the transmission line corridor in the 2 post-construction seasons.

RESULTS

Sage-Grouse Capture and Data Collection

The GPS data set for the winters of 2014-2015 and 2015-2016 included locations from 18 individual sage-grouse ($n = 2$ females, $n = 16$ males, Fig. 3-2) and included 7534 locations (Table 3-2). Sexes were pooled because male and female sage-grouse can occupy mixed-sex flocks in the winter months (Swanson et al. 2013) and examination of GPS locations indicated this was the case in my study area for the time periods included

in my analysis. Birds caught from both the Mud Springs and Little Horse Valley leks moved frequently between these two locations during the spring, and thus were assumed to be part of the same breeding population. Malfunction of transmitter GPS components occurred on 2 individuals during the study, and consequently their location data were supplemented with the highest quality Argos location data (class LC3).

Table 3-2. Individual greater sage-grouse (*Centrocercus urophasianus*) winter location data collected from the winters of 2014-2015 and 2015-2016 and used for Resource Selection Function (RSF) modeling of habitat use in the Bald Hills Sage-Grouse Management Area, Southern Utah, USA.

Bird ID	Capture Lek	Sex	Number of Locations
LH12	Little Horse Valley	Male	252
LH13	Little Horse Valley	Male	359
LH14	Little Horse Valley	Male	72
LH4	Little Horse Valley	Male	420
LH5	Little Horse Valley	Male	54
LH7	Little Horse Valley	Female	398
LH9	Little Horse Valley	Female	570
MS1	Mud Springs	Male	802
MS10	Mud Springs	Male	391
MS11	Mud Springs	Male	265
MS12	Mud Springs	Male	394
MS13	Mud Springs	Male	419
MS14	Mud Springs	Male	396
MS15	Mud Springs	Male	427
MS3	Mud Springs	Male	586
MS5	Mud Springs	Male	784
MS8	Mud Springs	Male	310
MS9	Mud Springs	Male	635

Number of locations per bird ranged from 54 to 802, depending on the length of transmitter deployment for that particular bird (Table 3-2). The VHF data set from 2011-2012 used in external validations contained 85 locations from 19 sage-grouse (n = 11 males, n = 8 females).

Resource Selection Function Modeling

Global models for the topographic and anthropogenic categories indicated that all *a priori* selected predictors contributed significantly ($P \leq 0.05$) and no variables were collinear, so all predictors were included in the final model for each of those groups (Table 3-3). Because many of the vegetation predictors were collinear (Pearson's correlation coefficient ≥ 0.70), a set of candidate models for the vegetation category was developed *post priori* and a top model was selected using AICc (Table 3-4). Once top models for anthropogenic (*anth_final*), vegetation (*vg_final*), and topographic (*topo_final*) categories were selected, these models were combined and compared against the individual top models as well as a null model (Table 3-5) to determine which best described winter habitat use in the Bald Hills. Variables that became non-significant ($P > 0.05$) when the models were combined (*twi*² and *shrubheight_sd*) were dropped because removing them significantly improved model fit ($>2 \Delta AICc$, Burnham and Anderson 2002).

Table 3-3. Final resource selection function models selected to represent topographic and anthropogenic categories for winter greater sage-grouse (*Centrocercus urophasianus*) habitat selection within the Bald Hills Sage-Grouse Management Area, Utah, USA.

Model	Structure
<i>anth_final</i>	<i>develop_564</i> + <i>roadlow_km</i> + <i>roadlow_km</i> ² + <i>roadhi_km</i>
<i>topo_final</i>	<i>twi</i> + <i>twi</i> ² + <i>asp.f</i> + <i>dem</i> + <i>dem</i> ² + <i>slope</i> + <i>slope</i> ²

After confirming a combination of top anthropogenic, topographic, and vegetation models outperformed any individual model, I investigated which scale of exponential decay function best described habitat use in relation to the West-Wide Energy Corridor, and whether an interaction between distance to transmission line and average salt-desert coverage within a 1-km² moving window improved model fit (Table 3-5). The top model (*rsf_final*) included the smallest scale of decay for distance to transmission line (*SRBIPP_564*) as well as an interaction between distance to transmission line and average coverage of salt-desert (*SRBIPP_564*saltdesert_avg*).

Table 3-4. Akaike Information Criterion (corrected for small sample sizes; AICc)-ranked vegetation models for winter habitat selection of greater sage-grouse (*Centrocercus urophasianus*) within the Bald Hills Sage-Grouse Management Area, Utah, USA.

Model	Structure	AICc	ΔAICc	ω _i
<i>vg_final</i>	<i>sagelow_avg</i> + <i>sagelow_avg</i> ² + <i>sagebig_avg</i> + <i>sagebig_avg</i> ² + <i>sageall_sd</i> + <i>shrubheight_sd</i> + <i>saltdesert_avg</i> + <i>juniper_avg</i>	32935.48	0	1
<i>vg4</i>	<i>sagelow_avg</i> + <i>sagelow_avg</i> ² + <i>sagebig_avg</i> + <i>sagebig_avg</i> ² + <i>sageall_sd</i> + <i>saltdesert_avg</i> + <i>juniper_avg</i>	32956.81	21.33	<0.001
<i>vg2</i>	<i>sagelow_sd</i> + <i>sagelow_sd</i> ² + <i>sagebig_sd</i> + <i>sagebig_sd</i> ² + <i>sageall_avg</i> + <i>sageall_avg</i> ² + <i>shrubheight_sd</i> + <i>saltdesert_avg</i> + <i>juniper_avg</i>	33235.92	300.44	<0.001
<i>vg5</i>	<i>sagelow_sd</i> + <i>sagelow_sd</i> ² + <i>sagebig_sd</i> + <i>sagebig_sd</i> ² + <i>sageall_avg</i> + <i>sageall_avg</i> ² + <i>saltdesert_avg</i> + <i>juniper_avg</i>	33277.79	342.31	<0.001
<i>vg3</i>	<i>sagelow_avg</i> + <i>sagelow_avg</i> ² + <i>shrubheight_avg</i> + <i>shrubheight_sd</i> + <i>saltdesert_avg</i> + <i>juniper_avg</i>	33538.11	602.63	<0.001
<i>vg8</i>	<i>sagelow_avg</i> + <i>sagelow_avg</i> ² + <i>sagebig_avg</i> + <i>sagebig_avg</i> ² + <i>saltdesert_avg</i> + <i>juniper_avg</i>	33672.67	737.19	<0.001
<i>vg7</i>	<i>sageall_avg</i> + <i>sageall_avg</i> ² + <i>saltdesert_avg</i> + <i>juniper_avg</i>	34234.52	1299.04	<0.001
<i>vg6</i>	<i>shrubheight_avg</i> + <i>saltdesert_avg</i> + <i>juniper_avg</i>	34789.11	1853.63	0

Table 3-5. Akaike Information Criterion (corrected for small sample size, AICc)-ranked final models for winter greater sage-grouse (*Centrocercus urophasianus*) habitat selection in the Bald Hills Sage-Grouse Management Area, Utah, USA.

Model	Structure	AICc	Δ AICc	ω_i
<i>rsf_final</i> <i>SRBIPP564_int</i>	$dist_develop + dist_rdlow + dist_rdlow^2 + dist_rdhi + juniper_avg + sagebig_avg + sagebig_avg^2 + sagelow_avg + sagelow_avg^2 + sageall_sd + saltedest_avg + twi + slope + slope^2 + dem + dem^2 + asp.f + SRBIPP_564 + (SRBIPP_564 * saltedest_avg)$	23175.15	0	1
<i>SRBIPP564</i>	$dist_develop + dist_rdlow + dist_rdlow^2 + dist_rdhi + juniper_avg + sagebig_avg + sagebig_avg^2 + sagelow_avg + sagelow_avg^2 + sageall_sd + saltedest_avg + twi + slope + slope^2 + dem + dem^2 + asp.f + SRBIPP_564$	23241.73	66.58	<0.001
<i>SRBIPP1000_int</i>	$dist_develop + dist_rdlow + dist_rdlow^2 + dist_rdhi + juniper_avg + sagebig_avg + sagebig_avg^2 + sagelow_avg + sagelow_avg^2 + sageall_sd + saltedest_avg + twi + slope + slope^2 + dem + dem^2 + asp.f + SRBIPP_1000 + (SRBIPP_1000 * saltedest_avg)$	23252.52	77.37	<0.001
<i>SRBIPP1000</i>	$dist_develop + dist_rdlow + dist_rdlow^2 + dist_rdhi + juniper_avg + sagebig_avg + sagebig_avg^2 + sagelow_avg + sagelow_avg^2 + sageall_sd + saltedest_avg + twi + slope + slope^2 + dem + dem^2 + asp.f + SRBIPP_1000$	23440.38	265.23	<0.001
<i>SRBIPP6400_int</i>	$dist_develop + dist_rdlow + dist_rdlow^2 + dist_rdhi + juniper_avg + sagebig_avg + sagebig_avg^2 + sagelow_avg + sagelow_avg^2 + sageall_sd + saltedest_avg + twi + slope + slope^2 + dem + dem^2 + asp.f + SRBIPP_6400 + (SRBIPP_6400 * saltedest_avg)$	23604.13	428.98	<0.001
<i>veg_topo_anthro</i>	$dist_develop + dist_rdlow + dist_rdlow^2 + dist_rdhi + juniper_avg + sagebig_avg + sagebig_avg^2 + sagelow_avg + sagelow_avg^2 + sageall_sd + saltedest_avg + twi + slope + slope^2 + dem + dem^2 + asp.f$	23661.11	485.96	<0.001
<i>SRBIPP_6400</i>	$dist_develop + dist_rdlow + dist_rdlow^2 + dist_rdhi + juniper_avg + sagebig_avg + sagebig_avg^2 + sagelow_avg + sagelow_avg^2 + sageall_sd + saltedest_avg + twi + slope + slope^2 + dem + dem^2 + asp.f + SRBIPP_6400$	23665.96	490.82	<0.001
<i>anth_final</i>	$develop_564 + roadlow_km + roadlow_km2 + roadhi_km$	31904.55	8729.40	0
<i>vg_final</i>	$sagelow_avg + sagelow_avg^2 + sagebig_avg + sagebig_avg^2 + sageall_sd + shrubheight_sd + saltedest_avg + juniper_avg$	32935.48	9760.33	0
<i>topo_final</i>	$twi + twi^2 + asp.f + dem + dem^2 + slope + slope^2$	35558.01	12382.87	0
<i>null</i>	----	38043.09	14867.94	0

Table 3-6. Beta coefficients (β_i) and standard errors (SE) for the final selected resource selection function model (*rsf_final*) describing winter habitat use of greater sage-grouse (*Centrocercus urophasianus*) within the Bald Hills Sage-Grouse Management Area, Utah, USA. Non-significant coefficients ($p > 0.05$) are designated with a dash (-)

Predictor	β_i	SE
Vegetation		
<i>sageall_sd</i>	0.296	0.026
<i>sagebig_avg</i>	-0.960	0.030
<i>sagebig_avg</i> ²	0.706	0.039
<i>sagelow_avg</i>	1.957	0.056
<i>sagelow_avg</i> ²	-0.733	0.026
<i>juniper_avg</i>	-2.501	0.070
<i>saltdesert_avg</i>	-	-
Topographic		
<i>asp.Flat</i>	-	-
<i>asp.North</i>	0.854	0.111
<i>asp.Northeast</i>	-	-
<i>asp.Southeast</i>	0.479	0.088
<i>asp.South</i>	0.303	0.086
<i>asp.Southwest</i>	0.557	0.086
<i>asp.West</i>	0.384	0.087
<i>asp.Northwest</i>	-0.222	0.103
<i>slope</i>	-0.495	0.043
<i>slope</i> ²	-0.047	0.018
<i>dem</i>	1.805	0.047
<i>dem</i> ²	0.661	0.028
<i>twi</i>	0.076	0.021
Anthropogenic		
<i>dist_rdlow</i>	0.639	0.029
<i>dist_rdlow</i> ²	-0.319	0.016
<i>dist_rdhi</i>	1.259	0.025
<i>dist_develop</i>	0.392	0.021
Transmission Line		
<i>SRBIPP_564</i>	-1.407	0.350
<i>SRBIPP_564*saltdesert_avg</i>	-2.440	0.302

The final RSF model included multiple topographic, anthropogenic, and vegetation covariates (Table 3-6). Distances to low-speed roads and high-speed roads were classified as linear functions, thus the direction of their coefficients needs to be reversed when interpreting selection or avoidance. For example, $\beta_{dist_rdhi} = 1.259$

indicated sage-grouse avoid areas near high-speed roads. Covariates that also included a squared term indicated a non-linear relationship to the response variable (i.e. $slope + slope^2$ indicated sage-grouse selected for moderately steep slopes). The interaction between salt-desert coverage and proximity to transmission line ($SRBIPP_{564} * saltdesert_{avg}$) negatively influenced predicted probability of habitat use.

Model Validation

The model performed well in both internal and external validation (Table 3-7). The average Spearman rank correlation coefficient (r_s) for k-fold cross-validation was 0.90 across all 5 folds. Four of the 5 iterations of k-fold validation exhibited excellent predictive capacity ($r_s = 0.92$ to 1.00). However, 1 fold (Fold 4, Table 3-7), had a much lower predictive success ($r_s = 0.64$, $P = 0.054$) which lowered the average overall.

Table 3-7. Spearman-rank correlations (r_s) for internal k-fold cross-validation of model predicted probability of habitat use after construction of the Sigurd-Red Butte 345 kV transmission line; and external validation of the model mapped across the pre-construction landscape and validated using 2011-2012 data collected within the Bald Hills Sage-Grouse Management Area, Utah, USA 2014-2016.

Test Fold	r_s	P -value
1	1.00	≤ 0.001
2	0.92	≤ 0.001
3	0.96	≤ 0.001
4	0.64	0.054
5	0.97	≤ 0.001
Mean R_s across folds	0.90	-
External 2011-2012 Validation	0.95	≤ 0.001

Correlations were also high for the 2011-2012 external validation with $r_s = 0.86$ ($P = 0.001$), which suggested good predictive capacities for the model across years. Visual examination of RSFs mapped for both timeframes indicated good model fit across available winter habitat within the Bald Hills SGMA (Figs. 3-5 and 3-6).

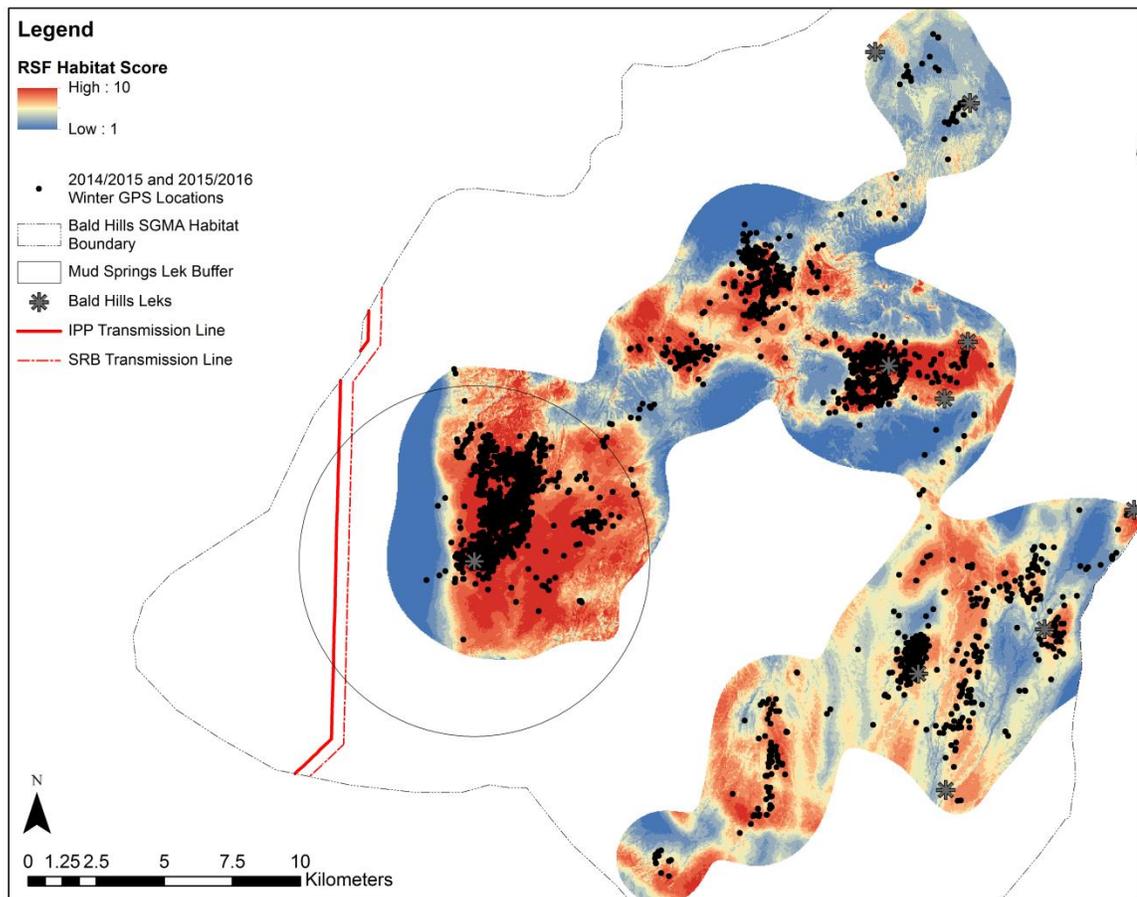


Figure 3-5. Resource selection function (RSF) predicted relative probability of presence (ranked in 10 equal area bins, 1 = low through 10 = high) for winter greater sage-grouse (*Centrocercus urophasianus*) habitat in the Bald Hills Sage-Grouse Management Area (Utah, USA) after the installation of the Sigurd-Red Butte 345kV transmission line. All sage-grouse locations collected for both the 2014-2015 and 2015-2016 winters are shown in black.

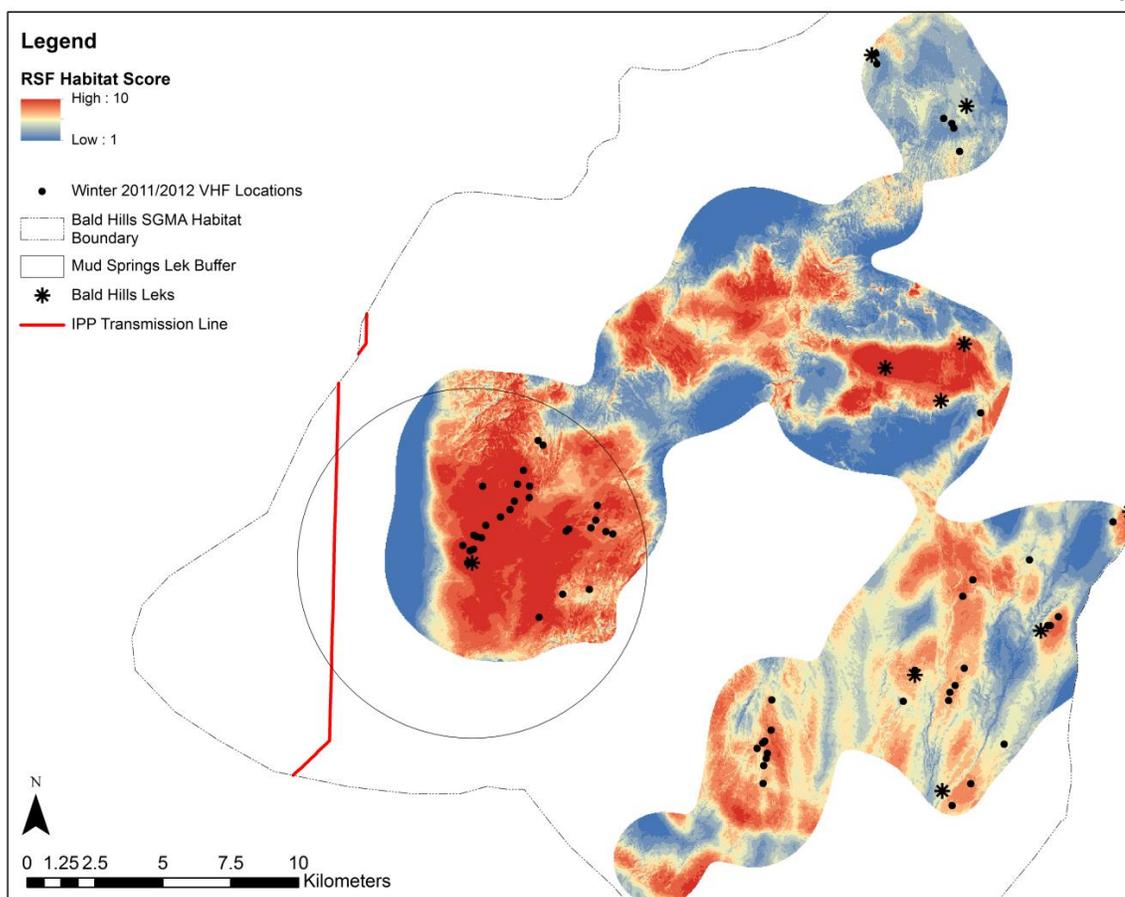


Figure 3-6. Resource selection function (RSF) predicted relative probability of presence (ranked in 10 equal area bins, 1 = low through 10 = high) for winter greater sage-grouse (*Centrocercus urophasianus*) habitat prior to the construction of the Sigurd-Red Butte (SRB) transmission line. All sage-grouse locations utilized for validation of the pre-construction (2011-2012) winter are shown in black.

Comparisons of Pre- and Post-Construction Data

Comparisons of the pre- and post-construction RSF maps indicated a decrease in predicted probability of use for winter habitat in the vicinity of the West-Wide Energy Corridor after the addition of the SRB line (Fig. 3-7). The mean Δ RSF score for available winter habitat within the 6.4-km Mud Springs lek buffer was -0.03, or an overall 3% decrease in predicted probability of winter habitat use within that area.

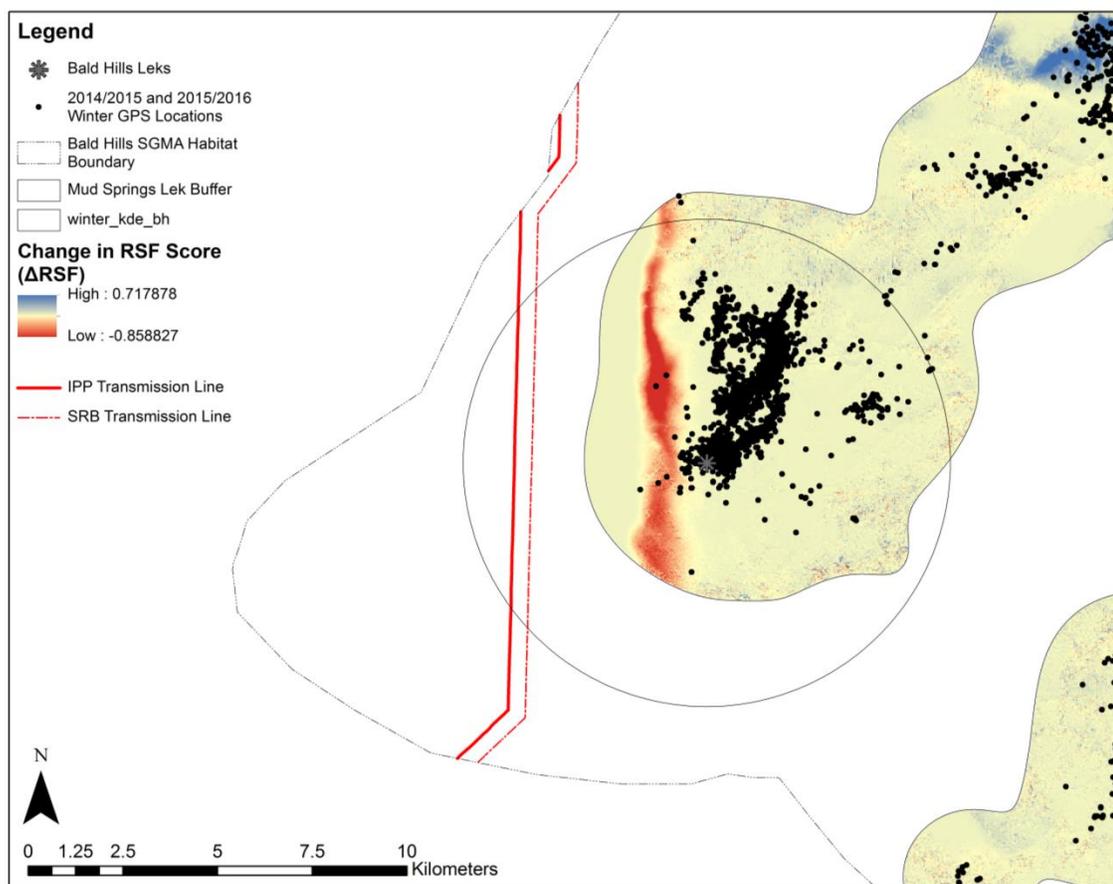


Figure 3-7. Changes in probability of greater sage-grouse (*Centrocercus urophasianus*) habitat use predicted by resource selection function (RSF) modeling in the vicinity of the Mud Springs lek (Bald Hills Sage-Grouse Management Area, Utah, USA) between pre- and post-construction landscapes (Δ RSF). A positive Δ RSF value (blue regions) indicates an increase in predicted probability of use from pre- to post- construction maps, while negative Δ RSF values (red regions) indicate a decrease in predicted probability of use from pre- to post-construction maps. Because RSF probabilities of use range from 0 to 1, Δ RSF values were constrained between -1 and 1, with values of 0 indicating no change (pale yellow regions). The average Δ RSF value for winter habitat within the Mud Springs lek buffer was 0.03, indicating a 3% decrease in predicted probability of use within that region after the addition of the Sigurd-Red Butte 345 kV transmission line.

However, this change did not result in detectable changes in sage-grouse avoidance of the transmission line corridor between the pre- and post-construction winters when comparing sage-grouse spatial distributions across years. The MCP centroid farthest from the transmission line corridor occurred in the pre-construction

season, and was located 7.4 km from the IPP transmission line. MCP centroids for both post-construction seasons were located 6.4 km from the SRB line, and were closer to a transmission line than the pre-construction season. The MCP centroids for all 3 seasons were located <1 km from each other (Fig. 3-8).

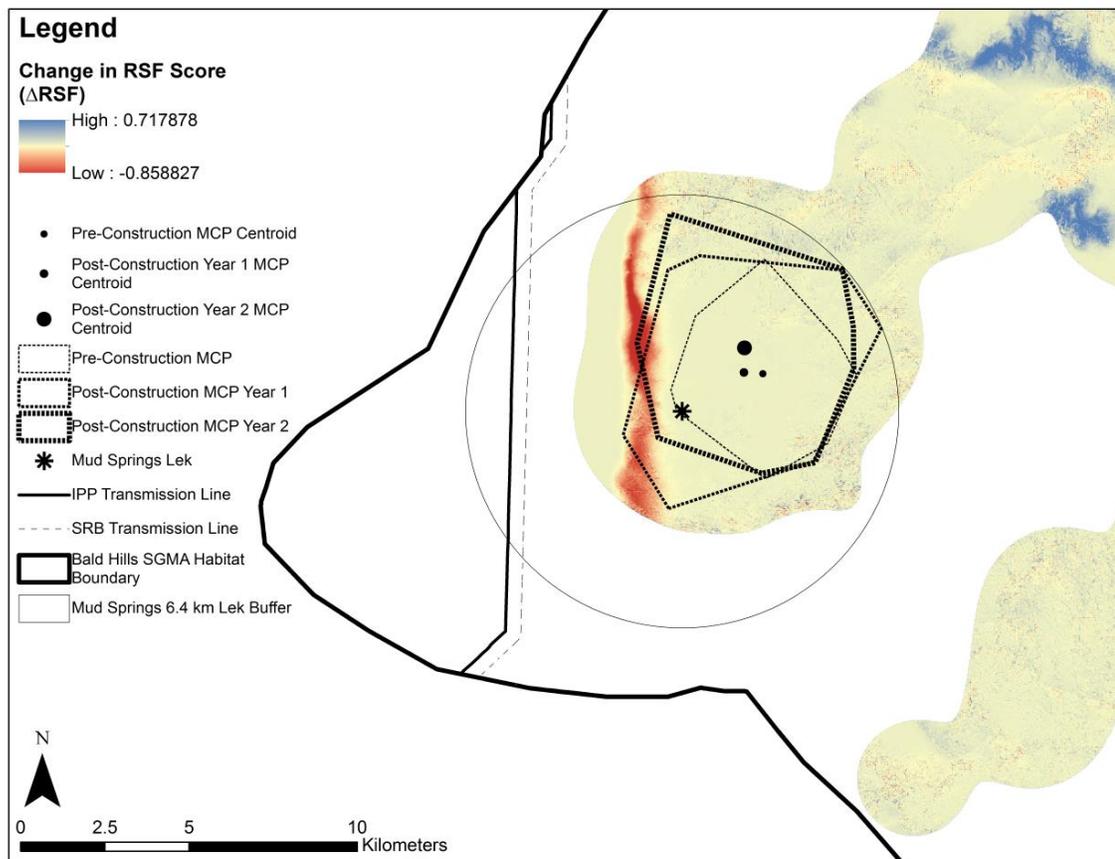


Figure 3-8. Changes in probability of use predicted by the final resource selection function (RSF) model in the vicinity of the Mud Springs lek between pre- and post-construction maps (Δ RSF), and minimum convex polygons (MCPs) for greater sage-grouse (*Centrocercus urophasianus*) locations within the Mud Springs lek buffer for one pre-construction and 2 post-construction winters. Negative Δ RSF values (red regions) indicate a decrease in predicted probability of use from pre- to post-construction maps, while positive values (blue regions) indicate an increase. Placement of MCPs and corresponding centroids does not indicate increased avoidance after construction, with the furthest MCP centroid from the transmission line corridor occurring in the pre-construction data set.

DISCUSSION

This project was initiated because the new transmission line was located in winter habitat, which is considered lacking in Utah (State of Utah 2013). I confirmed that transmission line presence negatively influenced probability of sage-grouse winter habitat use through RSF modeling. The interaction between *saltdesert_avg* and *SRBIPP_564* indicated that with greater coverage of salt-desert, the effect of transmission line proximity on probability of use grew increasingly negative. Thus, sage-grouse avoided areas of high salt-desert coverage near transmission lines more strongly than would be expected when each effect was included in the model independently. Although the final RSF model predicted a 3% decrease in probability of use within the lek buffer due to the construction of the new transmission line, I did not observe any detectable shifts in habitat used by sage-grouse near the transmission line corridor when comparing MCPs. The closest sage-grouse location to a transmission line recorded after construction was 2.9 km from the SRB line, while the closest location recorded prior to construction was 4.9 km from the original IPP transmission line. Visual examination of both sets of locations overall did not suggest any avoidance induced by the construction of the new line, as evidenced by the close placement of MCP centroids for all 3 winters considered in the analysis. A failure to document any differences in avoidance of the transmission line corridor before and after construction, in spite of a negative interaction between *saltdesert_avg* and *SRBIPP_564* in the modeled RSF, could arise from multiple sources.

Efforts to minimize project footprint, implement best management practices, and reclaim habitat after construction may have lessened impacts of the project on sage-grouse habitat use (Bureau of Land Management [BLM] 2012*b*, Avian Power Line

Interaction Committee [APLIC] 2015, Fedy et al. 2015). The area within the seasonal winter KDE that was located near the transmission line corridor had a low probability of use in both pre- and post-construction maps. Thus, the area closest to the West-Wide Energy Corridor was avoided by sage-grouse in the winter prior to the addition of the SRB line. The habitat to the west of the energy corridor was not considered high-quality sage-grouse winter habitat, therefore sage-grouse use of this area was not anticipated. No birds crossed the West-Wide Energy Corridor during the course of my entire study in either the pre- or post-construction time periods (2011-2013, Burnett 2013; 2014-2016, Fig. 3-7). The placement of the SRB 345-kV transmission line, in an area of low predicted probability of use that was located on the western periphery of the SGMA, likely reflects a best-case scenario for minimizing direct impacts to winter habitat use or movement patterns.

It is also possible that the presence of the new transmission line did negatively influence habitat suitability, but that the change was not dramatic enough to override the strong site-fidelity of sage-grouse (e.g. Fischer et al. 1993, Holloran and Anderson 2005), or that site fidelity could cause sage-grouse to continue to use this habitat for multiple years before adjusting movement patterns (Harju et al. 2010). Time lag delays for negative impacts of energy development on male lek attendance in Wyoming have been suggested to range from 2-10 years (Harju et al. 2010, Walker et al. 2007). Although little information is available regarding time lag delays on winter habitat selection or transmission line development, my study only included 2 years of post-construction data and thus may not cover a sufficient temporal scale for this impact to detectably alter spatial distributions of sage-grouse that overwinter in the area.

Alternatively, the influence of the transmission line corridor on habitat use as detected by the RSF may not have been a function of direct avoidance of a tall structure on the landscape, but rather by some associated, indirect impact. These effects may not manifest immediately after construction because they require a longer time period for the negative change to occur, and could include increased traffic due to the addition of ancillary roads, or changes in avian predator abundance as a result of increased perching substrate. It is unlikely that the installation of the access road under the SRB line would result in future increased avoidance by sage-grouse during the winter months. This is because the new road under the SRB line was revegetated to discourage non project-related use of the ROW, and vehicular access to the area in the winter months is difficult given its remote location (Appendix B).

Increased perching substrate for avian predators of sage-grouse is also a major concern related to power line development (Messmer et al. 2013), and I were not able to incorporate avian predator presence into my RSF model. The portion of the SRB transmission line that passed through the 6.4-km lek buffer around the Mud Springs lek was fitted with perch deterrents, but the effectiveness of these can vary widely (Prather and Messmer 2010, Slater and Smith 2010, Dwyer and Doloughan 2014), and historic perching locations were still available on the original IPP transmission line (Appendix B). Avian predator species that had winter ranges which overlapped the study area included golden eagles (*Aquila chrysaetos*; Kochert et al. 2002) and ferruginous hawks (*Buteo regalis*; Bechard and Schmutz 1995), both of which were observed nesting on the original IPP towers during the breeding season in 2014 and 2015 (Appendix B). An assessment of overwintering avian predator presence along the transmission line across

years would provide more information about the indirect consequences of energy corridor expansion located adjacent to sage-grouse critical winter habitat.

Within the 2-year post-construction temporal scale covered by my study, I did not observe increased avoidance of the West-Wide Energy Corridor by sage-grouse. This is likely because the SRB line was sited outside of utilized winter habitat, in an area of low predicted probability of use, and was located within an existing energy corridor. This suggests that the co-location of new transmission lines with those that are already in place is an effective technique for mitigating the short-term impacts of transmission line construction on sage-grouse habitat use. The interaction between average coverage of salt-desert and transmission line proximity included in the final model also indicated that sage-grouse spatial response to transmission lines in the winter can be influenced by the type of habitat surrounding the ROW. This should be addressed in development plans when assessing the potential for either increased avoidance or increased fragmentation of movement patterns within existing habitat. For example, siting a new transmission line in an existing corridor that is located in low-quality winter habitat (and thus potentially already avoided by sage-grouse) may reduce negative effects on overwintering populations, provided that avoidance of the corridor does not fragment existing habitat use. Continued monitoring of spatial distributions for sage-grouse that overwinter in the Mud Springs area, as well as collection of relevant demographic parameters, would yield additional information about this sage-grouse population in the long-term.

MANAGEMENT IMPLICATIONS

Utah's sage-grouse conservation plan calls for the avoidance and minimization of disturbance in winter habitat (State of Utah 2013). When disturbance cannot be avoided or minimized, mitigation is required. These results provide a quantitative assessment of winter sage-grouse habitat use in relation to the West-Wide Energy Corridor. I did not observe increased avoidance of the transmission line corridor by sage-grouse as distance to transmission line changed after the addition of a new line. Siting the line in an area of poor-quality habitat (salt-desert) on the periphery of the SGMA represents a best-case scenario for reducing the influence of new energy development projects. My results suggest that existing transmission line corridors located in poor-quality winter habitat are likely already avoided by sage-grouse, and co-locating additional lines within these corridors may dampen the effects of new tall structures on the landscape in the years immediately following construction. I emphasize that more data collection is required to determine if this technique also minimizes impacts to habitat use across long-term time scales. Because future indirect disturbances are still possible in the project area, I suggest monitoring of avian predator presence along the transmission line corridor, as well as management actions in that protect and increase winter habitat. Management actions should include maintaining $\geq 10\%$ sagebrush cover, maintaining $\leq 5\%$ tree cover in and adjacent to currently used winter habitat, and protecting designated winter habitat from wildfire (State of Utah 2013).

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CHAPTER 4

SUMMARY

Greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse) are a species of conservation concern that have been the focus of intensive study over the last several decades. Habitat loss and fragmentation as the result of natural and anthropogenic landscape disturbance have consistently been implicated as major threats to the species' persistence in sagebrush ecosystems across the western United States and southern Canada. As sage-grouse occupy a broad geographic range, it is essential to assess population-specific habitat use and quantify how disturbance can influence that habitat selection across relevant spatial and temporal scales. The results addressed within this thesis provide critical information regarding the influence of landscape disturbance on habitat use of a peripheral population of sage-grouse in the Bald Hills Sage-Grouse Management Area (SGMA) in southern Utah. To obtain detailed spatial data on habitat use across the SGMA, I deployed Global Positioning System/Platform Transmitting Terminal (GPS/PTT) transmitters on 26 sage-grouse ($n = 5$ females and $n = 21$ males) in 2014 and 2015. This data was used to develop resource selection function (RSF) models to quantify the role of landscape disturbance on seasonal habitat selection in the Bald Hills SGMA.

In Chapter 2, I assessed the impact of wildfire and subsequent rehabilitation efforts on summer habitat selection of non-reproductive sage-grouse within the Bald Hills SGMA (second order selection). I used a resource selection function (RSF) framework to develop generalized linear mixed-models containing multiple biologically relevant

covariates used to classify habitat across the SGMA. I included two categorical variables (landcover type and aspect), and 6 continuous variables (slope, distance to high speed roads, distance to low speed roads, distance to water, elevation, and Normalized Difference Vegetation Index (NDVI) for 12 July averaged across seasons). The landcover variable contained multiple categories describing vegetation communities that were biologically relevant to sage-grouse, and was also updated using spatial data provided by the Bureau of Land Management (BLM) to include categories for areas that were “NewBurn” (burns 0-10 years old, reclaimed by the BLM), “OldBurn” (burns 11-20 years old, reclaimed by the BLM) and “Treated” (habitat treatments not related to wildfire reclamation). Sagebrush habitat was used as the reference category within landcover to aid in interpretation because the relationship between sage-grouse and sagebrush is well-known.

I found that sage-grouse showed stronger preference for NewBurn, OldBurn, and Treated areas than sagebrush habitat during the summer months. Specifically, NewBurn was selected for most strongly ($\beta = 2.84 \pm 0.06$) of all landcover categories included in my analysis other than Agriculture. My model was validated internally through k-fold cross-validation and externally with independently collected telemetry locations from the Bald Hills in the summers of 2011 and 2012. The model showed high predictive success for both data sets, suggesting that it is applicable for sage-grouse in the Bald Hills across temporal scales. These results confirmed that non-reproductive sage-grouse can utilize areas that have been recently burned by wildfire in the summer months if the areas are promptly reclaimed following a wildfire event. This supports guidelines outlined in the Utah Sage-Grouse Management Plan, which allows 5 years for an area to be restored to

habitat prior to being classified as non-habitat if reclamation efforts are unsuccessful. I emphasized that more data collection is necessary to determine the long-term impacts of wildfire on sage-grouse in the Bald Hills. These data should specifically include: 1) measurements to quantify the vegetative community structure of burned patches used by sage-grouse, and 2) demographic data summarizing the reproductive and vital rates of sage-grouse which are interacting with burned patches.

My third chapter focused on assessing the spatial impact of transmission line installation on sage-grouse habitat selection within a population-level winter home range (third order selection) in the Bald Hills SGMA. The new, Sigurd-Red Butte (SRB) 345kV transmission line ran parallel to a preexisting 500kV transmission line, and violated a 6.4 km disturbance buffer around the Mud Springs lek on the western side of the SGMA. The transmission line corridor was located in poor-quality sage-grouse habitat (salt-desert). I used data collected from the first two winters after construction to develop an RSF model, and compared this to independently collected telemetry data collected from the winter of 2011-2012 (pre-construction) to see if habitat use changed after the addition of the new transmission line. I employed a multi-step model selection process using Akaike information criterion corrected for small sample sizes (AICc) to choose my top model from suite of biologically relevant covariates shown in other studies to be good predictors of sage-grouse winter habitat selection. The final model included a significant negative interaction between average salt-desert within a 1-km² moving window and distance to transmission line ($\beta = -2.44 \pm 0.30$). Internal validation with k-fold methodology and external validation with telemetry data collected from the

winter of 2011-2012 exhibited good predictive capacity for the model overall across individuals and years within the winter seasonal habitat boundary.

My mapped RSFs predicted that as distance to transmission line decreased with the construction of the new SRB line, winter habitat within the 6.4 km Mud Springs lek buffer should have experienced a 3% decrease in predicted probability of use. The interaction between average coverage of salt-desert and distance to transmission line indicated that this effect was particularly apparent in areas that were both salt-desert habitat *and* adjacent to the transmission line corridor. However, I saw no visible shifts in habitat use in the area between the winters of 2011-2012, 2014-2015, and 2015-2016 when comparing Minimum Convex Polygons (MCPs) of habitat use in the immediate vicinity of the transmission line. This indicated that colocation of the new transmission line along an existing transmission line corridor (which was located in poor-quality habitat and did not fragment existing habitat) effectively mitigated short-term displacement as a consequence of the new line. This provides important guidance for land managers because it suggests that the impacts of novel anthropogenic structures on the landscape can be dampened by pairing them with preexisting structures in areas of low-quality habitat. However, I caution that sage-grouse can exhibit strong site-fidelity in spite of disturbance events, and that displacement due to landscape alterations can be delayed by many years. Thus, I recommend continued monitoring of sage-grouse habitat use in the vicinity of the SRB line to determine whether the line results in displacement across longer temporal scales.

These results provide important information regarding the influence of landscape disturbance on habitat selection of a peripheral population of greater sage-grouse. The

isolation of the Bald Hills population, coupled with the marginal quality of available habitat, may put them at increased risk of extinction. Due to this potential sensitivity, it is critical to define the role of landscape disturbance on seasonal habitat selection of birds in the area. My results support existing best management practices for mitigating both the impacts of wildfire and transmission line construction on sage-grouse. I found that areas burned by wildfire and reclaimed within that same year were selected for by non-reproductive sage-grouse in the summer months. This is important information for managers because it indicates that burned areas can still be actively used by sage-grouse in the years following a fire, providing the area is reseeded shortly after the disturbance event. I also found that sage-grouse avoided a preexisting transmission line corridor, but that avoidance of that corridor did not increase following the addition of a second line. Managers can use this information to guide the siting process for additional transmission lines in future years to minimize impacts to sage-grouse as anthropogenic development increases across western landscapes.

APPENDICES

APPENDIX A
SUPPLEMENTARY TABLES AND
FIGURES FOR CHAPTERS 2 AND 3

Table A-1. Classification of LANDFIRE vegetation categories for final landcover predictor variable utilized in summer resource selection function modeling to describe greater sage-grouse (*Centrocercus urophasianus*) habitat use within the Bald Hills Sage-Grouse Management Area, Utah, USA.

Category ^{1,2,3}	% Total	Source Vegetation Category
NonHabitat	1.13	Inter-Mountain Basins Sparsely Vegetated Systems, Rocky Mountain Alpine/Montane Sparsely Vegetated Systems, Inter-Mountain Basins Montane Riparian Forest and Woodland, Rocky Mountain Montane Riparian Forest and Woodland, Inter-Mountain Basins Sparsely Vegetated Systems II, Rocky Mountain Alpine/Montane Sparsely Vegetated Systems II, Rocky Mountain Montane Riparian Shrubland, Rocky Mountain Subalpine/Upper Montane Riparian Shrubland, Open Water, Snow-Ice, Barren
Sage	34.36	Colorado Plateau Mixed Low Sagebrush Shrubland, Great Basin Xeric Mixed Sagebrush Shrubland, Inter-Mountain Basins Big Sagebrush Shrubland, Columbia Plateau Low Sagebrush Steppe, Inter-Mountain Basins Big Sagebrush Steppe, Inter-Mountain Basins Montane Sagebrush Steppe, <i>Artemisia tridentata</i> ssp. <i>vaseyana</i> Shrubland Alliance
Forest	0.41	Rocky Mountain Aspen Forest and Woodland, Rocky Mountain Bigtooth Maple Ravine Woodland, Rocky Mountain Lodgepole Pine Forest, Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland, Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland, Southern Rocky Mountain Ponderosa Pine Woodland, Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland, Rocky Mountain Subalpine Mesic-Wet Spruce-Fir Forest and Woodland, Rocky Mountain Subalpine-Montane Limber-Bristlecone Pine Woodland, Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland, Inter-Mountain Basins Curl-leaf Mountain Mahogany Woodland, Southern Rocky Mountain Ponderosa Pine Savanna, <i>Abies concolor</i> Forest Alliance
Developed	1.78	Quarries-Strip Mines-Gravel Pits, Developed-Low Intensity, Developed-Medium Intensity, Developed-High Intensity, Developed-Roads, Western Cool Temperate Urban Deciduous Forest, Western Cool Temperate Urban Evergreen Forest, Western Cool Temperate Urban Mixed Forest, Western Cool Temperate Urban Herbaceous, Western Cool Temperate Urban Shrubland, Western Cool Temperate Developed Ruderal Deciduous Forest, Western Cool Temperate Developed Ruderal Evergreen Forest, Western Cool Temperate Developed Ruderal Mixed Forest, Western Cool Temperate Developed Ruderal

Shrubland, Western Cool Temperate Developed Ruderal Grassland		
Grass	6.31	Rocky Mountain Alpine Dwarf-Shrubland, Inter-Mountain Basins Semi-Desert Grassland, Rocky Mountain Alpine Turf, Rocky Mountain Subalpine-Montane Mesic Meadow, Southern Rocky Mountain Montane-Subalpine Grassland, Introduced Upland Vegetation-Annual Grassland, Introduced Upland Vegetation-Perennial Grassland and Forbland, Introduced Upland Vegetation-Annual and Biennial Forbland,
Shrub	8.50	Rocky Mountain Lower Montane-Foothill Shrubland, Great Basin Semi-Desert Chaparral, Rocky Mountain Gambel Oak-Mixed Montane Shrubland, Inter-Mountain Basins Semi-Desert Shrub-Steppe, Inter-Mountain Basins Greasewood Flat, Coleogyne ramosissima Shrubland Alliance, Grayia spinosa Shrubland Alliance, Arctostaphylos patula Shrubland Alliance, Quercus gambelii Shrubland Alliance
Juniper	13.39	Colorado Plateau Pinyon-Juniper Woodland, Great Basin Pinyon-Juniper Woodland, Rocky Mountain Foothill Limber Pine-Juniper Woodland, Inter-Mountain Basins Juniper Savanna
Agriculture	2.00	Western Cool Temperate Row Crop - Close Grown Crop, Western Cool Temperate Row Crop, Western Cool Temperate Close Grown Crop, Western Cool Temperate Fallow/Idle Cropland, Western Cool Temperate Pasture and Hayland, Western Cool Temperate Wheat
Salt Desert	8.48	Inter-Mountain Basins Mat Saltbush Shrubland, Inter-Mountain Basins Mixed Salt Desert Scrub, Mojave Mid-Elevation Mixed Desert Scrub
Treated	2.35	Treatments not related to wildfire reclamation; BLM habitat treatment data
OldBurn	2.92	Areas burned and reseeded from 1995-2004, BLM wildfire perimeter polygon data
NewBurn	18.37	Areas burned and reseeded from 2005-2014, BLM wildfire perimeter polygon data

¹Non-Habitat, Sage, Forest, Developed, Grass, OtherShrub, Juniper, Agriculture, and SaltDesert derived from LANDFIRE 2010 and 2012 Existing Vegetation Type data. Source vegetation categories obtained from CLASSNAME categories.

²Treated data classified from Color Country BLM habitat treatment polygon data

³OldBurn and NewBurn classified from BLM wildfire perimeter data

Table A-2. Classification of LANDFIRE vegetation categories utilized for final landcover predictor variables utilized in winter resource selection function modeling for greater sage-grouse (*Centrocercus urophasianus*) habitat selection within the Bald Hills Sage-Grouse Management Area, Utah, USA.

Final RSF Landcover Category ¹	Source Vegetation Category
<i>Sage_low</i>	Colorado Plateau Mixed Low Sagebrush Shrubland, Great Basin Xeric Mixed Sagebrush Shrubland, Columbia Plateau Low Sagebrush Steppe
<i>Sage_big</i>	Inter-Mountain Basins Big Sagebrush Shrubland, Inter-Mountain Basins Big Sagebrush Steppe, Inter-Mountain Basins Montane Sagebrush Steppe, Inter-Mountain Basins Semi-Desert Shrub-Steppe, <i>Artemisia tridentata</i> ssp. <i>vaseyana</i> Shrubland Alliance
<i>Sage_all Develop</i>	Combination of all categories from <i>sage_low</i> and <i>sage_big</i> Developed-Low Intensity, Developed-Medium Intensity, Developed-High Intensity, Western Cool Temperate Urban Deciduous Forest, Western Cool Temperate Urban Evergreen Forest, Western Cool Temperate Urban Mixed Forest, Western Cool Temperate Urban Herbaceous, Western Cool Temperate Urban Shrubland, Western Cool Temperate Developed Ruderal Deciduous Forest, Western Cool Temperate Developed Ruderal Evergreen Forest, Western Cool Temperate Developed Ruderal Mixed Forest, Western Cool Temperate Developed Ruderal Shrubland, Western Cool Temperate Developed Ruderal Grassland
<i>Juniper</i>	Colorado Plateau Pinyon-Juniper Woodland, Great Basin Pinyon-Juniper Woodland, Rocky Mountain Foothill Limber Pine-Juniper Woodland, Inter-Mountain Basins Juniper Savanna
<i>SaltDesert</i>	Inter-Mountain Basins Mixed Salt Desert Scrub, Mojave Mid-Elevation Mixed Desert Scrub

¹ Derived from LANDFIRE 2010 and 2012 Existing Vegetation Type data. Listed classes indicate CLASSNAME from original data set.

APPENDIX B
COMPARISONS OF AVIAN POINT COUNTS AND
VEHICULAR TRAFFIC FREQUENCIES BEFORE AND AFTER
TRANSMISSION LINE CONSTRUCTION

To supplement information regarding sage-grouse habitat use in the vicinity of the new, Sigurd-Red Butte (SRB) 345 kV transmission line, I conducted point counts for avian predators along the transmission line corridor, and placed trail cameras along the new transmission line Right of Way (ROW) in the summers of 2014 (pre-construction) and 2015 (post-construction). Fig. B-1 shows locations of all survey points across the Bald Hills Sage-Grouse Management Area (SGMA).

Bald Hills Survey Locations

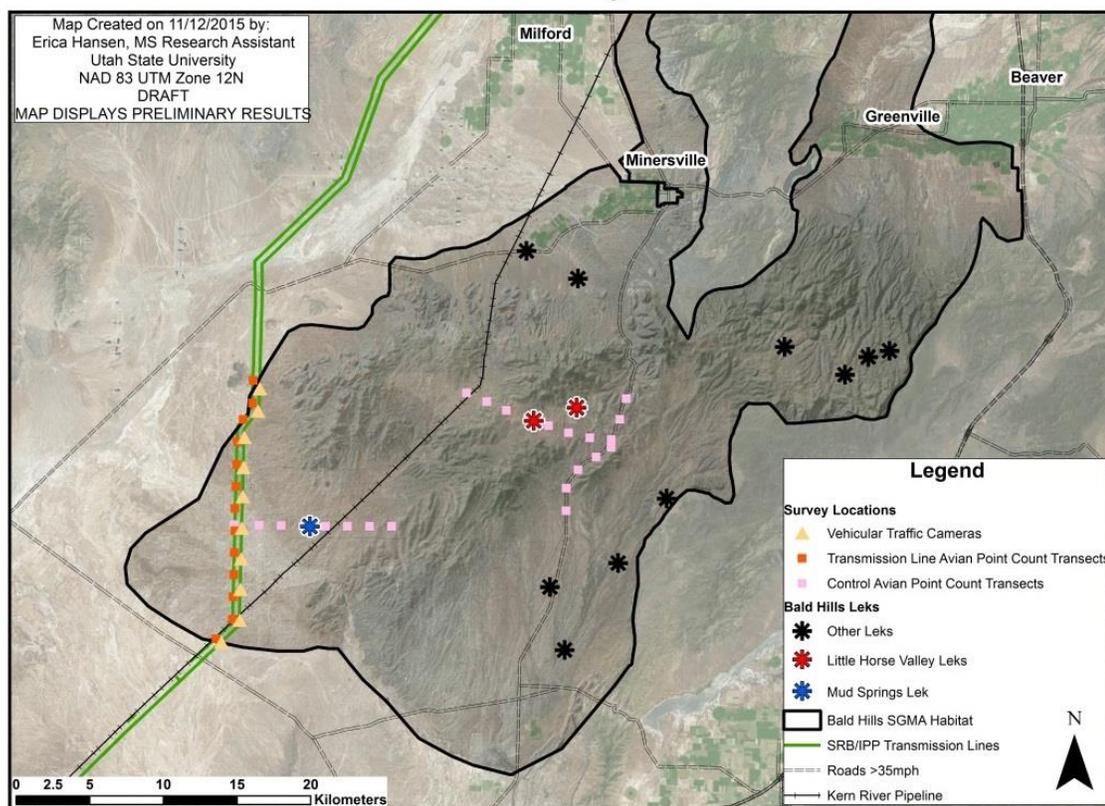


Figure B-1. Survey locations utilized for point counts for avian predators (squares) and traffic counts using trail cameras (triangles) within the Bald Hills Sage-Grouse Management Area (SGMA) in Utah, USA during the summers of 2014 and 2015. Avian survey locations along the transmission line right-of-way are shown in orange, while alternate point count locations (intended as a baseline for comparison) are shown in pink.

AVIAN POINT COUNTS

Methods

I conducted point counts for known avian predators of sage-grouse (raptors and corvids) at regular (1.5km) intervals along the transmission line corridor, for a total of 13 survey points along the transect. At each point, I counted birds that were within 750 meters of my location in a north-south direction, and no greater than 250 m to the exterior of the transmission line corridor in the east-west direction (i.e. to the west of the IPP line and the east of the SRB line). This resulted in a fixed-area rather than fixed-radius point count, but due to the large size of the species being surveyed and the absence of trees in the area, I assumed there were no differences in detection within any part of the fixed survey area for each point. I was able to visually confirm the future location of the SRB line prior to construction because company surveyors had placed flagging along the right-of-way (ROW) that was visible with binoculars. All distances were checked during every survey using a rangefinder to ensure accuracy. Point count for survey transects not located on the transmission line corridor (Mud Springs Lek Diameter, Little Horse Valley Lek Diameter, and Minersville Highway) were fixed at a radius of 750m and 5 minute duration. I conducted one morning survey and one evening survey whenever possible for April-August in the summers of 2014 (pre-construction) and 2015 (post-construction). Surveys were not conducted during the middle of the day because temperatures were often hot (> 90 degrees Fahrenheit) and I assumed that detection probabilities would go down during that part of the day. Surveys were not conducted if it was raining or if the average wind speed at the nearest weather station (Minersville) exceeded 20 km/hour to minimize impacts of weather on point count results. During surveys, I opportunistically

documented any observed perching by avian predators on towers fitted with perch deterrents. Comparisons were conducted between mean corvid/raptor counts for each summer. Data was blocked by survey location to help control for spatial variability between locations. The mean count of raptors and corvids, respectively, was calculated for each location per season, and compared using a paired t-test (two-tail).

Results

I detected statistically significant increases in both the average corvid count by location ($t = -5.36$, $p < 0.05$) and average raptor count by location ($t = -2.60$, $P < 0.05$) on the transmission line transect between 2014 and 2015 (Table B-1). I did not detect any statistically significant differences for raptors or corvids between 2014 and 2015 for any other transect except for the raptor counts on the Minersville Highway transect, which showed a statistically significant increase between 2014 and 2015 ($t = -3.86$, $P < 0.05$).

Table B-1. Paired t-test results comparing relative abundance of raptors and corvids between 2014 and 2015 for each transect in the Bald Hills Sage-Grouse Management Area, Utah, USA. Counts were blocked by survey location along the transect to control for spatial variability. Significant results are bolded.

Transect	Species	t-statistic	P-value
Transmission Line	Corvid	-5.36	< 0.01
	Raptor	-2.60	0.02
Mud Springs Lek Diameter	Corvid	-0.48	0.65
	Raptor	-0.14	0.89
Little Horse Valley Lek Diameter	Corvid	0.60	0.57
	Raptor	0.63	0.55
Little Horse Valley Highway	Corvid	-0.28	0.79
	Raptor	-3.86	< 0.01

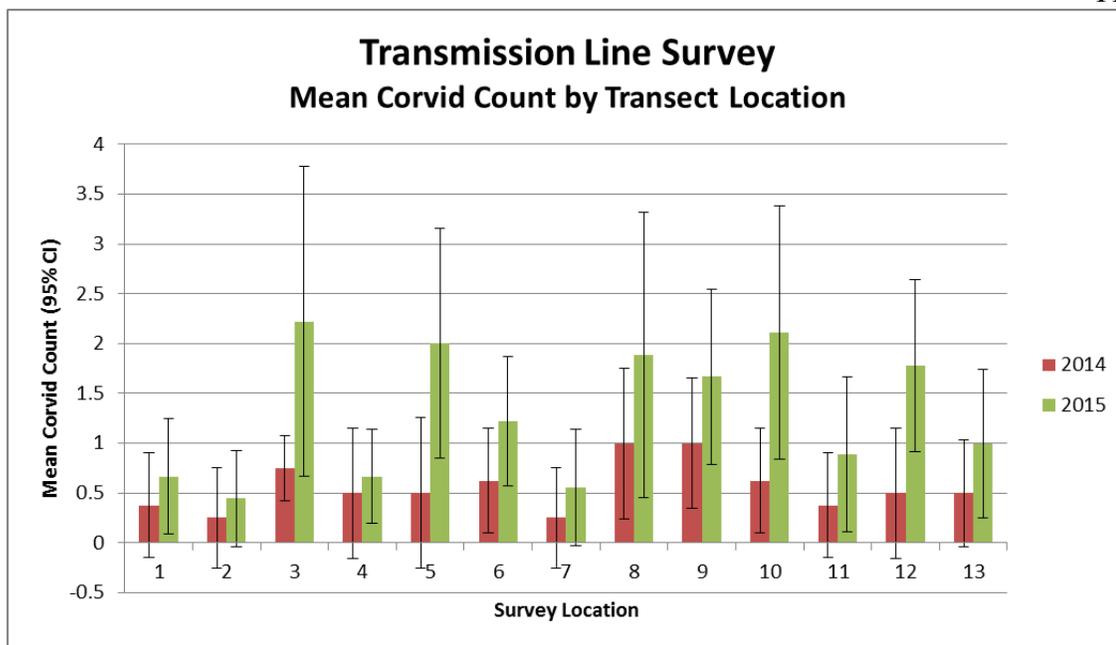


Figure B-2. Comparison between mean corvid counts for each survey location along the transect located in the West-Wide Energy Corridor, Bald Hills Sage-Grouse Management Area, Utah, USA, in 2014 and 2015. Error bars indicate 95% confidence intervals.

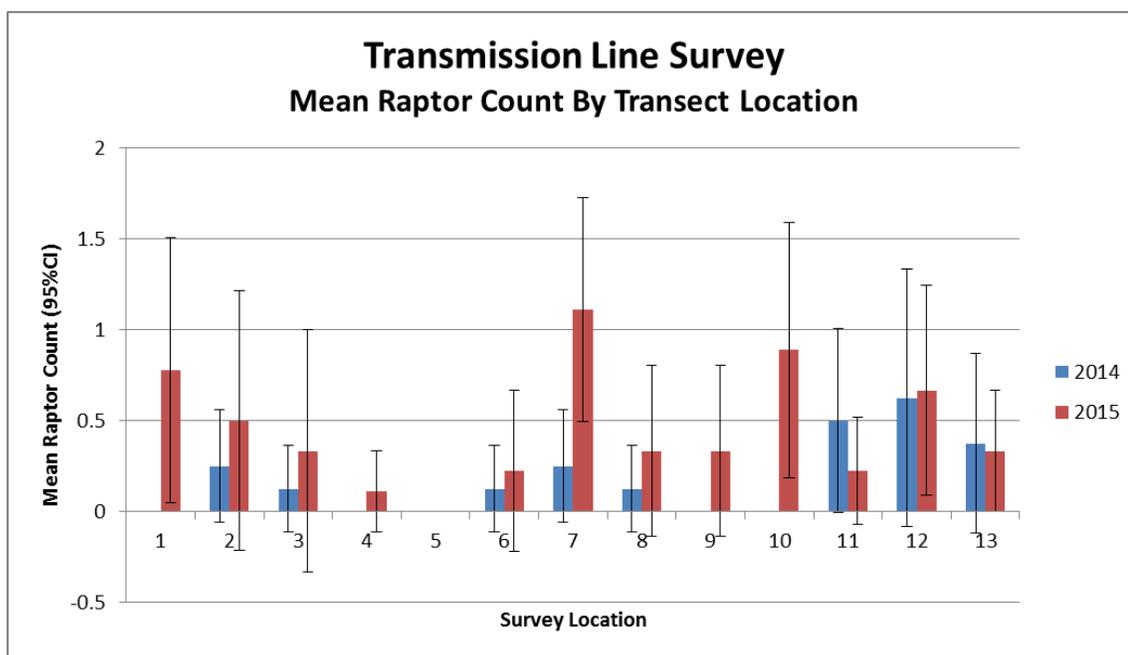


Figure B-3. Comparisons between mean corvid counts for each survey location along the transect located in the West-Wide Energy Corridor, Bald Hills Sage-Grouse Management Area, Utah, USA, in 2014 and 2015. Error bars indicate 95% confidence intervals.

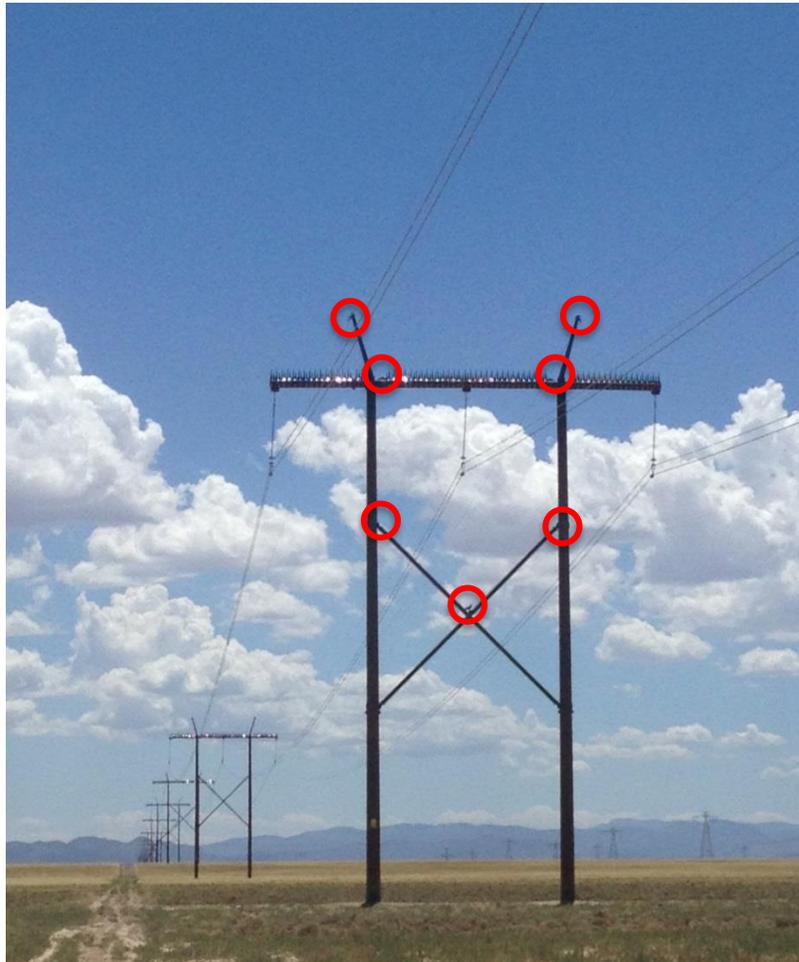


Figure B-4. Locations where avian predators were observed perching on Sigurd-Red Butte 345 kV transmission line towers fitted with perch deterrents during the summer of 2015 in the Bald Hills Sage-Grouse Management Area, Utah, USA. A raven (*Corvus corax*) is visible in the lowest central circle where the two support beams cross.

Discussion

Because this was a comparison between only two years, it is possible that the increase in raptor and corvid relative abundance along the transmission line transect between 2014 and 2015 was a natural fluctuation and not indicative of a larger trend driven by the addition of a new transmission line. However, it does suggest that continued monitoring of raptor and corvid presence along the transmission line ROW is

warranted, particularly in the context of protecting sage-grouse that utilize the Mud Springs Bench area near the ROW.

TRAIL CAMERA TRAFFIC COUNTS

Methods

I placed 10 trail cameras at evenly-spaced (1.9 km) intervals along the Right-of-Way (ROW) for the Sigurd-Red Butte 345 kV transmission line in the summers of 2014 and 2015. In 2014 (pre-construction), the ROW was visible by some staked areas and shrub removal conducted by Rocky Mountain Power. In 2015, after construction, the ROW was reseeded to discourage recreational use of the road. Active dates for cameras ranged from May 1 2014 to July 27 2014 and April 21 2015 to August 28 2015 for each summer, respectively. The active dates were shorter for the first summer because cameras were removed prior to initiation of transmission line construction in the late summer of 2014. Cameras were checked approximately every 30 days. I classified traffic as research-related (Utah State University truck or ATV), project-related (Rocky Mountain Power operation and maintenance), or other (private vehicles). Cameras were placed on the eastern side of the ROW, facing west. The same cameras were placed at the same location in both summers to ensure consistency within locations.

Results

Vehicle counts were generally very low, so I pooled vehicle types for analysis. Due to high densities of cattle in the area around the ROW, cameras were often knocked down between monthly checks. Additionally, one camera was stolen in May of 2015, so the data from that camera was excluded from all analyses. I calculated the mean number

of vehicle detections per active camera day per location for each summer. These were compared using a paired t-test (two-tail).

The only vehicle detections in the summer of 2014 were research-related (as a result of my going and checking cameras and traveling along the ROW). Average vehicle count/camera day/location ranged from 0.045 to 0.182. After construction, traffic rates were slightly higher overall, with average detections of all pooled vehicle types per location ranging from 0.0645 vehicles/camera day to 0.24 vehicles/camera day. I did not detect a statistically significant difference in vehicle presence between the summers of 2014 and 2015 ($t = -1.76$, $P = 0.12$).

Discussion

Although vehicle traffic was slightly more common in the summer of 2015, this increase was not statistically significant. Moreover, due to the very low frequencies of vehicular traffic overall for both summers, it is unlikely that traffic presence along the new ROW will have any impact on sage-grouse that utilize habitat near the Mud Springs lek. Low traffic on the road under the SRB line is potentially due to the presence of a well-established road under the Intermountain Power Project (IPP) transmission line that provides an alternate route for vehicles traveling through the area.

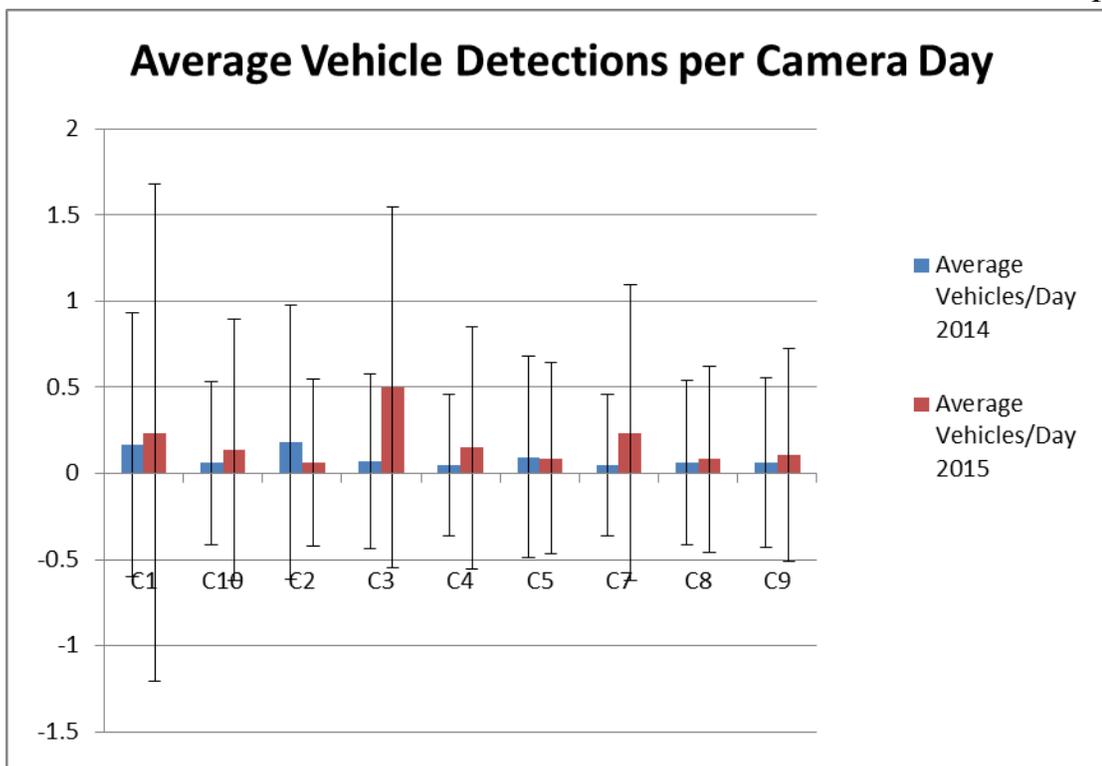


Figure B-5. Average vehicle detections per active camera day in 2014 and 2015 along the Sigurd-Red Butte 345 kV transmission line in the Bald Hills Sage-Grouse Management Area, Utah, USA. Vehicle detections were very low overall with no statistically significant difference between the two summers. Error bars indicate 95% confidence intervals.

APPENDIX C
PERMISSIONS LETTERS

November 15, 2016

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Logan, Utah 84322-5230

To the Permissions Editor:

I am in the process of preparing my Master's in Wildlife Biology at Utah State University. I hope to complete my degree program in December. The article **Influence of Transmission Line Construction on Greater Sage-Grouse Habitat Use in Southern Utah**, of which I am first author, and which will soon appear in *Human Wildlife Interactions*, reports an essential part of my thesis research. I would like permission to reprint it as a chapter in my thesis, which may require some revision. Please note that USU sends every thesis and dissertation to ProQuest to be made available for reproduction. I will include acknowledgment to the article on the first page of the chapter, as shown below. Copyright and permission information will be included in a special appendix. Please let me know if you would like a different acknowledgment. Please indicate your approval of this request by signing in the space provided, and attach any other form necessary to confirm permission. If you charge a reprint fee for use of an article by the author, please indicate that as well. If you have any questions, please contact me at the phone number or email below. Thank you for your assistance.

Erica P. Hansen

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Hansen, E. P., A. C. Stewart, and S. N. Frey. 2016. Influence of transmission line construction on winter sage-grouse habitat use in southern Utah. *Human-Wildlife Interactions* 10(2):169-187

Signed: 

Date: 11/16/16

November 15, 2016

Erica P. Hansen
Department of Wildland Resources
Utah State University
Logan, Utah 84322-5230

Dear A. Cheyenne Stewart,

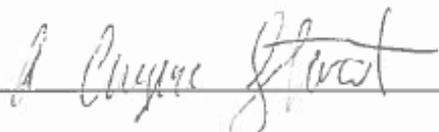
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Date: 11/21/2016

November 15, 2016

Erica P. Hansen
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Logan, Utah 84322-5230

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Signed: Shandra Nicole Frey

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