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Modeling Habitat Use of a Fringe Greater Sage-Grouse Population at Multiple Spatial Scales

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MODELING HABITAT USE OF A FRINGE GREATER SAGE-GROUSE

POPULATION AT MULTIPLE SPATIAL SCALES

by

Anya Cheyenne Burnett

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ABSTRACT

Modeling Habitat Use of a Fringe Greater Sage-Grouse Population

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by

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Utah State University, 2013

Major Professor: S. Nicole Frey
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While range-wide population declines have prompted extensive research on greater sage-grouse (*Centrocercus urophasianus*), basic information about southern periphery populations, such as the Bald Hills population in southern Utah, has not been documented. The objective of this research was to determine habitat preferences and space use patterns of the Bald Hills sage-grouse population which occurs in an area of high potential for renewable energy development. I tracked 66 birds via VHF telemetry in 2011 and 2012 and surveyed vegetation plots throughout the study area. I found that the population was primarily one-stage migratory with seasonal distributions that did not correspond well with previously developed suitable habitat maps (based on local biologist knowledge and lek data) for all seasons; I also found that mean home range sizes ranged from 82 km^2 to 157 km^2.

Nesting hens did not select for any measured vegetation characteristics within the study area, while brood-rearing hens selected for high forb cover. Birds at summer sites

(non-reproductive bird locations during the summer season) selected for greater grass and forb cover and lower shrub cover compared with random sites. Overall, Bald Hills sage-grouse used areas with greater shrub canopy cover and lower grass and forb cover than recommended in habitat guidelines.

Ten predictor variables were used to model suitable seasonal habitat using Maximum Entropy (maxent). All models were created for the Bald Hills population and projected to the Bureau of Land Management Cedar City Field Office management area and produced excellent model fit (AUC > 0.900). The Bald Hills population had similar nesting and winter habitat preferences as other populations but different brood-rearing and summer habitat preferences. I found local management techniques to be an important driver of seasonal habitat selection; birds selected for areas that had undergone habitat treatments (such as broadcast burn and crushing) within the previous 10 years. My results indicated the Bald Hills periphery population occupies marginal habitat and has adapted unique seasonal habitat preferences. Managers of isolated, fringe, and low-density populations should develop locally specific management guidelines to address the unique adaptations and ensure the persistence of these populations.

(179 pages)

PUBLIC ABSTRACT

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Greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse) are a prominent bird species of sagebrush-dominated landscapes across the western United States. Over the past 15 years, sage-grouse have gained international attention due to decreasing population trends despite management efforts. In 2010 the U.S. Fish and Wildlife Service designated this species as warranted for listing under the Endangered Species Act, but the listing was precluded by other species at higher conservation risk. Habitat loss, degradation, and fragmentation have been implicated as primary sources of declines in sage-grouse distribution and abundance. The Bald Hills population in southwestern Utah occupies an area with high potential for renewable energy development. This population is on the southern fringe of the species range and fringe populations are often under greater risk of extinction. The objective of this research was to determine the habitat preferences and space use patterns of the Bald Hills sage-grouse

population to better understand how southern fringe sage-grouse populations interact with their habitat.

In May 2010 the Bureau of Land Management was awarded a grant by the American Recovery and Reinvestment Act to conduct research on the habitat use and movement of the Bald Hills sage-grouse population prior to renewable energy development in the area. This grant was provided with the goal of improving the management of lands that may be open to energy development in the future as well as job creation for the duration of the research project. Over the duration of the project, one full-time graduate student and more than five seasonal undergraduate students were employed. This project created jobs and provided invaluable field experience for students pursuing wildlife-related careers.

Understanding the relationship between sage-grouse and their habitat will assist land managers in mitigating threats to the population while balancing the demands to further develop renewable energy resources. The research was successful. All of my results indicated that by occupying marginal habitat, the Bald Hills periphery population has adapted unique seasonal habitat preferences. I made management recommendations based on these results. I concluded that researchers and resource managers should examine isolated, fringe, and low-density populations more closely to develop local-specific management techniques to account for unique adaptations and ensure the persistence of these sage-grouse populations.

ACKNOWLEDGMENTS

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

GREATER SAGE-GROUSE ECOLOGY AND MANAGEMENT

Greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse) are the largest grouse species in North America. Sage-grouse are a ground-dwelling bird and a prominent species of sagebrush-dominated landscapes across the western United States (Schroeder et al.1999). In the past 15 years, sage-grouse have gained international attention due to decreasing population trends despite management efforts (Stiver 2011). In March 2010, the U.S. Fish and Wildlife Service (USFWS) designated this species as a candidate for listing under the Endangered Species Act (USFWS 2010).

Sage-grouse are sagebrush obligates, relying on sagebrush habitats during each part of their life history for food and cover (Wisdom et al. 2005). Sage-grouse consume the leaves of big sagebrush (*Artemesia tridentata*) year-round and as the principle component of their winter diet. They also rely on other food sources that require diverse sagebrush habitats. For example, insects, which are attracted to sagebrush habitats with a forb understory, are an important food source during early brood-rearing and forbs themselves are consumed at high percentages in the late summer (Connelly et al. 2000). Because of their need for diverse sagebrush habitats, sage-grouse are considered an umbrella species for other sagebrush-obligate species (Rowland et al. 2006) and an indicator of sagebrush habitat health (Connelly et al. 2004).

Sage-grouse breed on lekking grounds where males perform a courtship display and females choose their mate. The strutting display usually lasts 3-4 hours during sunrise for up to 3 months in the spring (Schroeder et al.1999). Dunn and Braun (1985)

found that males have high lek site fidelity, displaying on the same lek each year for the

duration of the lekking season. At a given lek the number of displaying males can range

from a few to over 100, with individual leks persisting for decades (Connelly et al. 2004,

Crawford et al. 2004). Counts of male birds at leks ("lek counts") have been used as a

standardized method to monitor populations. While the accuracy of using lek counts in

this way is controversial, the long-term dataset has proved integral to observing

population trends (UDWR 2009, Walsh et al. 2004)

Seasonal Habitat Requirements

While integral to the life history of sage-grouse, lek habitat does not limit sage-

grouse population growth (Schroeder et al.1999). Leks occur in areas of sparse vegetation

surrounded by sagebrush habitat. In Wyoming, increased distance from lek to nest sites

was found to decrease nest success (Holloran and Anderson 2005). This may explain why

leks often form opportunistically near potential nesting habitat. Lek sites may include

ridge tops, dry lake beds, burned areas, or cleared roadsides, and can be created via

management techniques (Connelly et al. 2000, Crawford et al. 2004).

Sagebrush-dominated over-story and herbaceous understory are cumulatively

important to nest success. Connelly et al. (2000) indicated that specific habitat

characteristics for pre-laying hens (5 weeks before incubation) and nest sites affected nest

success. Forbs provided pre-laying hens with nutrients (calcium, phosphorus, and

protein) that increased their reproductive success (Connelly et al. 2000, Crawford et al.

2004). In studies conducted in Colorado, Idaho, Montana, Oregon, Washington, and

Wyoming, hens were found to select nest sites based on micro-site sagebrush and grass

characteristics (reviewed in Connelly et al. 2000). When cover is inadequate, nests are more susceptible to predation (Holloran and Anderson 2005).

During early brood-rearing (April/May), sage-grouse prefer relatively open habitats with high forb density and insect abundance (Connelly et al. 2000). Forbs and insects (commonly grasshoppers, ants, and beetles) are an important source of protein for chicks and hens. As forbs begin to desiccate during late brood-rearing (June/July), sage-grouse move to mesic areas such as riparian meadows and chicks begin adding sagebrush to their diet (Crawford et al. 2004). During this time, birds have been observed using small burned areas in sagebrush habitat, wet meadows, farmland, and irrigated areas (Connelly et al. 2000). Brood-less hens and males use similar habitat during the brood-rearing season; however, they often move to riparian areas sooner and travel in increasingly larger mix-sexed groups (Crawford et al. 2004).

Sage-grouse select for habitat dominated by relatively tall sagebrush in the winter. Because their diet is primarily sagebrush leaves, they require gentle south and west facing slopes where sagebrush leaves remain exposed above the snow (Doherty et al. 2008). Sage-grouse have low reproductive success and juvenile survival during the spring/summer as compared with other Galliformes species (Schroeder et al. 1999). In contrast, adult over-winter survival of sage-grouse is typically greater than other seasons. This highlights the importance of suitable winter habitat to maintain high over-winter survival for species persistence (Aldridge et al. 2004, Battazzo 2007).

Migration and Seasonal Home Range

Sage-grouse vary in their types of seasonal movements, which can make it challenging to define migration patterns. Populations are most easily classified into 3

different types: non-migratory, 1-stage migratory, and 2-stage migratory. Migratory

movements were defined by Connelly et al. (2000) as movements greater than 10 km in

one direction. Non-migratory populations do not make any long-distance movements

between seasonal ranges. Populations that exhibit 1-stage migrations move between 2

distinct ranges, usually a summer and a winter range. Two-stage migratory populations

move between 3 distinct seasonal ranges. To further complicate migratory patterns, not

all individuals in a population will exhibit the same seasonal movements (Connelly et al.

2000). Migratory movements may be caused by sage-grouse seeking areas that meet

specific seasonal habitat requirements (Leonard et al. 2000).

Complex movement patterns make it challenging to characterize home ranges

across populations (Crawford et al. 2004). For example, the annual home range for a

migratory sage-grouse population in Idaho was 2,764 km^2 while non-migratory

populations can have much smaller seasonal home ranges (Leonard et al. 2000, Wallestad

1971). In a non-migratory population in central Montana, summer home range for hens

with broods remained <1 km^2 (Wallestad 1971). As represented in these examples,

generalizations about home range sizes are not informative because of the population-

specific nature of the sage-grouse movements. Identifying home range on a population-

by-population basis is, however, an important and useful tool for local land managers.

Conservation Status

Sage-grouse populations have been declining since the 1930s throughout most of

their range (Beck et al. 2003). The current distribution is estimated at 56% of their pre-

settlement distribution and populations are becoming increasingly isolated (Schroeder et

al. 2004). Today, core populations occur in parts of California, Colorado, Idaho, Montana, Nevada, Oregon, Utah, Washington, and Wyoming (Schroeder et al. 2004).

Beck et al. (2003) estimated that the sage-grouse population in Utah occupies 41% of the potential historic distribution. Schroeder et al. (2004) suggested that populations have undergone greater impacts in Utah as compared to further north, because the southwest was settled prior to the more northern parts of the sage-grouse range. Lek counts have been conducted in Utah since 1959. Statewide populations have exhibited an overall decreasing trend. A steeper decline has occurred in the last 7 years, which may be attributed to a 7-year cyclical pattern (UDWR 2009).

After receiving multiple petitions to list sage-grouse under the Endangered Species Act (ESA), the USFWS conducted an initial species status review, published in January 2005. Their finding that the species did not warrant protection under the ESA was remanded in 2007. Most recently, in March 2010 the USFWS conducted and published an additional species status review. This report currently designates greater sage-grouse (range-wide) as warranted for listing as endangered or threatened under the ESA. Their listing is precluded, however, by other higher priority listing actions. A final listing determination is expected in 2015 (USFWS 2010, 2012). This has effectively given state and other federal agencies time to sufficiently increase protections for sage-grouse and their habitat to avoid future listing under the ESA).

Major Threats and Management

Habitat loss, degradation, and fragmentation have been implicated as primary sources for declines in sage-grouse distribution and abundance (Schroeder et al.1999). According to Connelly et al. (2000) the quality and quantity of range-wide sage-grouse

habitat has declined significantly in the last 50 years. Habitat quantity has been impacted by the development of over 4 million hectares of western rangelands. Major changes in the proportions of trees, shrubs, grasses, and forbs have impacted habitat quality (West 1999, Crawford et al. 2004).

Threats to sage-grouse habitat include the invasion of exotic species, particularly cheatgrass (*Bromus tectorum*), altered fire regimes, improper livestock management, and juniper encroachment (reviewed in Connelly et al. 2011, UDWR 2009). Interactions between these threats can be additive and cyclical. Improper grazing techniques have led to cheatgrass invasion that increases fire frequency, which further perpetuates the cheatgrass invasion, for example (Miller et al. 2011). Threats involving habitat loss and fragmentation include development of agriculture, energy infrastructure, and roads (reviewed in Connelly et al. 2011).

Management efforts have emphasized lek locations, core populations, mitigation measures for future development, and sagebrush habitat restoration (UDWR 2009, Connelly et al. 2000, Crawford et al. 2004, Dahlgren et al. 2006). It is important to note that based on the umbrella-species-effect hypothesis, efforts to improve sage-grouse habitat at a landscape scale may also benefit a suite of other sagebrush obligate species (Rowland et al. 2006).

In Wyoming, nest locations are spatially distributed relative to lek sites. A 5-km buffer was found to include over 60% of nest locations (Holloran and Anderson 2005). In Montana, Doherty et al. (2008) found that sage-grouse selected for winter habitat within 4 km^2 of leks. Identifying lek buffers as critical sage-grouse habitat during multiple seasons has become integral information for range-wide management efforts. The Utah

Division of Wildlife Resources (UDWR) has used this relationship to identify core populations based on lek buffers. Lek density circles are developed using a lek buffer and density information about every lek in the state. The result is a representation of "hot-spots", where core populations that represent the greatest percentages of the state's breeding populations are identified. These core areas have become the focus for mitigation and habitat restoration efforts. Habitat improvement projects have included revised wildfire rehabilitations, juniper removal, and seasonal restrictions on disturbance to sage-grouse habitat (UDWR 2009).

Over-winter survival is a key component to species persistence. Winter habitat has therefore gained more attention recently as being potentially limiting to populations and in need of protection. (Aldridge et al. 2004, Battazzo 2007). In migratory populations, winter habitats outside of the core area buffers receive little protection and may, in some areas be under threat from energy and other development (Doherty et al. 2008).

ENERGY DEVELOPMENT

The effects of oil and gas development on sage-grouse have a long history, with oil exploration of the west beginning in the mid-1800's (US Department of Energy 2012). In recent federal and state policy, the development of non-carbon based energy resources has been emphasized. For example, the American Recovery and Reinvestment Act (ARRA) of 2009 designated $90 billion to invest in clean energy projects with the goal of doubling national renewable energy production (US Department of Energy 2012). In Utah, the Energy Resource and Carbon Emission Reduction Initiative was signed into law in 2008 (Utah Code 54-17-602), which was aimed at taking measurable steps to

increase development of non-carbon based energy resources (wind, solar, and natural gas) within the state. To facilitate this undertaking, Governor Huntsman commissioned the Utah Renewable Energy Zones (UREZ) Task Force to identify cost-effective non-carbon based resource and transmission zones. One of the resource zones identified (Milford) overlaps with almost half of the study area, providing an opportunity to study the Bald Hills sage-grouse population prior to potential development (Berry et al. 2009).

The impacts of wind, solar, and geothermal energy development on sage-grouse are not well understood. Direct impacts of concern are collisions, habitat fragmentation, and habitat loss. Potential indirect impacts include increased perching structures for avian predators, habitat degradation and fragmentation, noise and traffic disturbance, and avoidance of suitable habitat (Walker et al. 2007, Doherty et al. 2008, Holloran et al. 2009, Pruett et al. 2009, Harju et al. 2010, Utah Wildlife in Need 2010, Gilbert and Chalfoun 2011).

SPECIES DISTRIBUTION MODELING

Predicting species distributions and modeling habitat suitability are essential to wildlife conservation and management (Elith et al. 2006). Species Distribution Modeling (SDM) relates species-presence data to environmental variables to produce predictions of a species distribution as it relates to suitable habitat. SDMs have been used to model populations of various sizes, from continental distributions to small endemic populations (Franklin 2011).

Machine-learning methods have becoming increasingly useful for biologists to create SDMs (Franklin 2011). It is often difficult to obtain true absence data (locations that are available to, but not used by the target species) for these models, particularly with

radio-telemetry studies (method of species presence data collection). Maximum Entropy

(Maxent) has emerged as a popular machine-learning tool for SDMs. This is because it

out-performs other methods with presence-only data, for spatial and temporal projections,

and in data-poor situations (Elith et al. 2006, Phillips et al. 2006, Phillips and Dudík

2008, Yost et al. 2008, Baldwin 2009). Yost et al. (2008) used Maxent to model and map

sage-grouse nesting habitat in southern Oregon. Environmental variables were obtained

from Digital Elevation Models (DEM) and vegetation classification. Species-presence

data was obtained from nest-site locations. Maxent provided a highly predictive SDM

with minimal type I and type II errors (Yost et al. 2008).

STUDY PURPOSE AND RESEARCH OBJECTIVES

The sage-grouse population in the Bald Hills region of Iron and Beaver Counties,

Utah is an isolated population at the southern fringe of the species distribution. As such, I

predict that climate, topography, and habitat characteristics for this population will differ

from populations elsewhere in the sage-grouse range. As an isolated peripheral

population with potential local adaptations, this population may have habitat

characteristics different from the accepted norms (e.g., Connelly et al. 2000). This

population may therefore be of increased conservation importance (Oyler-McCance and

Leberg 2005). Notably, the Southwestern Desert Adaptive Resources Management

(SWARM) Local Working Group identified the Bald Hills region as a priority focus area

for sage-grouse (Frey et al. 2006).

The UREZ Task Force determined that the Bald Hills region contains energy

zones with high wind, solar, and geothermal energy output potential (Berry et al. 2009).

UREZ identified the Milford Energy Zone, for example, as containing high output

potential for all three renewable resources. When compared with other zones, the

Milford zone ranked well for capacity, energy production, transmission access, and cost

effectiveness to develop. The Milford Zone overlaps with almost half (43.65%) of the

Bald Hills study area (Black and Veatch Corporation 2010). The Bald Hills study area is

primarily managed by the Bureau of Land Management (BLM), which is trying to

balance the needs of both energy developers and species of concern.

The Bald Hills sage-grouse population has never been studied and basic

information about this population's seasonal movements, distributions, and habitat

preferences are unknown. Current management of this population is based on the

assumption that the Bald Hills population exhibits the same ecological and behavioral

characteristics as well-studied Utah populations. The goal of my study is to determine the

habitat characteristics of the Bald Hills sage-grouse population and compare them to

more central, less isolated populations across the greater sage-grouse distribution. I will

also determine the season spatial patterns of the Bald Hills sage-grouse using VHF radio-

telemetry. Because of the high potential for renewable energy development in the area, it

is important to have population-specific analyses of spatial patterns and habitat use for

management purposes (Crawford et al. 2004).

This study examines important life history attributes of the Bald Hills population.

The objectives of this research are to 1) determine movement patterns and seasonal space

use, 2) analyze habitat characteristics, and 3) develop a Species Distribution Model that

predicts and maps the probability of sage-grouse presence for the Bald Hills population.

LITERATURE CITED

Aldridge, C., R. Lee, P. Jones, and J. Nicholson. 2004. Winter habitat selection and survival by sage-grouse in southeastern Alberta. Final Project Report for 2003-2004; Sage-Grouse Funding Partners. Fort Collins, Colorado, USA.

Baldwin, R. A. 2009. Use of maximum entropy modeling in wildlife research. Entropy 11:854-866.

Battazzo, A. M. 2007. Winter survival and habitat use by female greater sage-grouse in south Phillips County, Montana 2004-2006. Thesis. University of Montana, Missoula, Montana, USA.

Beck, J. L., D. L. Mitchell, and B. D. Maxfield. 2003. Changes in the distribution and status of sage-grouse in Utah. Western North American Naturalist 63:203-214.

Berry, J., D. Hurlbut, R. Simon, J. Moore, and R. Blackett. 2009. Utah renewable energy zones task force phase I report; Renewable energy zone resource identification. Miscellaneous Publication 09-1. Utah Geologic Survey. Salt Lake City, Utah, USA.

Black and Veatch Corporation. 2010. Utah renewable energy zone (UREZ) task force, phase II; Zone identification and scenario analysis. Utah Office of Energy Development. Salt Lake City, Utah, USA.

Connelly, J. W., S. T. Knick, C. E. Braun, W. L. Baker, E. A. Beever, T. Christiansen, K. E. Doherty, E. O. Garton, S. E. Hanser, D. H. Johnson, M. Leu, R. F. Miller, D. E. Naugle, S. J. Oyler-McCance, D. A. Pyke, K. P. Reese, M. A. Schroeder, S. J. Stiver, B. L. Walker, and M. J. Wisdom. 2011. Conservation of greater sage-grouse: A synthesis of current trends and future management. Pages 549-563 *in*

Greater sage-grouse: ecology and conservation of a landscape species and habitats. Studies in avian biology (vol. 38). University of California Press, Berkeley, California, USA.

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

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

Crawford, J. A., R. A. Olson, N. E. West, J. C. Mosley, M. A. Schroeder, T. D. Whitson, R. F. Miller, M. A. Gregg, and C. S. Boyd. 2004. Ecology and management of sage-grouse and sage-grouse habitat. Rangeland Ecology & Management 57:2-19.

Dahlgren, D. K., R. Chi, and T. A. Messmer. 2006. Greater sage-grouse response to sagebrush management in Utah. Wildlife Society Bulletin 34:975-985.

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

Dunn, P. O., and C. E. Braun. 1985. Natal dispersal and lek fidelity of sage grouse. The Auk 102:621-627.

Elith, J., C. H. Graham, R. P. Anderson, M. Dudík, S. Ferrier, A. Guisan, R. J. Hijmans, F. Huettmann, J. R. Leathwick, A. Lehmann, J. Li, L. G. Lohmann, B. A. Loiselle, G. Manion, C. Moritz, M. Nakamura, Y. Nakazawa, J. McC. M. Overton, A. Townsend Peterson, S. J. Phillips, K. Richardson, R. Scachetti-

Pereira, R. E. Schapire, J. Soberón, S. Williams, M. S. Wisz, and N. E. Zimmermann. 2006. Novel methods improve prediction of species' distributions from occurrence data. Ecography 29:129-151.

Franklin, J. 2011. Mapping species distributions: spatial inference and prediction. Cambridge University Press, Cambridge, UK.

Frey, S. N., S. G. Lupis, C. Reid, T. A. Black, T. A. Messmer, and D. L. Mitchell. 2006. Southwest desert greater sage-grouse (*Centrocercus urophasianus*) local conservation plan. Utah's Community Based Conservation Program Unpublished Report. Logan, Utah, USA.

Gilbert, M. M., and A. D. Chalfoun. 2011. Energy development affects populations of sagebrush songbirds in wyoming. Journal of Wildlife Management 75:816-824.

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

Holloran, M. J., and S. H. Anderson. 2005. Spatial distribution of greater sage-grouse nests in relatively contiguous sagebrush habitats. The Condor 107:742-752.

Holloran, M. J., R. C. Kaiser, and W. A. Hubert. 2009. Yearling greater sage-grouse response to energy development in Wyoming. Journal of Wildlife Management 74:65-72.

Leonard, K. M., K. P. Reese, and J. W. Connelly. 2000. Distribution, movements and habitats of sage grouse *Centrocercus urophasianus* on the upper Snake River plain of Idaho: changes from the 1950s to the 1990s. Wildlife Biology 6:265-270.

Miller, R. F., S. T. Knick, D. A. Pyke, C. W. Meinke, S. E. Hanser, M. J. Wisdom, and
    A. L. Hild. 2011. Characteristics of sagebrush habitats and limitations to long-
    term conservation. Pages 145-184 *in* S. T. Knick and J. W. Connelly, editors.
    Greater sage-grouse: ecology and conservation of a landscape species and its
    habitats. Studies in avian biology (vol. 38), University of California Press,
    Berkeley, California, USA.

Oyler-McCance, S. J., and P. L. Leberg. 2005. Conservation genetics in wildlife biology.
    Sixth edition. Pages 632-657 *in* C. E. Braun, editor. Techniques for wildlife
    investigations and management. The Wildlife Society, Bethesda, Maryland, USA.

Phillips, S. J., R. P. Anderson, and R. E. Schapire. 2006. Maximum entropy modeling of
    species geographic distributions. Ecological Modelling 190:231-259.

Phillips, S. J., and M. Dudík. 2008. Modeling of species distributions with maxent: new
    extensions and a comprehensive evaluation. Ecography 31:161-175.

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

Rowland, M. M., M. J. Wisdom, L. H. Suring, and C. W. Meinke. 2006. Greater sage-
    grouse as an umbrella species for sagebrush-associated vertebrates. Biological
    Conservation 129:323-335.

Schroeder, M. A., J. R. Young, and C. E. Braun. 1999. Greater sage-grouse
    (*Centrocercus urophasianus*), the birds of North America Online (A. Poole, Ed.).
    Ithaca: Cornell Lab of Ornithology; Retrieved from the Birds of North America
    Online: http://bna.birds.cornell.edu/bna/species/425. Accessed 12 Oct 2012.

Schroeder, M. A., C. L. Aldridge, A. D. Apa, J. R. Bohne, C. E. Braun, S. D. Bunnell, J. W. Connelly, P. A. Deibert, S. C. Gardner, M. A. Hilliard, G. D. Kobriger, S. M. McAdam, C. W. McCarthy, J. J. McCarthy, D. L. Mitchell, E. V. Rickerson, and S. J. Stiver. 2004. Distribution of sage-grouse in North America. The Condor 106:363-376.

Stiver, S. J. 2011. The legal status of greater sage-grouse: Organizational structure of planning efforts. Pages 33-49 *in* S. T. Knick and J. W. Connelly, editors. Greater sage-grouse: ecology and conservation of a landscape species and its habitats. Studies in avian biology (vol. 38). University of California Press, Berkeley, California, USA.

U. S. Fish and Wildlife Service, Interior (USFWS). 2010. Endangered and threatened wildlife and plants; 12-month findings for petitions to list the greater sage-grouse (*Centrocercus urophasianus*) as threatened or endangered. 50 CFR Part 17. Department of the Interior; Federal Register, Washington D.C., USA.

U. S. Fish and Wildlife Service, Interior (USFWS). 2012. Endangered Species Mountain-Prairie Region: Greater sage-grouse. <http://www.fws.gov/mountain-prairie/species/birds/sagegrouse/%3E>. Accessed 27 July 2012.

U. S. Department of Energy. 2012. Success of the recovery act - January 2012. <http://energy.Gov/downloads/successes-recovery-act-january-2012%3E>. Accessed 28 July 2012.

Utah. Division of Wildlife Resources (UDWR). 2009. Utah greater sage-grouse management plan. Utah Department of Natural Resources, Division of Wildlife Resources Publication 09-17, Salt Lake City, Utah, USA.

Utah Wildlife in Need. 2010. Contemporary knowledge and research needs regarding the potential effects of tall structures on sage-grouse (*Centrocercus urophasianus* and *C. minimus*). Utah Wildlife in Need Cooperative. Salt Lake City, Utah, USA.

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

Wallestad, R. O. 1971. Summer movements and habitat use by sage grouse broods in central Montana. The Journal of Wildlife Management 35:129-136.

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

West, N. E. 1999. Vegetation types of Utah. Pages 284-301 *in* K.L. Johnson, editor. Rangeland resources of Utah. Cooperative Extension Services Publication. Utah State University, Logan, USA.

Wisdom, M. J., M. M. Rowland, L. H. Suring, D. S. Dobkin, and B. Abbey. 2005. Habitat threats in the sagebrush ecosystem : Methods of regional assessment and applications in the great basin. Alliance Communications Group, Lawrence, Kansas, USA.

Yost, A. C., S. L. Petersen, M. A. Gregg, and R. F. Miller. 2008. Predictive modeling and mapping sage grouse (*Centrocercus urophasianus*) nesting habitat using maximum entropy and a long-term dataset from southern Oregon. Ecological Informatics 3:375-386.

CHAPTER 2

SEASONAL SPACE USE OF A GREATER SAGE-GROUSE FRINGE POPULATION

ABSTRACT The Bald Hills greater sage-grouse (*Centrocercus urophasianus*) population in Utah is located at the southern edge of the species' range. As range-wide greater sage-grouse populations decline, peripheral populations such as those in southern Utah are more likely to be extirpated. These populations may be of conservation importance because of local phenotypic adaptations to marginal fringe habitats. Due to lack of research, basic information about the Bald Hills, Utah, population's seasonal movements, distributions, and home ranges are unknown. The need for this information is immediate because the area has been identified as having high potential for wind, solar, and geothermal energy development. I tracked 66 birds (17 females & 49 males) via VHF telemetry in 2011 and 2012 in order to determine spatial ecology traits such as seasonal movement patterns, distributions, and home ranges. My results suggested the population was primarily 1-stage migratory (80%). Migratory movement dates varied more in the spring than in the fall, with a spring migratory period of 10 March to 30 May, and a fall migratory period of 8 October to 12 November. Population-wide seasonal distributions were delineated for summer ($n = 815$, 869 km^2), winter ($n = 181$, 603 km^2), and nest/brood-rearing ($n = 51$, 225 km^2); study birds were located outside of suitable habitat identified in Utah Division of Wildlife Resources maps during summer (1.41%), winter (43.65%), and nest/brood-rearing (7.84%). Mean home range sizes for individuals in summer (82 km^2, 95% CI = 38.84-125.16) and winter (157.82 km^2, 95% CI = 76.95-238.69) provide new information about habitat patch size requirements for the species.

Migratory movements, distributions that differ from Utah Division of Wildlife

Resources maps, and large home ranges all indicate that this population occupies

marginal habitat. By quantifying spatial ecology patterns exhibited by this population,

these data will aid in the planning process for the persistence of this population.

Greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse)

populations have been declining since the 1930's throughout most of their range

(Connelly and Braun 1997). In Utah, sage-grouse occupy an estimated 41% of their

potential historic distribution (Beck et al. 2003). Loss, degradation, and fragmentation of

habitat have been indicated as primary sources for declines in sage-grouse distribution

and abundance (Schroeder et al.1999). Energy development has been implicated as one

mechanism by which sage-grouse habitat is altered due to direct effects (habitat

conversion and development) and indirect effects (avoidance behavior and altered

vegetation composition due to disturbance; Walker et al. 2007, Doherty et al. 2008,

Holloran et al. 2009, Pruett et al. 2009, Harju et al. 2010).

The sage-grouse distribution ranges from southern Utah to southern Alberta,

Canada, and from western South Dakota to central Oregon (Aldridge et al. 2008). This

range extent provides a geographical gradient of environmental conditions. While

environmental conditions vary throughout a species range, Carbonell et al. (2003) defined

a species range extents as the edges at which environmental and habitat conditions

become unsuitable for a species to persist. Albeit the relationship is seldom linear,

population success (density, abundance, survival, and body condition) is greatest near the

center of a species range and decreases towards the periphery (Hengeveld and Haeck

1982, Brown 1984, Carbonell et al. 2003). Decreased success, utilization of marginal

habitats, and increased fragmentation leading to isolation are all factors that contribute to

increased extinction rates at population fringes as compared to the interior (Doherty et al.

2003). Due to these additional selective pressures, fringe populations often develop

unique adaptive phenotypic attributes that may increase overall species diversity as well

as their conservation importance (Lesica and Allendorf 1995, Haak et al. 2010). The

sage-grouse population in the Bald Hills region of Iron and Beaver Counties, Utah, is at

the southern fringe of the species' range-wide distribution (Fig. 2-2). As a fringe

population, the Bald Hills sage-grouse are likely to exhibit these fringe population traits

and may have an additional extirpation risk because of shrinking sage-grouse

distributions (Aldridge et al. 2008).
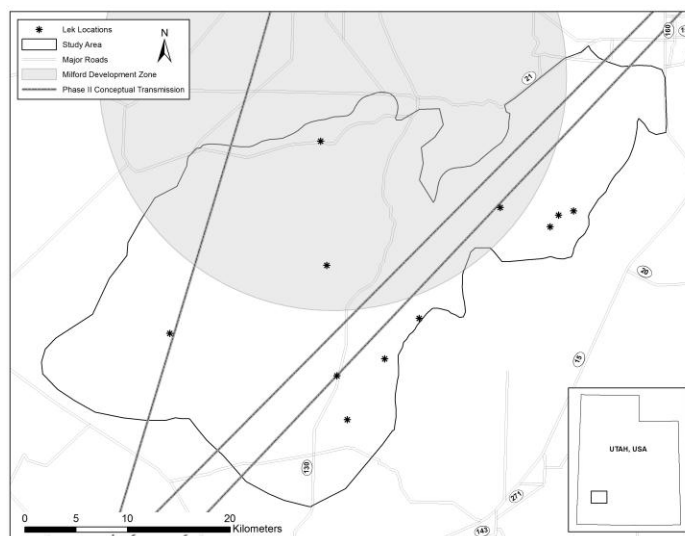
Figure 2-1. Overlap among the Milford development zone and the Bald Hills study area. The Milford development zone was identified by the Utah Renewable Energy Zones Task Force as an area with high wind, solar, and geothermal renewable energy resources (Berry et al. 2009 and Black, Veatch Corporation 2010). The Bald Hills study area corresponds to the Utah Division of Wildlife Greater sage-grouse brood-rearing habitat map (UDWR 2010).

The Bald Hills population inhabits an area with high potential for wind, solar, and geothermal energy resources. The Milford development zone has been identified as having quality renewable energy resources that are economically viable to develop and this zone overlaps with almost half of the Bald Hills study area ($545.59 \text{ km}^2/1250.01 \text{ km}^2$ = 43.65%; Fig. 2-1; Black and Veatch Corporation 2010). Development of these resources could present an additional threat to this peripheral population.

While sage-grouse ecology has been well documented, the Bald Hills population has never been studied. Due to lack of research, basic information about this population's seasonal movements, distributions, and home ranges are unknown. In addition, few studies have examined sage-grouse ecology at the edge of their distribution (Aldridge and Brigham 2001, Herman-Brunson et al. 2009, Bush et al. 2011).

Sage-grouse movements among seasons (from one season to the next) are determined by the distribution of suitable seasonal habitats (Leonard et al. 2000). Populations can be described as non-migratory (or resident), 1-stage migratory (move >10 km between two distinct seasonal ranges), and 2-stage migratory (move >10 km between three distinct seasonal ranges; Connelly et al. 2000). To further complicate movement patterns, birds from the same geographic area can display multiple movement behaviors (Fischer et al. 1996, Connelly et al. 2000). For example, Wallestad (1975), found a population in central Montana to have high association between nest sites and wintering areas, indicating a non-migratory population. Conversely, in October and November, a 1-stage migratory population in Idaho was found to migrate 48-80 km (Dalke et al. 1963). Furthermore, two other Idaho populations' seasonal movements differed by 20% between autumn and winter ranges (Beck et al. 2006). In Wyoming,

radio-collared sage-grouse moved an average distance of 8.1 km from nesting to summer locations and 17.3 km from summer to winter (Fedy et al. 2012). These studies emphasize the importance of examining spatial movement patterns on a population-by-population basis for management purposes (Crawford et al. 2004).

Sage-grouse distributions are determined by the availability of suitable habitat and can be examined at temporal increments relevant to the species life history (nesting, summer, and winter; Fedy et al. 2012). Patchy and seasonal habitats can create complex movement patterns that make it challenging to summarize distributions across populations and seasons (Crawford et al. 2004). For example, the annual distribution for a migratory sage-grouse population in Idaho was 2,764 km^2 (Leonard et al. 2000). Two adjacent populations in southeastern Idaho had distributions of 157 km^2 and 451 km^2 (Beck et al. 2006). According to the Utah Division of Wildlife Resources (UDWR) potential suitable habitat maps for sage-grouse in the state, there is approximately 1408 km^2 of annual suitable habitat for the Bald Hills population. These maps are delineated using lek count data, historic sightings, habitat types, and expertise of local biologists. The UDWR habitat maps delineate 1,250 km^2 of suitable brood-rearing habitat and 427 km^2 of suitable winter habitat for the Bald Hills area. All of the UDWR seasonal habitat maps for the Bald Hills population overlap considerably (UDWR 2010).

In non-territorial species, home range is an area that contains the essential requirements (food, cover, and water) for survival and is repeatedly traversed during a specific time period (Fuller et al. 2005). Miller et al. (2011) reviewed home range sizes across sage-grouse populations and found differences in annual (4-615 km^2), summer (<1-29 km^2), and winter (<1-195 km^2) home range sizes. In marginal habitat, adequate

resources (food, cover, and water) may be spread over a larger area, leading to larger home ranges for individuals to access the resources (Carbonell et al. 2003, Doherty et al. 2003). As a peripheral population I expect the Bald Hills sage-grouse to occupy marginal habitat and therefore occupy larger home ranges than those of central populations.

By describing fundamental population attributes such as seasonal movements, distributions, and home ranges this study will create a platform upon which further research can build. I will identify movement patterns exhibited by the Bald Hills population and delineate migratory distances and periods. I will determine annual and seasonal distributions of the Bald Hills population; I expect these distributions to reflect suitable habitat and therefore be comparable to UDWR suitable habitat maps. Finally, I will delineate seasonal home ranges to assess the area required by sage-grouse from the Bald Hills population to obtain all of their resources. This will provide insight about how seasonal space use patterns of a species in decline may vary between peripheral and non-peripheral populations. These data will assist federal and state agencies in the development of appropriate local management strategies in advance of energy development.

STUDY AREA

Located primarily on public land managed by the Bureau of Land Management (BLM), the Bald Hills study area was delineated from the boundaries of the UDWR 2010 sage-grouse suitable brood-rearing habitat map (UDWR 2010). This area was designated with the purpose of tracking birds radio-collared from the known leks (breeding areas) encompassed by the area. Birds collared within the study area were tracked both inside and outside of the original designated study area (Fig. 2-2).

The study area (1,250 km^2) covered portions of Iron and Beaver counties in Utah. The southern edge of the study area was located 20 km north of Cedar City, and the northeast corner was located 3 km south of Beaver (Fig. 2-2). State highway 130 (hereafter, HWY 130) bisected the study area from Cedar City to Minersville and Interstate 15 from Cedar City to Beaver was east of the study area. The majority of the study area was public land managed by the BLM (968 km^2), with some private (170 km^2) and State Trust Lands (112 km^2; UDWR 2010). The elevation ranged from 1550 m to 2400 m. Average annual precipitation in Minersville (within low elevation portion of study area) was 28.96 cm (11.4 in) (from 1948-2005) with mean annual total snowfall of 48.01 cm (18.9 in; Western Regional Climate Center [WRCC] 2012). Habitat types were diverse yet characterized by Great Basin sagebrush (more arid and southerly as compared with sagebrush steppe; West and Young 2000), juniper forest, salt-desert shrub, and disturbed areas with invasive cheatgrass (*Bromus tectorum*), and annual mustard (*Brassicaceae* fam.). Dominant sagebrush species included mountain big sagebrush (*Artemisia tridentate vaseyana*) at high elevations, Wyoming big sagebrush (*Artemisia tridentata wyomingensis*) at intermediate elevations and overlapping with the other two species, and black sagebrush (*Artemisia nova*) at low elevations. During spring and summer, cattle and sheep grazing was common throughout the study area. Crop agriculture (primarily alfalfa and corn) was common in the northwest portion. The northeast portion had been re-seeded twice with a native and non-native mix of perennial grasses, forbs, and shrubs after the Greenville Bench wildfire (July 2007, 15.98 km^2; C.S. Pontarolo, Bureau of Land Management, unpublished data; Appendix Table A.1). The Wrangler (7 Aug 2011, 34.21 km^2) and Baboon (25 Jul 2012, 80.04 km^2) wildfires

occurred during the study but did not burn areas where radio-collared sage-grouse were

being tracked at those times (C.S. Pontarolo, Bureau of Land Management, unpublished

data).

Eleven known leks (Horseshoe Flat, Jackrabbit, Little Horse Valley, Lost Spring,

Minersville, Mud Springs, Parowan Gap, Poorman Flat, Poorman Jeff, Poorman Ridge,

and Upper Long Hollow) were within the study area (Fig. 2-2). Of the 3 leks that were

impacted by the Greenville Bench wildfire (Poorman Flat, Poorman Jeff, and Poorman

Ridge) only the Poorman Jeff lek was active during this study. The Lost Spring lek was

also inactive in 2011 and 2012. Two possible new leks were identified during the study

period: Little Horse Valley (2012) and Upper Long Hollow (2011).

Figure 2-2. Bald Hills study area in southwestern Utah with dominant vegetation types and sage-grouse occupied habitat designated by the UDWR (UDWR 2010). The 1,250 km^2 area encompassed 11 known leks.

METHODS

Capture and Monitoring

I captured sage-grouse in 2011 and 2012 using common spotlighting techniques (Wakkinen 1990) on and around 8 leks in the study area (Horseshoe Flat, Jackrabbit, Little Horse Valley, Minersville, Mud Springs, Parowan Gap, Poorman Jeff, and Upper Long Hollow). My goal was to capture 60 sage-grouse over the study duration with a minimum of 40% hens and at least 2 birds from each active lek. For all captured birds, I weighed, collected a feather, and noted age class (sub-adult and adult) and sex (Eng 1955). All birds captured in 2011 were fitted with 24-g necklace VHF transmitters with an 8-hr mortality switch (model A4060; Advanced Telemetry Systems, Isanti, MN). Sage-grouse captured in 2012 were fitted with 19-g necklace VHF transmitters with an 8-hr mortality switch (model A4050; Advanced Telemetry Systems, Isanti, MN). Larger collars were used in 2011 to ensure battery life throughout the study duration. All capture and handling procedures were approved through the Protocol Application for Live Animal Use in Research, Teaching, or Training at Utah State University (Protocol #1322) and Certificate of Registration for Banding, Collection, Depredation, and/or Salvage from the UDWR (R657-3). Prior to this study, 15 male sage-grouse were radio-collared in 2010 by BLM personnel using the same techniques and equipment as the 2011 capture operations; several of these birds were still alive during my study and thus I incorporated them into my research. I assumed that the radio-collared birds were a representative sample of the population and that the capture event and transmitter attachment did not alter radio-collared bird behavior (Palmer and Wellendorf 2007).

I monitored sage-grouse via VHF radio-telemetry year round starting daily telemetry with a randomly selected individual and locating other birds opportunistically by proximity to the first. During the spring (Mar through May), summer (Jun through Aug), and fall (Sep through Nov) I attempted to locate and flush each bird one time per week via ground telemetry (Beck et al. 2006). During nesting and brood-rearing (Apr through Aug) I located nesting and brood-rearing hens without flushing them (Schroeder 1997). During the winter (Dec through Feb) access within the study area was limited and I attempted to locate each bird one time per month. At every ground telemetry location I recorded the radio frequency, number of birds in the group, habitat type (UDWR 2010), Universal Transverse Mercator (UTM) coordinate, date, time, and elevation (m). All UTM coordinates were collected using a handheld Global Positioning System (GPS) with <5 m error (model eTrex Venture HC, Garmin International, Inc., Olathe, KS). As weather permitted, I located missing birds within and outside of the study area via aerial telemetry using a fixed-wing aircraft one time per month year-round. Flight locations were used to assist with ground telemetry and were not used for analysis.

Seasonal Movements

I examined movements among seasons from March 2011 through August 2012. Collared sage-grouse with ≥ 2 locations in each season were used to avoid individual bird bias and outlier locations (Beck et al. 2006, Baxter et al. 2008). For this analysis I did not include any birds collared in 2012 because these birds were not tracked through multiple seasons. Contrary to Leonard et al. (2000) and Beck et al. (2006) I included initial capture locations and mortality locations. Evidence from my field investigations suggested that capture locations and mortality locations could be considered independent bird roosting

locations. For example, sage-grouse are known to roost near leks during breeding season and birds captured near leks were later found using the same associated lek again (Connelly et al. 2004). Additionally, one live hen was located without being flushed (to avoid disturbing her brood) and the following week her mortality location was <5 m from the live location. This observation indicated that the collar was not moved post-mortality and represented her last live location.

I measured the distance traveled between summer range and winter range by examining long distance movements from winter to summer (1 Jan to 30 Jun) and from summer to winter (1 Jul to 31 Dec). I did not follow seasonal cut-off dates from other studies because I did not assume this population would follow the same movement patterns, given its southerly location (Leonard et al. 2000, Baxter et al. 2008). I used ArcGIS Desktop (Environmental Systems Research Institute, Redlands, CA) Minimum Bounding Geometry tool to create a convex hull polygon (for birds with >2 seasonal locations) or a polyline (for birds with 2 seasonal locations) encompassing all telemetry locations in each season, per bird (Beck et al. 2006). Using the Geospatial Modelling Environment (GME; Spatial Ecology LLC, www.spatialecology.com, accessed 14 May 2012) Generate Point in Polygon command I determined the centroid for each polygon and polyline. The centroid represented the average seasonal location for each collared sage-grouse. I then calculated the linear distance (Euclidean distance) between centroids for each grouse using the GME Convert Points to Lines command (Beck et al. 2006).

I classified individual bird movements as non-migratory, 1-stage migratory, or 2-stage migratory. Birds were classified as migratory when the linear seasonal movement distance was >10 km (Connelly et al. 2000). Using R (R Version 2.15.1, www.r-

project.org, accessed 9 Aug 2012) I performed one-sample t-tests to test the null

hypotheses that 1) the mean seasonal movement distance for all 1-stage migratory birds

was equal to 10 km and 2) the mean seasonal movement distance for all 2-stage

migratory birds was equal to 10 km. My H_a was that the mean seasonal movement

distances were greater than 10 km, denoting migratory movements. I evaluated my

hypotheses at p-value threshold p = 0.05.

Seasonal Distributions

I examined annual, summer (31 May to 21 Oct), winter (13 Nov to 9 Mar), and

nest and brood-rearing distributions. For this analysis I excluded telemetry locations

within key migratory periods identified in the Seasonal Movements analysis. I pooled

years for analysis because I was interested in population level distribution patterns, not

per year distributions (Leonard et al. 2000). For annual distribution I included all birds

and all telemetry locations from 12 March 2010 through 16 August 2012. For summer

and winter distributions I included all telemetry locations from all birds tracked over

summer (31 May to 21 Oct) and winter (13 Nov to 9 Mar), respectively. For the nest and

brood-rearing distribution I included all nest and brood-rearing locations from

reproductive hens (Baxter et al. 2008). I included successful and unsuccessful nests and

broods. By pooling years, my analysis includes hens that were reproductive during 2011

and 2012. Hens have high fidelity to nesting locations; therefore this method may serve

to emphasize some reproductive areas (Berry and Eng 1985).

In order to obtain maximum distribution estimates, rather than core use areas, I

delineated 100% Minimum Convex Polygons (MCP) around the outermost geographic

telemetry locations (Mohr 1947). MCP distributions were used to 1) represent the

complete area of use, 2) decrease the likelihood that un-collared birds would occupy

areas outside of my polygons, and 3) be most comparable with the UDWR habitat maps

(Leonard et al. 2000, Beck et al. 2006). I used the GME Generate Minimum Convex

Polygon command for all locations, locations per season, and locations of reproductive

hens. I described similarities and differences among the size, location, and shape of the

MCPs and their corresponding UDWR seasonal habitat maps. The UDWR seasonal

habitat maps available were: occupied, winter, and brood-rearing. These maps were

compiled from direct observation, radio telemetry, field notes, and best professional

judgment from biologists within the state (UDWR 2010).

Seasonal Home Ranges

Seasonal home ranges were calculated for summer and winter seasons based on

results from the Seasonal Movements analysis; locations during the migration periods

were discarded (Doherty et al. 2008). I combined years in individual home range analyses

to increase the number of locations per bird. This was based on the assumption that high

fidelity to seasonal ranges would result in negligible differences in home ranges between

years (Berry and Eng 1985, Connelly et al. 2000, Crawford et al. 2004). Lichti and

Swihart (2011) compared kernel density estimation (KDE) with other home range

estimators at multiple sample sizes and bandwidth selectors (Worton 1989). Based on

their work and others I used Gaussian fixed KDE to determine 95% probability contours

using the least-square cross-validation bandwidth (smoothing factor) selector and cell

size of 10 m to estimate the seasonal home range for each bird (Bradbury et al. 1989,

Sheather and Jones 1991, Seaman et al. 1999, Kochanny et al. 2009, Lohr et al. 2011).

KDE performance has been tested successfully with a minimum sample size of 10

location points without over- or under-estimating home range sizes (Lichti and Swihart 2011). I did not find any difference between mean home range areas for KDEs with ≥ 5 location points ($n = 49$ birds, $\bar{x} = 82.00$ km^2, 95% CI $= 38.84\text{-}125.16$) and ≥ 10 location points ($n = 32$ birds, $\bar{x} = 76.20$ km^2, 95% CI $= 24.67\text{-}127.72$) per bird ($t_{68.77} = 0.1751$, $P = 0.8615$) from my summer data. I therefore used birds with ≥ 5 location points to delineate seasonal KDEs. I used the seasonal home range estimates for each bird to calculate mean home range sizes for summer and winter. I used GME, ArcGIS, and R to complete this analysis.

RESULTS

I captured 25 sage-grouse in 2011 ($n = 8$ hens, $n = 17$ males) from the Horseshoe ($n = 5$ hens, $n = 5$ males), Minersville ($n = 1$ hens, $n = 4$ males), Mud Springs ($n = 2$ hens, $n = 7$ males), and Parowan Gap ($n = 1$ male) leks. In 2012, I captured 25 sage-grouse ($n = 9$ hens, $n = 16$ males) from the Jackrabbit ($n = 2$ males), Little Horse Valley ($n = 8$ hens, $n = 6$ males), Minersville ($n = 1$ male), Parowan Gap ($n = 1$ male), Poorman Jeff ($n = 1$ hens, $n = 5$ males), and Upper Long Hollow ($n = 1$ male) leks. I was able to locate and track 9 males that were captured by the BLM in 2010, increasing my total sample size to 59 birds ($n = 17$ hens, $n = 42$ males) with 29% hens and all 8 leks represented.

Seasonal Movements

For my seasonal movement analysis, I used data from 20 birds (representing all of the leks sampled in 2011). I did not examine sex as a covariate and therefore pooled all data for analysis. Large movements occurred between January and July as birds moved

from winter to summer range, with the peak migration period (50% of migratory movements) from 10 March to 30 May. Birds moved from summer range to winter range between September and December, with all birds migrating from 22 October to 12 November after removing two outliers (17 Sept and 4 Dec; Fig. 2-3). The population exhibited non-migratory, 1-stage migratory, and 2-stage migratory movement patterns. The population was primarily 1-stage migratory (80%), moving >10 km between 2 distinct seasonal ranges ($\bar{x}$ = 22.48 km, 95% CI = 20.72-24.24, t_{29} = 14.50, $P \leq 0.001$). These birds moved northeast in the spring and southwest in the fall, with one exception where the bird exhibited the opposite pattern (Fig. 2-4A). The birds mostly avoided crossing HWY 130, a two-lane paved road which runs north-south through the center of the study area.
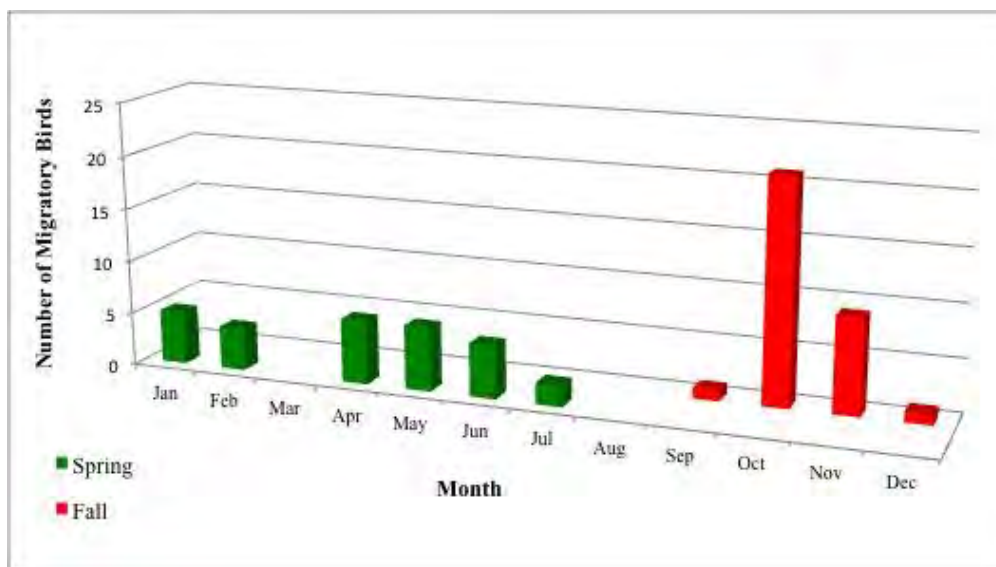
Figure 2-3. Distribution of migratory movements during spring and fall in the Bald Hills population for individuals captured in 2011.

Smaller percentages of the population were classified as non-migratory (10%) or 2-stage migratory (10%). The non-migratory birds were both males that displayed erratic long-distance movements, but did not travel >10 km between seasons. One of these birds (Bird 053) primarily resided near the Minersville lek, and the other (Bird 404) primarily resided near the Mud Springs lek (Fig. 2-4B). The 2-stage migratory birds were both females that traveled from the northeastern mountains in the summer, to an intermediate location in the fall, to the Mud Springs lek area in the winter, and back to the northeastern mountains in the summer. Bird 353 used the Parowan Gap area as an intermediate location and Bird 452 used the Minersville area (Fig. 2-4C). The distances traveled between the three seasonal ranges were >10 km and were therefore sufficient to classify these birds as 2-stage migrants ($\bar{x}$ = 25.37, 95% CI = 12.69-38.05, t_5 = 3.12, P = 0.026).

Seasonal Distributions

For my annual distribution calculations I included all birds (n = 59) and all telemetry locations (n = 996) from 12 March 2010 through 16 August 2012. For summer and winter distributions I included all telemetry locations (n = 654 and n = 100, respectively) from all birds tracked over summer (31 May through 21 Oct, n = 58) and winter (13 Nov through 9 Mar, n = 48). For the nest and brood-rearing distribution I included all nest and brood-rearing locations (n = 51) from reproductive hens (n = 10).
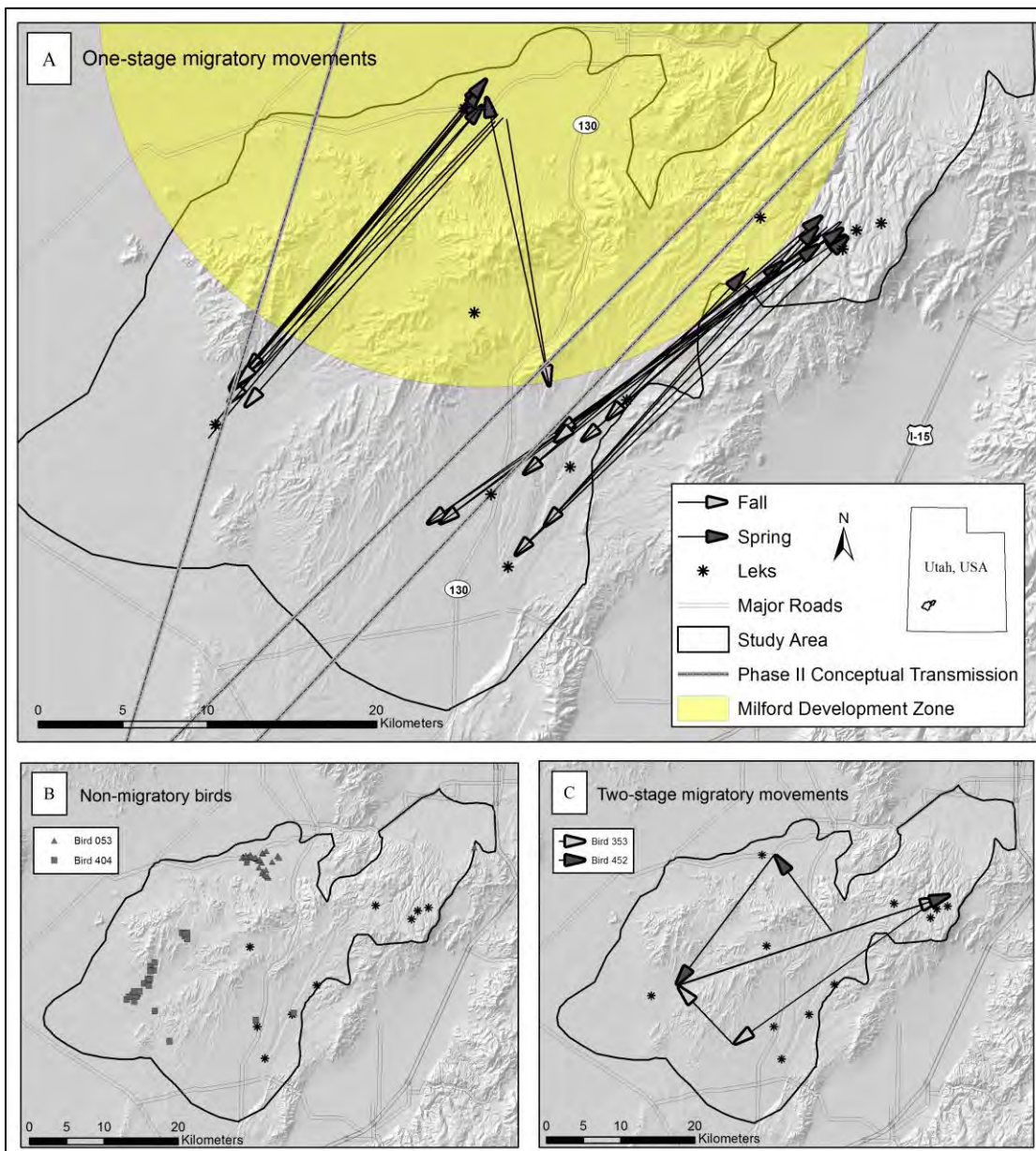
Figure 2-4. Movement patterns of the Bald Hills population. The population was primarily 1-stage migratory (n = 16; Fig. 2-4A). Two birds were non-migratory (Fig. 2-4B) and two birds were 2-stage migratory (Fig. 2-4C). Milford development zone and phase II conceptual transmission were identified by the Utah Renewable Energy Resources task force as having high potential for renewable energy development and overlap with the study area (Berry et al. 2009 and Black, Veatch Corporation 2010).

The winter and nest/brood-rearing seasonal MCP distributions varied more from the corresponding UDWR sage-grouse habitat maps then the summer and annual distributions (Table 2-1, Fig. 2-5). The annual MCP (896 km^2) was slightly smaller than the UDWR occupied habitat map area (1,408 km^2); however, it overlapped with the majority of the UDWR occupied habitat map. The UDWR occupied habitat map included large areas in the north, south, and west that were not represented by the annual MCP. The annual MCP extended slightly further to the east than the UDWR occupied habitat map, with 14 telemetry points located outside of the UDWR map (Fig. 2-5A). The summer MCP exhibited the same patterns as the annual MCP when compared with the UDWR occupied habitat map. The summer MCP (869 km^2) was smaller than the corresponding UDWR occupied habitat map, however 14 summer telemetry points were located outside the UDWR map to the east (Table 2-1, Fig. 2-5B).

The winter MCP varied greatly from the UDWR winter habitat map in size, location, and shape with only 67% (67/100) of telemetry locations within the UDWR map. This was the only season where the MCP encompassed a larger area, (603 km^2) than the corresponding UDWR map (427 km^2; Table 2-1). The overlap is apparent in the habitat patch in the northeast and in portions of the southern habitat areas. The overall pattern shows that the MCP encompasses a central winter habitat area and the UDWR winter habitat encompasses an area on the southern and western edge of the MCP distribution (Fig. 2-5C).

Table 2-1. Areas (km^2) of seasonal distributions for the Bald Hills population. Minimum Convex Polygons (MCP) were delineated for annual, summer (1 Apr to 31 Oct), winter (1 Nov to 31 Mar), and nest and brood-rearing telemetry locations. The MCPs are compared with the UDWR habitat maps for occupied (compared with annual and summer MCPs), winter, and brood-rearing (compared with nest and brood-rearing MCP) habitats (UDWR 2010).

	Annual	Summer	Winter	Nest and Brood-rearing
	Distribution Area (km^2)			
MCP	896	869	603	225
UDWR habitat	1408	1408	427	1250

The UDWR brood-rearing habitat encompasses most of the nest and brood-rearing MCP estimates with all but 4 telemetry locations within the UDWR map. The MCP distributions (225 km^2) are much smaller than the UDWR brood-rearing habitat designation (1,250 km^2). Large portions of the south, west, and north UDWR brood-rearing habitat maps are not represented by the nest and brood-rearing MCP (Fig. 2-5D).

Seasonal Home Ranges

My sample size for the summer and winter home range analyses was 49 and 17 birds, respectively. For home range calculations I defined summer as 1 June to 21 October and winter as 13 November to 9 March, based on the seasonal movements analysis. The mean home range for winter was approximately 157 km^2 (n = 17, $\bar{x}$ = 157.82km^2, 95% CI = 76.95-238.69). The mean home range for summer was 82 km^2 (n = 49 birds, 95% CI = 38.84-125.16). The mean number of locations per bird to delineate the 95% density polygons was 14.82 (95% CI = 12.51-17.12) for summer and 8.12 (95% CI = 7.03-9.21) for winter.
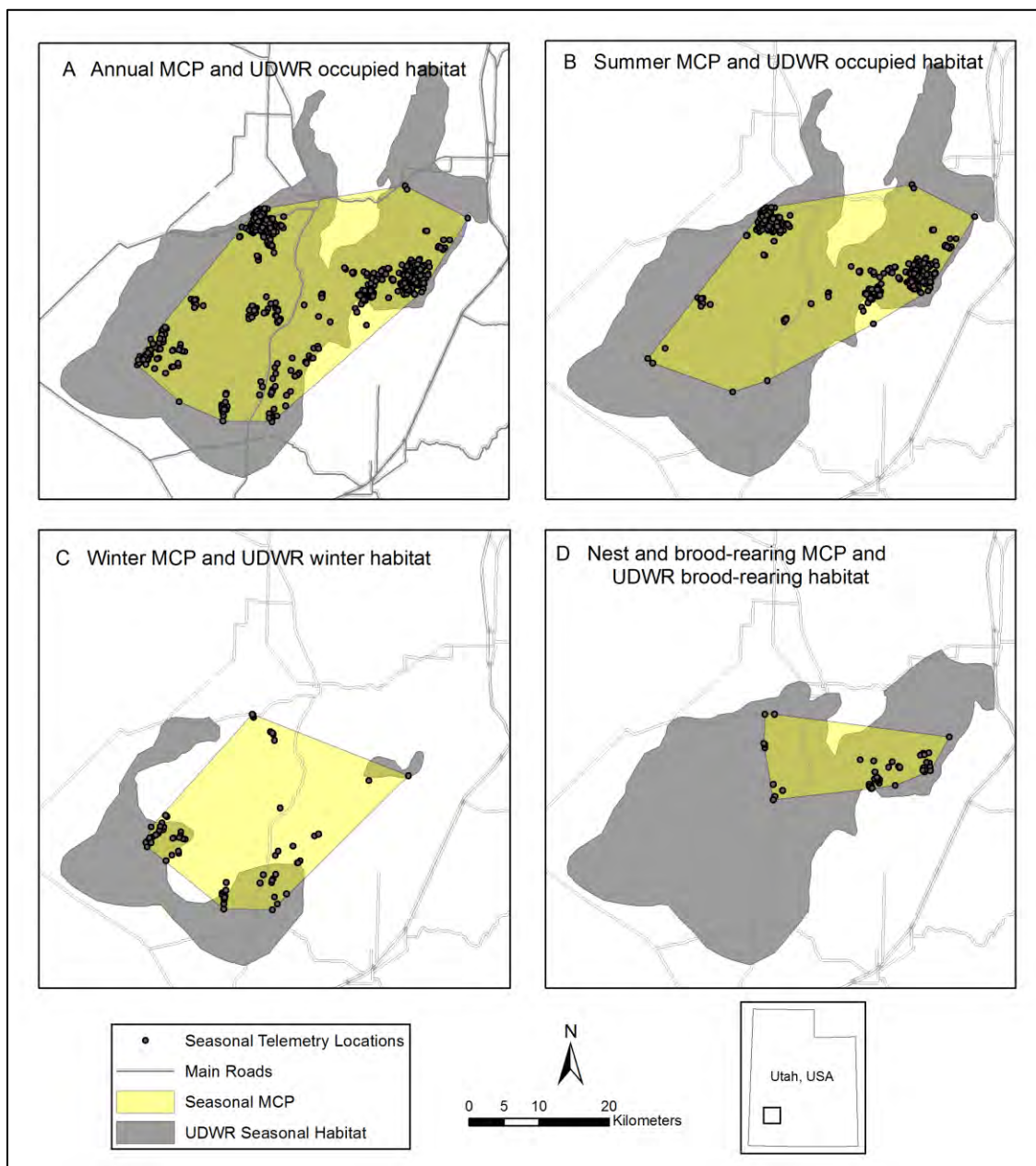
Figure 2-5. Seasonal distributions of greater sage-grouse in the Bald Hills Utah. Minimum Convex Polygons (MCP) shown are for annual (all telemetry locations, $n = 996$), summer (1 Apr to 31 Oct, $n = 815$), winter (1 Nov to 31 Mar, $n = 181$), and nest and brood-rearing (all nest and brood-rearing locations, $n = 51$) distributions (Mohr 1947, Baxter et al. 2008). Utah Division of Wildlife Resources (UDWR) seasonal habitat maps for occupied, winter, and brood-rearing habitat are used for comparison (UDWR 2010).

DISCUSSION

Seasonal Movements

Sage-grouse migrate because an area with suitable resources (habitat that provides food, water, and cover) for one season does not contain suitable resources for another season (Leonard et al. 2000). This is likely driving migratory movements in the Bald Hills population, where 90% of the population exhibits 1- or 2-stage migratory behavior. The variation in migration times (spring migration period as 10 Mar to 30 May and fall migration period as 8 Oct to 12 Nov) in the Bald Hills population may indicate that individuals migrate when their individual resources are decreasing, rather than moving together as a population or flock. Migration times coincided with similar seasonal cut-off dates used in other studies for summer (31 May to 31 Oct) and winter (1 Nov to 31 Mar; Baxter et al. 2008). Connelly et al. (1988) found similar variations in both timing and distance travelled among individuals in a southeastern Idaho population. While I pooled data over two years for this analysis, variation in seasonal migration dates may be influenced by differences between years. Annual weather patterns can cause significant differences in vegetation between years that impact sage-grouse space-use (Prentice et al. 1992, Hagen et al. 2007). This study summarizes a snap-shot of the spatial ecology of this population during the study duration.

The 1-stage migratory birds moved northeast in the summer and southwest in the winter. The summer habitat in the northern portion of the study area, represented by spring movement patterns (Fig. 2-4A) is very different on the eastern and western sides of the HWY 130 (personal observation). The birds on the eastern side of the highway occupied habitat at high elevation (1180-2500 m) with a large mosaic of mature big

sagebrush (*Artemesia tridentata* spp.) stands with limited understory, post-fire habitat treatment with forbs and grasses, and stands of juniper forest. These birds may be seeking out the sagebrush and juniper for daytime cover and moving to the post-fire areas to forage. The birds on the western side of HWY 130 occupied habitat at low elevation (1590-1800 m) with irrigated crop agriculture surrounded by flat rangeland, with rabbitbrush (*Ericameria nauseosa*), cheatgrass, (*Bromus tectorum*), and annual mustard (*Brassicaceae* fam.) representing the dominant vegetation. The birds may be seeking out the crop agriculture because it attracts insects and the adjacent rabbitbrush between irrigation pivots for cover.

I obtained 50 telemetry locations and flushed 6 un-collared sage-grouse that were roosting under or within 5 m of standing live or dead juniper trees (Fig. 2-6). These instances ranged from a single bird roosting under a standing live juniper in a small stand of trees to a group of 15 birds at the edge of a fire break in a thick juniper forest. These locations ranged temporally from 0837 to 1700 and occurred from 7 March to 27 November. Twenty-seven unique radio-collared birds were found associated with juniper for at least one location. To my knowledge, there are no published observations of sage-grouse roosting under juniper trees, although others have reported some bird locations near juniper in late-summer (O. Duvuvuei, Utah State University, S. Frey, Utah State University, H. McPherron, Utah State University, and J. Severson, University of Idaho, personal communication 2012).
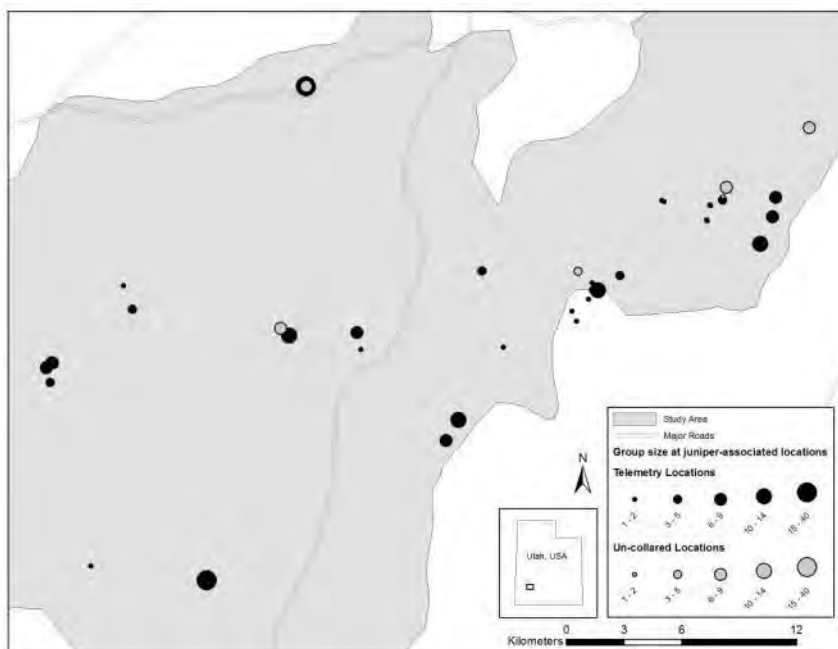
Figure 2-6. Sage-grouse locations associated with juniper trees included 50 telemetry locations and 6 un-collared bird locations. Juniper association occurred from 0837 to 1700 and from 7 March to 27 November. Twenty-seven unique radio-collared birds had at least 1 telemetry location associated with juniper.

The winter habitat in the southern portion of the study area, represented by fall movement patterns (Fig. 2-4A), is similar on the eastern and western sides of HWY 130 (personal observation). These areas consist primarily of black sagebrush (*Artemisia nova*) and big sagebrush (*Artemisia tridentata*), lacking a diversity of grasses and forbs. Weather station data in the area shows that average annual snow fall at low elevations (Minersville, 1600 m elevation, average annual total [1948-2005] = 48.01 cm [18.9 in], average maximum monthly total = 11.43 [4.5 in]) is much lower than at high elevations (Brian Head, 2926 m elevation, average annual total [1948-2005] = 903.99 cm [355.9 in], average maximum monthly total = 164.59 cm [64.8 in]; WRCC 2012). Sage-grouse seek winter habitat in areas where sagebrush height exceeds snow depth (Eng and Schladweiler 1972). The weather station data suggests that the Bald Hills sage-grouse

may seek low elevation areas in the winter because the sagebrush leaves would remain exposed above snow level with ≤ 11.43 cm (4.5 in) of maximum monthly snow fall (WRCC 2012). Birds likely leave these areas in the spring because of the lack of understory for food and cover (Connelly et al. 2000). The 2-stage migratory birds shared the behavioral response of migrating to seek suitable seasonal resources and used the same areas used by the 1-stage migratory birds (Fig. 2-4C).

The non-migratory birds were able to find suitable habitat year-round without making distinct long-distance seasonal movements. For example, bird 053 remained near the Minersville lek year-round, showing that the area contains enough big sagebrush to sustain at least one bird throughout the winter. Bird 404 remained near the Mud Springs lek but made more sporadic movements. These movements were not classified as migratory but they may be due to bird 404 seeking alternative habitats. The erratic movement by both of these birds emphasizes the individual variation in this population (Fig. 2-4B).

While the majority of the birds remained on either the eastern or western side of HWY 130, there was enough movement across the HWY 130 to conclude that the eastern and western birds are not isolated from each other. I did not record any radio-collared birds north of HWY 21 or east of Interstate 15 via aerial or ground telemetry, and all radio-collared birds were accounted for throughout the study. Conversely, the UDWR occupied habitat maps do show suitable habitat north of HWY 21 (UDWR 2010). Highways 21 and 130 are similar in size and traffic volume, so it is unlikely that HWY 21 would cause a barrier to dispersal if HWY 130 did not. If HWY 21 is not a barrier to dispersal then other factors such as human development or lack of quality habitat north of

HWY 21 may prevent birds from moving further north. For example, human activity has been found to cause avoidance behavior in sage-grouse (Harju et al. 2010). Both HWY 21 and Interstate 15 have associated townships in the area surrounding the Bald Hills sage-grouse population that may cause a barrier to dispersal and Interstate 15 is a 4-lane freeway. While there are known sage-grouse populations to the east of Interstate 15, telemetry data did not show evidence of Bald Hills birds moving across the Interstate or immigrating into other populations (UDWR 2010). While the cause of barriers to dispersal in the Bald Hills population requires further investigation, the lack of movement outside the study area leads me to conclude that the Bald Hills population is more isolated from other sage-grouse populations than the UDWR occupied habitat maps suggest (UDWR 2010). Telemetry studies do not always reveal long-distance emigration events if they rarely occur, thus genetics testing would provide additional evidence to determine the degree of isolation in the Bald Hills.

A possible new lek, Little Horse Valley, was found in 2012 (Fig. 2-2). Birds from this possible lek were radio-collared, but this project concluded before winter data could be collected for these birds. Because it is centrally located in the study area, examining seasonal movement patterns of birds from the Little Horse Valley lek may influence the conclusions drawn here. Further research is needed to explore the mechanisms that are driving the movement patterns described here and to account for the new lek. Continued telemetry data should be collected to increase the sample size of this dataset (particularly for winter) and to record movements between seasons over multiple years as well as between years.

Habitat preferences need to be examined as potential drivers of daily and seasonal movements based on sage-grouse resource needs. Juniper encroachment, for example, has been implicated as a major threat to sage-grouse habitat and many habitat restoration projects include landscape-scale juniper removal (Connelly et al. 2000, Crawford et al. 2004, UDWR 2009, USFWS 2010). It is important to further examine sage-grouse use of juniper trees in the Bald Hills population to better understand for which characteristics the birds are selecting when they roost under juniper trees. Junipers may be a substitute for a habitat component that is lacking, and removal of junipers prior to restoring this habitat component could be detrimental to the local sage-grouse population. Finally, it is vital to further test the conclusion that this population is isolated using genetic techniques because of the limitations of studying dispersal using telemetry techniques (Connelly et al. 2004). If this population is found to be isolated, it may have increased conservation importance due to genetic diversity within the entire sage-grouse population (Young et al. 2000).

Seasonal Distributions

There was some variation between all of the seasonal MCP distributions and the UDWR seasonal habitat maps. In all of the maps, the southernmost and westernmost portions of the UDWR seasonal habitat maps were not represented by the MCP distributions (Fig. 2-5). This is could be due to 1) poor habitat in these areas, 2) the population using different habitat than expected by sage-grouse biologists, 3) avoidance behavior towards pipeline construction, and/or 4) inadequate number of birds sampled in these areas. These areas are dominated by black sagebrush (*Artemisia nova*) stands intermixed with some salt desert shrub species such as halogeton (*Halogeton glomeratus*)

and greasewood (*Sarcobatus vermiculatus*). Construction on the Utah-Nevada (UNEV) pipeline through the southwest portion of the study area occurred during 2011 (Incardine 2010). This pipeline crosses within 5.5 km of the Mud Springs lek (UDWR 2010). I do not have telemetry data for sage-grouse prior to construction, but sage-grouse are known to avoid disturbances such as infrastructure development (Walker et al. 2007, Doherty et al. 2008, Holloran et al. 2009). Because of the short duration of this study, more long-term data may locate birds within the UDWR habitat maps that are outside of the MCPs delineated here.

The annual and summer MCP distributions are very similar to the UDWR occupied habitat map with 98.59% (982/996) and 97.86% (640/654) telemetry points within the UDWR maps, respectively. These MCP distributions do not extend north of HWY 21 however, which is contrary to the UDWR occupied habitat map (Fig. 2-5a, Fig. 2-5b). This provides further evidence that this population is isolated and does not cross north of HWY 21. It is possible that over a longer study duration, birds would be located in areas of the UDWR maps that were not identified by the MCPs for this study. There are some bird use areas near the Minersville lek and south of the Horseshoe Flat lek that are not included in the UDWR occupied habitat map. Conversely, the MCP method may over-represent sage-grouse distributions in some areas because the method does not exclude potentially unused areas within the polygon (Lichti and Swihart 2011). Based on the MCP analysis for annual and summer habitat, I recommend that the UDWR maps be extended to include the telemetry locations currently outside the UDWR maps.

The winter UDWR map does not accurately represent the MCP distribution. Part of this discrepancy may be due to the identification of the Little Horse Valley lek in 2012

and its central location in the study area. In addition, the UDWR map does not include the Minersville area, which was occupied during the winter. Because the UDWR map is omitting large areas of winter habitat, I recommend that it be revised to include all occupied winter ranges identified by this study.

The UDWR brood-rearing habitat map may over-represent brood-rearing habitat. Conversely, my sample size of reproductive hens (n =10) may under-represent suitable brood-rearing habitat. Additional data is necessary to delineate a more representative nest and brood-rearing distribution. For example, no hens nested near the Mud Springs or Parowan Gap leks where 2 and 0 hens were radio-collared, respectively. The data collected from the 10 reproductive hens resulted in a very small (225 km^2) MCP and does suggest, however, that that there is a limited area with suitable habitat for nesting and brood-rearing. Marginal habitat may lead to decreased chick survival, which has been indicated as the most influential factor contributing to the decline of other fringe populations (Aldridge and Brigham 2001). Marginal nesting habitat near leks may cause hens to travel large distances from their breeding lek to their nest, which also decreases nest success (Holloran and Anderson 2005). Based on these data, I recommend that nesting habitat be further examined to increase sample size and that the current UDWR habitat map be extended to include the 4 telemetry locations outside the current map boundaries.

Further work should focus on the habitat characteristics that are driving the bird distributions. This will help us understand the discrepancies between the MCPs and UDWR habitat maps for all of the seasons, and particularly for winter. More hens should be radio-collared in the southern leks to further assess nesting habitat in the southern

portion of the study area. With the importance of recruitment to population viability, it should be determined if nests and broods were absent near the Parowan Gap and Mud Springs leks due to poor habitat or small sample size of radio-collared hens (Aldridge and Brigham 2001). It will also be important to continue monitoring this population year-round to see if the birds will inhabit the southwest portion of the UDWR habitat maps post-construction of the UNEV pipeline. With the results of this data, I suggest that current UDWR suitable habitat maps be extended to include areas indicated by the MCP distributions that fall outside the UDWR map boundaries.

Seasonal Home Ranges

I expected that the seasonal home ranges of the Bald Hills sage-grouse would be larger than home ranges reported for non-peripheral populations. This was based on the assumption that fringe populations occupy marginal habitat resulting in essential resources being distributed over a larger area (A. C. Burnett Chapter 3, Drut et al. 1994, Lohr et al. 2011). I found that the summer home range (82km^2, 95% CI = 38.84-125.16) was larger than summer home ranges in other populations. Summer home ranges reported for populations in central Montana, southeastern Idaho, and northwestern Colorado ranged from <1 to 26 km^2 (reviewed in Miller et al. 2011). Sage-grouse in the Bald Hills area require a larger area to obtain all of their resources as compared to other populations. This suggests that summer habitat in the Bald Hills region is marginal compared with non-peripheral sage-grouse habitat.

The mean winter home range for the Bald Hills population (157.82km^2, 95% CI = 76.95-238.69) was at the high end of home ranges reported for other populations. Winter home ranges reported for populations in central Montana, southeastern Idaho, and

northwestern Colorado ranged from <1 to 195 km^2 (reviewed in Miller et al. 2011). These results lead to the conclusion that winter habitat is suitable and that Bald Hills birds require similar home range sizes as compared with centralized populations to obtain all of their seasonal resources.

In the past 10 years, home range techniques have improved drastically in their ability to make accurate home range estimates. The type and quantity of data are important considerations when determining what home range estimation method to use (Seaman et al. 1999, Kochanny et al. 2009, Benhamou and Cornelis 2010, Lichti and Swihart 2011). It is difficult to estimate the home ranges of sage-grouse using VHF telemetry due to sample size limitations (Kochanny et al. 2009). While it is not practical to apply home range estimation techniques across studies, an effort should be made to quantify home ranges using contemporary techniques. Current home range information is lacking in the literature, and this type of data can be used to inform sage-grouse conservation and management. Home range data can provide insight into the theory that population success decreases toward the periphery of a species range due to changing environmental conditions (Hengeveld and Haeck 1982, Brown 1984, Carbonell et al. 2003). Home range data can also provide managers with information about patch size requirements to inform habitat improvement projects.

This is the first study on the Bald Hills sage-grouse population. As is common with baseline studies, there are more questions than answers. I have, however, established some important population parameters that will influence future studies of this and other fringe populations.

MANAGEMENT IMPLICATIONS

I recommend that disturbances be minimized during the migration periods so that important migrations are not disrupted. I also recommend that disturbances are concentrated during the season when the birds migrate away from the area under consideration. My seasonal distribution maps provide sound data that can be used for future habitat designations. I recommend that the UDWR occupied habitat maps be extended to include MCP data from this study. The home range sizes that I delineated allow us to indirectly assess habitat quality for this fringe population. Land managers will be able to use home range size as a surrogate for habitat patch size that the sage-grouse are capable of using within a season. This should guide the size and scope of habitat management activities based on the season of interest.

When considering plans to develop renewable energy resources within the Bald Hills study area, restraint should be exercised to maintain the extant sage-grouse population. This study has shown that these birds migrate long-distances to small areas of summer and winter habitat. Development within migration corridors (further research is required to identify specific migration corridors) or near summer and winter ranges are likely to disturb vital life-history patterns exhibited by this population and should be avoided. Conservative management would prevent any development within the UDWR occupied habitat map (with revisions to include MCP data provided here) until further research examines specific migration corridors used by the population, to prevent disturbance of important migration routes. Large home ranges in this population suggest that summer habitat may be marginal. Potential mitigation measures should include habitat improvement projects for summer habitat, including nesting and brood-rearing

habitat. This would provide larger areas of suitable habitat; decreasing the potential for minimal disturbances to have population-level impacts and allowing home range sizes to be smaller.

This new information will assist local managers in making informed management decisions that will safeguard the persistence of this population. With the high potential for renewable energy development in the area, mitigation measures can be developed to address the specific behaviors displayed by this population. Future research on this population should focus on 1) genetic methods to determine if the population is isolated, 2) increasing sample sizes for winter, nest, and brood-rearing distributions, and 3) examining specific habitat attributes (available cover of shrub, grass, and forb) in the area to understand how and why the habitat is marginal for sage-grouse (see A. C. Burnett Chapter 3). If further research indicates that this population is not only isolated, but genetically distinct, then this population may warrant special protections to preserve the genetic diversity and evolutionary potential (Young et al. 2000).

LITERATURE CITED

Aldridge, C., S. E. Nielsen, H. L. Beyer, M. S. Boyce, J. W. Connelly, S. T. Knick, and M. A. Schroeder. 2008. Range-wide patterns of greater sage-grouse persistence. Diversity and Distributions 14:983-994.

Aldridge, C. L., and R. M. Brigham. 2001. Nesting and reproductive activities of greater sage-grouse in a declining northern fringe population. The Condor 103:537-543.

Baxter, R. J., J. T. Flinders, and D. L. Mitchell. 2008. Survival, movements, and reproduction of translocated greater sage-grouse in Strawberry Valley, Utah. Journal of Wildlife Management 72:179-186.

Beck, J. L., D. L. Mitchell, and B. D. Maxfield. 2003. Changes in the distribution and status of sage-grouse in Utah. Western North American Naturalist 63:203-214.

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

Benhamou, S., and D. Cornelis. 2010. Incorporating movement behavior and barriers to improve kernel home range space use estimates. The Journal of Wildlife Management 74:1353-1360.

Berry, J., D. Hurlbut, R. Simon, J. Moore, and R. Blackett. 2009. Utah Renewable Energy Zones (UREZ) Task Force phase 1 report; renewable energy zone resource identification. Miscellaneous Publication 09-1. Utah Geologic Survey. Salt Lake City, Utah, USA.

Berry, J. D., and R. L. Eng. 1985. Interseasonal movements and fidelity to seasonal use areas by female sage grouse. The Journal of Wildlife Management 49:237-240.

Black and Veatch Corporation. 2010. Utah Renewable Energy Zone (UREZ) Task Force, phase 2 report; zone identification and scenario analysis. Utah Office of Energy Development. Salt Lake City, Utah, USA.

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

Brown, J. H. 1984. On the relationship between abundance and distribution of species. The American Naturalist 124:255-279.

Bush, K. L., C. K. Dyte, B. J. Moynahan, C. Aldridge, H. S. Sauls, A. M. Battazzo, B. Walker, K. E. Doherty, J. Tack, and J. Carlson. 2011. Population structure and genetic diversity of greater sage-grouse (*Centrocercus urophasianus*) in fragmented landscapes at the northern edge of their range. Conservation Genetics 12:527-542.

Carbonell, R., J. Perez-Tris, and J. L. Telleria. 2003. Effects of habitat heterogeneity and local adaptation on the body condition of a forest passerine at the edge of its distributional range. Biological Journal of the Linnean Society 78:479-488.

Connelly, J. W., and C. E. Braun. 1997. Long-term changes in sage grouse *Centrocercus urophasianus* populations in western North America. Wildlife Biology 3:229-234.

Connelly, J. W., H. W. Browers, and R. J. Gates. 1988. Seasonal movements of sage grouse in southeastern Idaho. The Journal of Wildlife Management 52:116-122.

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

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

Crawford, J. A., R. A. Olson, N. E. West, J. C. Mosley, M. A. Schroeder, T. D. Whitson, R. F. Miller, M. A. Gregg, and C. S. Boyd. 2004. Ecology and management of sage-grouse and sage-grouse habitat. Rangeland Ecology & Management 57:2-19.

Dalke, P. D., D. B. Pyrah, C. S. Don, J. E. Crawford, and E. F. Schlatterer. 1963. Ecology, productivity, and management of sage grouse in Idaho. The Journal of Wildlife Management 27:811-841.

Doherty Jr., P. F., T. Boulinier, and J. D. Nichols. 2003. Local extinction and turnover rates at the edge and interior of a species' range. Finnish Zoological and Botanical Publishing Board 40:145-153.

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

Drut, M. S., J. A. Crawford, and M. A. Gregg. 1994. Brood habitat use by sage grouse in Oregon. Great Basin Naturalist 54:170-176.

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

Eng, R. L., and P. Schladweiler. 1972. Sage grouse winter movements and habitat use in central Montana. The Journal of Wildlife Management 36:141-146.

Fedy, B. C., C. L. Aldridge, K. E. Doherty, M. O'Donnell, J. L. Beck, B. Bedrosian, M. J. Holloran, G. D. Johnson, N. W. Kaczor, C. P. Kirol, C. A. Mandich, D. Marshall, G. McKee, C. Olson, C. C. Swanson, and B. L. Walker. 2012. Interseasonal movements of greater sage-grouse, migratory behavior, and an assessment of the core regions concept in Wyoming. The Journal of Wildlife Management 76:1062-1071.

Fischer, R. A., K. P. Reese, and J. W. Connelly. 1996. Influence of vegetal moisture content and nest fate on timing of female sage grouse migration. The Condor 98:868-872.

Fuller, M. R., J. J. Millspaugh, K. E. Church, and R. E. Kenward. 2005. Wildlife radiotelemetry. Pages 377-418 *in* C. E. Braun, editor. Techniques for wildlife investigations and management. The Wildlife Society, Bethesda, Maryland, USA.

Haak, A. L., J. E. Williams, H. M. Neville, D. C. Dauwalter, and W. T. Colyer. 2010. Conserving peripheral trout populations: the values and risks of life on the edge. Fisheries 35:530-549.

Hagen, C. A., J. W. Connelly, and M. A. Schroeder. 2007. A meta-analysis of greater sage-grouse *Centrocercus urophasianus* nesting and brood-rearing habitats. Wildlife Biology 13:42-50.

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

Hengeveld, R., and J. Haeck. 1982. The distribution of abundance: I; measurements. Journal of Biogeography 9:303-316.

Herman-Brunson, K. M., K. C. Jensen, N. W. Kaczor, C. C. Swanson, M. A. Rumble, and R. W. Klaver. 2009. Nesting ecology of greater sage-grouse *Centrocercus urophasianus* at the eastern edge of their historic distribution. Wildlife Biology 15:395-404.

Holloran, M. J., and S. H. Anderson. 2005. Spatial distribution of greater sage-grouse nests in relatively contiguous sagebrush habitats. The Condor 107:742-752.

Holloran, M. J., R. C. Kaiser, and W. A. Hubert. 2009. Yearling greater sage-grouse response to energy development in Wyoming. Journal of Wildlife Management 74:65-72.

Incardine, J. 2010. Proposed pony express RMP amendment and final EIS for the UNEV pipeline. Utah State Office, Salt Lake City, Utah, USA.

Kochanny, C. O., G. D. Delgiudice, and J. Fieberg. 2009. Comparing global positioning system and very high frequency telemetry home ranges of white-tailed deer. The Journal of Wildlife Management 73:779-787.

Leonard, K. M., K. P. Reese, and J. W. Connelly. 2000. Distribution, movements and habitats of sage grouse centrocercus urophasianus on the Upper Snake River plain of Idaho: Changes from the 1950s to the 1990s. Wildlife Biology 6:265-270.

Lesica, P., and F. W. Allendorf. 1995. When are peripheral populations valuable for conservation? Conservation Biology 9:753-760.

Lichti, N. I., and R. K. Swihart. 2011. Estimating utilization distributions with kernel versus local convex hull methods. The Journal of Wildlife Management 75:413-422.

Lohr, M., B. M. Collins, P. M. Castelli, and C. K. Williams. 2011. Life on the edge: northern bobwhite ecology at the northern periphery of their range. The Journal of Wildlife Management 75:52-60.

Miller, R. F., S. T. Knick, D. A. Pyke, C. W. Meinke, S. E. Hanser, M. J. Wisdom, and A. L. Hild. 2011. Characteristics of sagebrush habitats and limitations to long-term conservation. Pages 145-184 *in* S.T. Knick and J. W. Connelly, editors.

Greater sage-grouse; ecology and conservation of a landscape species and its habitats. University of California Press, Berkeley, USA.

Mohr, C. O. 1947. Table of equivalent populations of north american small mammals. American Midland Naturalist 37:223-249.

Palmer, W. E., and S. D. Wellendorf. 2007. Effect of radiotransmitters on northern bobwhite annual survival. The Journal of Wildlife Management 71:1281-1287.

Prentice, I. C., W. Cramer, S. P. Harrison, R. Leemans, R. A. Monserud, and A. M. Solomon. 1992. Special paper; a global biome model based on plant physiology and dominance, soil properties and climate. Journal of Biogeography 19:117-134.

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

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

Schroeder, M. A., J. R. Young, and C. E. Braun. 1999. Greater sage-grouse (*Centrocercus urophasianus*), the birds of North America Online (A. Poole, Ed.). Ithaca: Cornell Lab of Ornithology; Retrieved from the Birds of North America Online: http://bna.birds.cornell.edu/bna/species/425. Accessed 12 Oct 2012.

Seaman, D. E., J. J. Millspaugh, B. J. Kernohan, G. C. Brundige, K. J. Raedeke, and R. A. Gitzen. 1999. Effects of sample size on kernel home range estimates. The Journal of Wildlife Management 63:739-747.

Sheather, S. J., and M. C. Jones. 1991. A reliable data-based bandwidth selection
method for kernel density estimation. Journal of the Royal Statistical Society.
Series B (Methodological) 53:683-690.

U. S. Fish and Wildlife Service, Interior [USFWS]. 2010. Endangered and threatened
wildlife and plants; 12-month findings for petitions to list the greater sage-grouse
(*Centrocercus urophasianus*) as threatened or endangered. 50 CFR Part 17.
Department of the Interior; Federal Register, Washington D.C., USA.

Utah Division of Wildlife Resources [UDWR]. 2009. Utah greater sage-grouse
management plan. Utah Department of Natural Resources, Division of Wildlife
Resources Publication 09-17, Salt Lake City, Utah, USA.

Utah Division of Wildlife Resources [UDWR]. 2010. Utah Automated Geographic
Reference Center [AGRC]. Spatial data for Utah, USA. <http://gis.utah.gov>.
Accessed 2 April 2012.

Wakkinen, W. L. 1990. Nest site characteristics and spring-summer movements of
migratory sage grouse in southeastern idaho.

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

Wallestad, R. 1975. Male sage grouse responses to sagebrush treatment. The Journal of
Wildlife Management 39:482-484.

West, N.E., and J.A. Young. 2000. Ch. 7 (Intermountain Valleys and Lower Mountain
Slopes). *in* M.G. Barbour and W.D. Billings, editors. North American terrestrial
vegetation. 2nd ed. Cambridge University Press, Cambridge, UK.

Western Regional Climate Center [WRCC]. 2012. Utah climate summaries. <http://www.Wrcc.Dri.Edu>. Accessed 20 November 2012.

Worton, B. J. 1989. Kernel methods for estimating the utilization distribution in home-range studies. Ecology 70:164-168.

Young, J. R., C. E. Braun, S. J. Oyler-McCance, J. W. Hupp, and T. W. Quinn. 2000. A new species of sage-grouse (phasianidae: *Centrocercus*) from southwestern colorado. The Wilson Bulletin 112:445-453.

CHAPTER 3

HABITAT CHARACTERISTICS OF A FRINGE GREATER SAGE-GROUSE

POPULATION: HOW DO THEY MEASURE UP?

ABSTRACT Range-wide declines in greater sage-grouse (*Centrocercus urophasianus,* hereafter sage-grouse) populations have prompted extensive research on sage-grouse habitat use. Information about habitat use in fringe populations, however, is still limited. I examined nest, brood-rearing and summer habitat use in a southern fringe sage-grouse population. I tracked 66 birds (17 females & 49 males) via VHF telemetry and surveyed vegetation plots at nest ($n = 9$), brood-rearing ($n = 13$), summer ($n = 53$), and random ($n = 75$) locations in 2011 and 2012. Nest sites were characterized by canopy cover of 36.00% $\pm$ 5.86 ($\bar{x} \pm$ SE) shrub, 4.74% $\pm$ 2.67 forb, 13.23% $\pm$ 1.62 grass, and 29.58% $\pm$ 2.94 bare ground. Brood-rearing sites were characterized by 28.08 $\pm$ 2.84% shrub, 16.86 $\pm$ 3.68% forb, 12.72 $\pm$ 1.51% grass canopy cover, and 24.08% $\pm$ 3.32 bare ground. Hens selected for higher forb cover at brood-rearing sites as compared with random sites within the study area. Summer sites were characterized by 9.21% $\pm$ 1.11 shrub cover, 16.19% $\pm$ 2.06 forb cover, 21.71% $\pm$ 1.78 grass cover, 19.13% $\pm$1.72 bare ground, and 37.63cm $\pm$ 1.78 mean maximum grass height. Birds at summer sites selected for lower shrub and bare ground but higher forb and grass cover from random sites. Shrub canopy cover was greater than habitat recommendations for productive sage-grouse habitat while canopy cover of grasses and forbs was lower. Management strategies should focus on maintaining current habitat conditions and increasing the availability of grasses and forbs. Future work should focus on the reproductive success of this population in order to

determine if this population has adapted to local habitat conditions or if the local habitat conditions are limiting sage-grouse productivity.

Greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse) population declines and range contraction have been attributed to the loss of both quality and quantity of sagebrush-steppe habitats in the western United States (Connelly and Braun 1997, Schroeder et al.1999, Aldridge et al. 2008). While habitat quantity is difficult to manage with continued infrastructure development, agricultural conversion, and human encroachment, habitat quality (composition, connectivity, lack of disturbance) can often be improved via management techniques (USFWS 2010, Dahlgren et al. 2006, Doherty et al. 2010, BLM 2011). Habitat quality can have direct impacts on sage-grouse productivity by affecting nest success, brood success, and adult survival (Sveum et al. 1998, Aldridge et al. 2004, Moynahan et al. 2006, Coates and Delehanty 2010). Declines in sage-grouse productivity have led to the large-scale population declines over the past 30 years (Connelly and Braun 1997). Understanding, maintaining, and restoring quality habitat is therefore a primary issue for sage-grouse conservation and management (Connelly et al. 2000b, Crawford et al. 2004, UDWR 2009, USFWS 2010, Wisdom and Chambers 2009).

Connelly et al. (2000b) published management guidelines for range-wide sage-grouse habitats, reporting specific habitat characteristics that are required for productive sage-grouse populations. Some of the most important habitat characteristics include the height and canopy cover of shrubs, grasses, and forbs. These plant types provide food and cover for sage-grouse during each part of their life history (Wisdom et al. 2005). Sage-

grouse consume the leaves of big sagebrush (*Artemesia tridentata*) year-round but also require a diverse understory of grasses and forbs. Grass and shrub cover is often greater at nest and brood-rearing locations compared with surrounding vegetation because it provides concealment from predators. This increases nest success and brood survival (Connelly et al. 2000b, Aldridge and Brigham 2002, Holloran and Anderson 2005, Kolada et al. 2009, Coates and Delehanty 2010). Forbs are consumed by sage-grouse and also provide habitat for invertebrates, an important food source for both chicks and adults (Connelly et al. 2000b, Crawford et al. 2004, Rhodes et al. 2010). Current range-wide management recommendations for sagebrush height range from 30-80 cm with 15-25% canopy cover. Grass/forb height recommendations are >18 cm with ≥15% canopy cover for arid sites and ≥25% canopy cover for mesic sites (Connelly et al. 2000b).

In 2010, the US Fish and Wildlife Service (USFWS) determined that sage-grouse warranted protection under the Endangered Species Act but were precluded from listing by higher priority species. The Connelly et al. (2000b) guidelines were cited extensively as the standard for sage-grouse habitat management in the USFWS 2010 listing decision as well as the Utah Division of Wildlife Resources (UDWR) 2009 management plan for the species (UDWR 2009, USFWS 2010).

Fringe populations are at the geographic periphery of a species range (Lesica and Allendorf 1995). While the habitat requirements of nesting and brood-rearing sage-grouse in non-fringe populations have been well studied, information about habitat use in fringe populations is limited (Patterson 1952, Wallestad 1975, Fischer et al. 1996, Holloran 1999, Connelly et al. 2000b, Aldridge and Brigham 2002, Kolada et al. 2009, Coates and Delehanty 2010). Peripheral populations often utilize marginal habitats that

can lead to lower success and unique adaptations to these marginal habitats (Lesica and

Allendorf 1995, Carbonell et al. 2003, Haak et al. 2010). With decreased success,

utilization of marginal habitats, increased isolation, and declining meta-population trends,

populations at the periphery of the sage-grouse range may have increased extinction risk

(Doherty et al. 2003). Unique adaptations in small isolated populations can also lead to

phenotypic variation. In extreme cases of isolation, phenotypic diversity leads to genetic

divergence, an integral consideration for the recovery of declining species (Young et al.

2000, Oyler-McCance and Leberg 2005). The Bald Hills sage-grouse population in

southwestern Utah is a geographically isolated peripheral population at the southern edge

of the species range, and may exhibit these fringe population attributes (see A. C. Burnett

Chapter 2, UDWR 2009; Fig. 3-1).

Studies on fringe populations have shown that sage-grouse habitat on the

periphery of the sage-grouse distribution does differ from the norm as well as from other

fringe populations. Aldridge and Brigham (2002) found that sagebrush cover (5-11%)

and forb cover (12%) at nest sites in a northern fringe population in southeastern Alberta,

Canada differed from the Connelly et al. (2000b) guidelines. Kolada et al. (2009) found

shrub canopy cover (42.4%) at nest sites to be greater than expected and recommended

management for greater shrub cover in the Mono County, California (east-central

California, USA) fringe population. This has important implications for the Bald Hills

population because the climate in southern Utah varies greatly from that in east-central

California and in southeastern Alberta, Canada (Brown et al. 1979). I expect habitat

characteristics in the Bald Hills region to be different from these fringe populations as

well as non-fringe populations because of the climatic differences in southern Utah. The

majority of the sage-grouse distribution is within sagebrush steppe habitat. West and Young (2000) classified southern Utah as a great basin sagebrush ecosystem, however, which is more arid with sandy soils. This would suggest that the Bald Hills study area provides inherently marginal sage-grouse habitat as compared with habitat in sagebrush steppe ecosystems.

There has been a large focus in the literature on nesting and brood-rearing habitat characteristics because of the direct impacts of habitat quality on reproductive success (Sveum et al. 1998, Aldridge et al. 2004, Moynahan et al. 2006, Coates and Delehanty 2010). Few studies have examined summer habitat characteristics of non-reproductive adults (hens that did not reproduce successfully that year and males; Wallestad 1971, Dunn and Braun 1986). Quality of summer habitat for non-reproductive birds may be an important factor influencing winter survival and reproductive success the following spring due to seasonal carry-over effects (Norris 2005). Sage-grouse depend solely on sagebrush for food and cover during the winter, which can add stress to populations if the sagebrush has been disturbed or if the birds have to migrate to find suitable winter habitat (Beck 1977, Beck et al. 2006). Despite these stressors, sage-grouse tend to have low overwinter mortality (Connelly et al. 2000a, Beck et al. 2006). This anomaly may indicate that sage-grouse occupying high quality summer habitat come into winter with good body condition, increasing their physiological ability to survive the winter (Haramis et al. 1986, Norris 2005). Saino et al. (2004) described a similar mechanism where high quality winter habitat conditions resulted in larger clutch sizes and increased male ornamentation and fitness during the breeding season. If a similar pattern is occurring in sage-grouse populations, then the carry-over effect could link all three seasons: quality

seasonal habitat influences summer body condition, which influences winter body condition and survival, which influences reproductive success. While the potential implications of seasonal carry-over effects on sage-grouse populations are unknown, it is important to examine habitat use of sage-grouse during each part of their life history.

The objective of this study was to examine the habitat characteristics of the Bald Hills sage-grouse population, a fringe population at the southern periphery of the species range. This population has never previously been studied and the lack of data is problematic because vegetation characteristics may differ from other parts of the sage-grouse distribution, which would necessitate unique habitat management goals. Results from this research are critical because of the high potential for renewable energy development in the Bald Hills area (Black and Veatch Corporation 2010). Understanding the relationship between this population and its habitat will assist local managers in mitigating threats to the population while balancing the demands to develop renewable energy resources (BLM 2011). I examined habitat characteristics at nest, brood-rearing, and summer sage-grouse locations at multiple spatial scales (distances within the study area) and resolutions (patch sizes). This study will compare habitat characteristics in a southern peripheral population with the Connelly et al. (2000b) guidelines as well as to other fringe populations.

STUDY AREA

Located primarily on public land managed by the Bureau of Land Management (BLM), the Bald Hills study area was delineated from the boundaries of the UDWR 2010 sage-grouse suitable brood-rearing habitat map (UDWR 2010). This area was designated with the purpose of tracking birds radio-collared from the known leks (breeding areas)

encompassed by the area. Birds collared within the study area were tracked both inside and outside of the original designated study area (Fig. 2-2).

The study area (1,250 km^2) covered portions of Iron and Beaver counties in Utah. The southern edge of the study area was located 20 km north of Cedar City, and the northeast corner was located 3 km south of Beaver (Fig. 2-2). State highway 130 (hereafter, HWY 130) bisected the study area from Cedar City to Minersville and Interstate 15 from Cedar City to Beaver was east of the study area. The majority of the study area was public land managed by the BLM (968 km^2), with some private (170 km^2) and State Trust Lands (112 km^2; UDWR 2010). The elevation ranged from 1550 m to 2400 m. Average annual precipitation in Minersville (within low elevation portion of study area) was 28.96 cm (11.4 in) (from 1948-2005) with mean annual total snowfall of 48.01 cm (18.9 in; Western Regional Climate Center [WRCC] 2012). Habitat types were diverse yet characterized by Great Basin sagebrush (more arid and southerly as compared with sagebrush steppe; West and Young 2000), juniper forest, salt-desert shrub, and disturbed areas with invasive cheatgrass (*Bromus tectorum*), and annual mustard (*Brassicaceae* fam.). Dominant sagebrush species included mountain big sagebrush (*Artemisia tridentate vaseyana*) at high elevations, Wyoming big sagebrush (*Artemisia tridentata wyomingensis*) at intermediate elevations and overlapping with the other two species, and black sagebrush (*Artemisia nova*) at low elevations. During spring and summer, cattle and sheep grazing was common throughout the study area. Crop agriculture (primarily alfalfa and corn) was common in the northwest portion. The northeast portion had been re-seeded twice with a native and non-native mix of perennial grasses, forbs, and shrubs after the Greenville Bench wildfire (July 2007, 15.98 km^2; C.S.

Pontarolo, Bureau of Land Management, unpublished data; Appendix Table A.1). The

Wrangler (7 Aug 2011, 34.21 km^2) and Baboon (25 Jul 2012, 80.04 km^2) wildfires

occurred during the study but did not burn areas where radio-collared sage-grouse were

being tracked at those times (C.S. Pontarolo, Bureau of Land Management, unpublished

data).

Eleven known leks (Horseshoe Flat, Jackrabbit, Little Horse Valley, Lost Spring,

Minersville, Mud Springs, Parowan Gap, Poorman Flat, Poorman Jeff, Poorman Ridge,

and Upper Long Hollow) were within the study area (Fig. 2-2). Of the 3 leks that were

impacted by the Greenville Bench wildfire (Poorman Flat, Poorman Jeff, and Poorman

Ridge) only the Poorman Jeff lek was active during this study. The Lost Spring lek was

also inactive in 2011 and 2012. Two possible new leks were identified during the study

period: Little Horse Valley (2012) and Upper Long Hollow (2011).

METHODS

Capture and Monitoring

I captured sage-grouse in 2011 and 2012 using spotlighting techniques on roosts

surrounding 8 leks in the study area (Horseshoe Flat, Jackrabbit, Little Horse Valley,

Minersville, Mud Springs, Parowan Gap, Poorman Jeff, and Upper Long Hollow;

Wakkinen 1990). My goal was to capture 60 sage-grouse over the study duration with a

minimum of 40% hens and at least 2 birds from each active lek. For all captured birds, I

weighed, collected a feather, and noted age class (sub-adult and adult) and sex (Eng

1955). All birds captured in 2011 were fitted with 24-g necklace VHF transmitters with
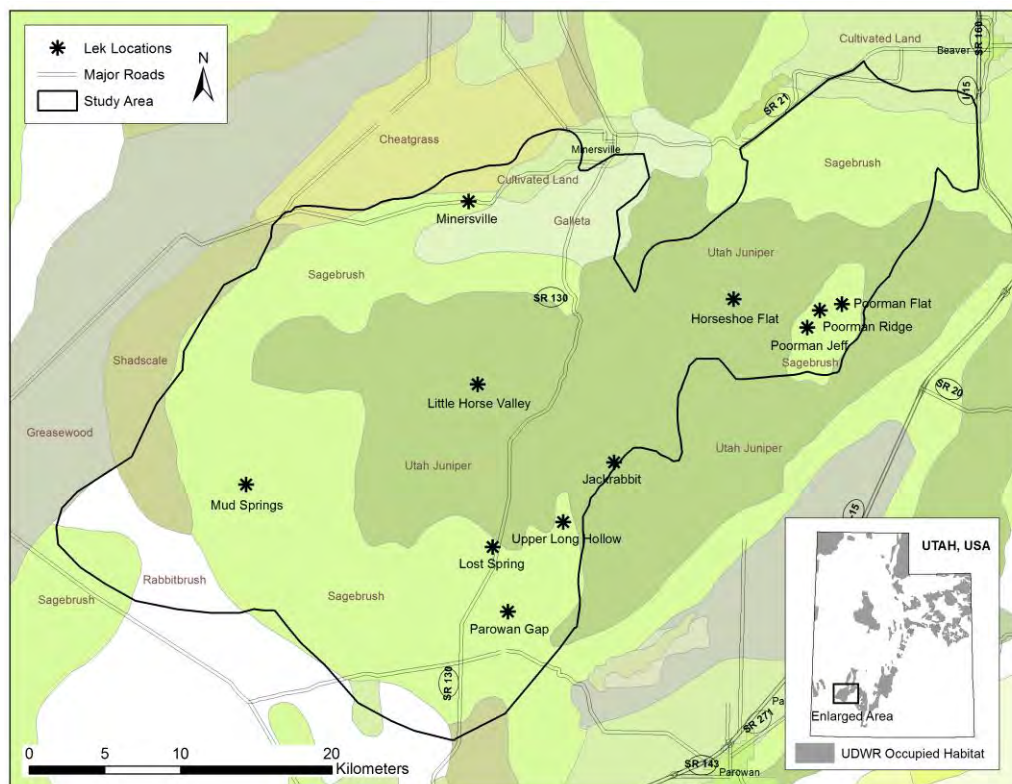
Figure 3-1. Bald Hills study area in southwestern Utah with dominant vegetation types and sage-grouse occupied habitat designated by the UDWR (UDWR 2010). The 1,250 km^2 area encompassed 11 known leks.

an 8-hr mortality switch (model A4060; Advanced Telemetry Systems, Isanti, MN).

Sage-grouse captured in 2012 were fitted with 19-g necklace VHF transmitters with an 8-hr mortality switch (model A4050; Advanced Telemetry Systems, Isanti, MN). Larger collars were used in 2011 to ensure battery life throughout the study duration. All capture and handling procedures were approved through the Utah State University Institutional Animal Care and Use Committee (Protocol #1322) and Certificate of Registration for Banding, Collection, Depredation, and/or Salvage from the UDWR (R657-3). Prior to this study, 15 male sage-grouse were radio-collared in 2010 by BLM personnel using the same techniques and equipment as the 2011 capture operations; 9 of these birds were still alive during my study and thus I incorporated them into my research. I assumed that the

radio-collared birds were a representative sample of the population and that the capture

event and transmitter attachment did not alter radio-collared bird behavior (Palmer and

Wellendorf 2007).

During the spring (Mar through May), summer (Jun through Aug), and fall (Sep

through Nov) I attempted to locate and flush each bird one time per week via VHF

ground telemetry (Beck et al. 2006). During nesting and brood-rearing (Apr through Aug)

I located nesting and brood-rearing hens without flushing them (Schroeder 1997). At

every ground telemetry location I recorded the bird identity, number of birds in the group,

habitat type (UDWR 2010), Global Positioning System (GPS) location, date, time, and

elevation (m). All Universal Transverse Mercator (UTM) coordinates were collected

using a handheld GPS with <5 m error (model eTrex Venture HC, Garmin International,

Inc., Olathe, KS). As weather permitted, I located missing birds via aerial telemetry using

a fixed-wing aircraft one time per month year-round. Flight locations were used to assist

with ground telemetry and were not used for analysis. This provided the potential to

locate missing birds both within and outside of the study area.

Habitat Characteristics

I surveyed 30m^2 vegetation plots to gain information about habitat use in the Bald

Hills sage-grouse population. Weekly sage-grouse ground telemetry locations were

classified as nest, brood-rearing, or summer (non-reproductive adults) use-sites. I

established vegetation plots at all nest and brood-rearing locations.

Nest and brood-rearing plots were sampled within 1 week of the hen leaving the

nest or brood-rearing location. Paired-random plots for each nest and each brood-rearing

location (Aldridge and Brigham 2002, Conover et al. 2010) were located 90 m from the

location in a random cardinal direction (Bunnell et al. 2004, Kolada et al. 2009, Conover et al. 2010) and centered at pseudo-nest sites that were located at the nearest sagebrush (Patterson 1952, Klebenow 1969, Connelly et al. 1991, Sveum et al. 1998, Holloran and Anderson 2005, Kolada et al. 2009, Conover et al. 2010). The 90-m scale was chosen because it is spatially available (hens can easily travel 90 m) and the distance is large enough to detect potential vegetation differences.

I surveyed summer plots on a weekly basis based on a random sampling of birds located during the previous week. Plots for used sites were centered at the bird's location; indicated by GPS waypoint from the telemetry location and identified by feces, nest, or feathers. Some bird telemetry sites were located within private agricultural fields; I did not sample plots at these sites in order to avoid potential crop damage so these sites were excluded from analysis. For each summer use location surveyed I also sampled a random vegetation plot during the same week. These random plots were used to determine the habitat characteristics that were available within the study area. Random plot locations were determined by selecting random UTM coordinates within the study area, excluding thick pinyon-juniper forest, using ArcGIS Desktop (Environmental Systems Research Institute, Redlands, CA software; Dunn and Braun 1986, Connelly et al. 1991, Kolada et al. 2009).

Vegetation survey design was based on established methods to assess sage-grouse habitats (Connelly et al. 2000b, Aldridge and Brigham 2002, Connelly et al. 2003, Conover et al. 2010). I recorded general information about all vegetation plots including: date, type (summer, random, nest, nest paired-random, brood, and brood paired-random), habitat classification, UTM coordinates, and elevation (Kolada et al. 2009). I was

interested in determining the habitat characteristics sage-grouse were using at a 30 m^2

patch size, which was found to be a meaningful resolution for habitat management by

Aldridge and Brigham (2002). Four 15-m transects were extended in each cardinal

direction from the plot center (Patterson 1952, Connelly et al. 1991, Aldridge and

Brigham 2002, Holloran and Anderson 2005). I used a 1-m^2 quadrat and methods similar

to Daubenmire (1959) to estimate vegetation cover. I placed the quadrat at the plot center

and on the lower compass degree side of each transect at 4-5m, 9-10m, and 14-15m.

Within each quadrat I measured maximum grass height and estimated percent cover of

shrub, forb, grass, litter, and bare ground in 5% increments so that cover would not

exceed 100% (Aldridge and Brigham 2002). I used the line intercept method similar to

Canfield (1941) to determine live shrub cover and height, excluding gaps greater than 4

cm between live shrubs (Dunn and Braun 1986). I measured vertical visual obstruction of

the bird location (plot center) using a modified Robel pole (Robel et al. 1970, Dunn and

Braun 1986). The pole was placed perpendicular to the ground and the observer noted the

lowest 5-cm increment section with no visual obstruction. The observer viewed the pole

from a distance of 5 m in each cardinal direction and at a height of 1 m from the ground

(Conover et al. 2010). Habitat classification was a general stand type description

determined by the dominant vegetation type(s) (Kolada et al. 2009). Habitat classification

types in the Bald Hills study area included: grass (GRAS), grass mix (GRMX), pinyon-

juniper mix (PJMX), sagebrush (SAGE), sagebrush mix (SAMX), salt-desert shrub

(SDSH), and post-fire rehabilitation treatment (TRT; Appendix Table A.2, UDWR 2010).

At nest sites I recorded additional data about the nest (or pseudo-nest) shrub including

maximum cover (cm) and height (cm).

I compared vegetation characteristics at use sites (nest and brood-rearing) to the vegetation characteristics at both paired-random and summer random sites. I included all of the random sites that were surveyed within the same time frame as the used (nest or brood-rearing, respectively) plots with the addition of a 1-week buffer (24 May to 28 June for nest and 6 Jun to 4 Aug for brood-rearing). This allowed me to examine hen habitat selection for nest sites at the 30-m patch resolution at two different spatial scales: 90-m (paired-random plots) and throughout the study area (random plots).

I calculated the mean value of each habitat measurement (measurement unit) for each plot (experimental units) and only conducted statistical analysis on the plot data (Kolada et al. 2009). I graphically checked that the assumptions to perform t-tests were met by the data. Residual normality was assessed with Q-Q plots and homogeneity of error variance was assessed with residual plots. The nest and brood-rearing data did not initially meet the model assumptions so I performed a square-root-transformation on all of the nest and brood-rearing data for analysis (Aldridge and Brigham 2002). I compared mean habitat characteristics among use and paired-random sites using paired t-tests with separate analyses for nest and brood-rearing data (T.TEST with option paired=TRUE, R Version 2.15.1, www.r-project.org, accessed 9 Aug 2012). I compared mean habitat characteristics among use and random sites using two-sample t-tests with separate analyses for nest and brood-rearing data (T.TEST with option paired=FALSE, R version 2.15.1). Habitat characteristics analyzed included total live shrub cover and mean maximum shrub height from the line transects, forb and grass canopy cover, bare ground cover, and mean maximum grass height from the quadrats, and maximum height of full visual obstruction from the Robel pole (Dunn and Braun 1986, Sveum et al. 1998,

Connelly et al. 2000b, Aldridge and Brigham 2002, Kolada et al. 2009, Conover et al. 2010). I evaluated significance at threshold $\alpha = 0.05$. For simple interpretation, I reported descriptive statistics (mean and standard errors) of the non-transformed data (Aldridge and Brigham 2002).

I examined two additional habitat characteristics for the nest data. I compared mean maximum cover (cm) and mean maximum height (cm) of the nesting shrub among used and paired-random sites. I performed paired t-tests for these comparisons. These tests were included to examine two habitat characteristics that were based on the individual nest shrub rather than the 30-m^2 plot. I did not collect pseudo-nest data at summer random plots, so I did not examine nest-shrub characteristics at the study area scale.

The habitat characteristics examined for summer locations were the same variables that were examined for brood-rearing locations. Using the same methods as for the nest and brood-rearing data, I graphically checked that the summer plot data met the model assumptions to conduct means comparison tests. The summer data violated the model assumptions of residual normality and homogeneity of error variance for the non-transformed and square-root-transformed data. To determine if sage-grouse were selecting specific summer habitat characteristics from what was available throughout the study area, I compared the distributions and variances of habitat characteristics among summer used and random sites with statistical tests and graphical checks. I used the Kolmogorov-Smirnov test to compare the distributions of habitat characteristics at used and random sites because I did not assume that the distributions were normal or equal (KS.TEST, R Version 2.15.1). I compared the variances among used and random sites

using F-tests because unequal variance could be indicative of habitat selection patterns

(VAR.TEST, R Version 2.15.1). I also graphically compared the variable distributions

using violin plots, a combination of kernel density and box plots, to discern potential

selection patterns identified using the statistical tests (GEOM_VIOLIN, R Version

2.15.1; Hintze and Nelson 1998).

The frequency of occurrence of each habitat classification type (habitat type

frequency) was graphically examined for all plot types. I used a χ^2 test to compare

relative frequencies of each habitat type among used and random plots, with separate

analysis for nest, brood-rearing, and random sites (CHISQ.TEST, R Version 2.15.1).

Habitat types were examined because they were determined by the dominant vegetation

of the habitat stand encompassing the plot rather than within the 30-m^2 plot area.

RESULTS

Capture and Monitoring

I captured 25 sage-grouse in 2011 ($n = 8$ hens, $n = 17$ males) from the Horseshoe

($n = 5$ hens, $n = 5$ males), Minersville ($n = 1$ hens, $n = 4$ males), Mud Springs ($n = 2$

hens, $n = 7$ males), and Parowan Gap ($n = 1$ male) leks. In 2012 I captured 25 sage-

grouse ($n = 9$ hens, $n = 16$ males) from the Jackrabbit ($n = 2$ males), Little Horse Valley

($n = 8$ hens, $n = 6$ males), Minersville ($n = 1$ male), Parowan Gap ($n = 1$ male), Poorman

Jeff ($n = 1$ hens, $n = 5$ males), and Upper Long Hollow ($n = 1$ male) leks. Of the 15 male

sage-grouse (from Horseshoe [$n = 4$], Minersville [$n = 2$], Mud Springs [$n = 5$], Parowan

Gap [$n = 1$], and Poorman Jeff [$n = 3$] leks) captured by the BLM in 2010, 4 died and 2

collars went offline prior to this study. I was able to locate and track 9 of these birds

during the study, increasing my total sample size to 59 birds ($n = 17$ hens, $n = 42$ males) with 29% hens and all 8 active leks represented.

Habitat Characteristics

I quantified vegetation characteristics at nest sites in the Bald Hills southern fringe sage-grouse population (Table 3-1). Vegetation characteristics were measured at $n = 9$ nest sites and an equal number of nest paired-random sites ($n = 9$) to examine habitat selection at a 90-m scale. I included $n = 12$ random sites that were sampled within 7 days of the nest plot surveys to examine habitat selection at a 1,250 km^2 scale (study area scale).

I did not detect any differences between nest sites and random sites at either scale. No difference was detected among nest and paired-random sites for percent cover of shrub ($t_8 = - 0.08$, $P = 0.936$), forb ($t_8 = 0.57$, $P = 0.582$), grass ($t_8 = 0.63$, $P = 0.547$), and bare ground ($t_8 = 1.27$, $P = 0.240$) or mean maximum height of grass ($t_8 = - 0.60$, $P = 0.568$), shrub ($t_8 = 0.87$, $P = 0.412$) and visual obstruction ($t_8 = - 1.42$, $P = 0.195$). Similarly, I did not detect differences among nest and random sites for percent cover of shrub ($t_{19} = 0.83$, $P = 0.418$), forb ($t_{15} = 0.16$, $P = 0.876$), grass ($t_{19} = 1.63$, $P = 0.120$), and bare ground ($t_{18} = -1.62$, $P = 0.121$) or mean maximum height of grass ($t_9 = - 0.97$, $P = 0.359$), shrub ($t_{16} = 1.93$, $P = 0.071$) and visual obstruction ($t_{16} = - 0.34$, $P = 0.741$). Shrub cover and height of the nest shrub did not vary between sites ($t_8 = 0.21$, P $= 0.839$ and $t_8 = 0.47$, P $= 0.651$, respectively).

Nest sites were located in GRMX (11.11%), SAGE (11.11%), and SAMX (77.78%) habitat stand types (Fig. 3-2). The relative frequency of habitat types did not vary between nest and paired-random sites ($\chi^2 = 5.58$, df $= 2$, $P = 0.061$).

Table 3-1. Vegetation characteristics ($\bar{x} \pm$ SE) at nest sites compared with random sites in the Bald Hills, Utah greater sage-grouse population (2011 and 2012).

Variable	Nest (n = 9)	Paired-Random[1] (n = 9)	Random[2] (n = 12)
Cover (%)			
Shrub	36.00 (5.86)	35.92 (4.21)	30.93 (3.68)
Forb	4.74 (2.67)	2.67 (0.69)	3.77 (1.28)
Grass	13.23 (1.62)	12.41 (2.64)	9.46 (2.30)
Bare Ground	29.58 (2.94)	25.12 (4.52)	38.25 (4.01)
Height (cm)			
Grass	28.93 (4.27)	29.82 (2.51)	32.90 (2.09)
Shrub	61.27 (5.94)	56.48 (5.74)	44.00 (7.37)
Visual Obstruction	25.97 (3.81)	30.97 (2.71)	27.43 (3.02)
Nest Shrub (cm)			
Cover	121.00 (18.48)	116.78 (20.13)	NA
Height	85.89 (10.38)	79.00 (4.76)	NA

[1]Paired-Random plots were conducted at a 90-m distance from the Nest plot in a random cardinal direction.
[2]Random plots were conducted at random locations throughout the study area.

My sample size for all brood-rearing locations from weekly ground telemetry was $n = 13$ with an equal number of brood-rearing paired-random sites ($n = 13$). My sample size for random sites surveyed within 7 days of the brood-rearing-plot surveys was $n = 25$. Forb canopy cover was greater at brood-rearing sites than at random sites ($t_{25} = 2.36$, $P = 0.027$; Table 3-2). Conversely, forb canopy cover did not differ among brood-rearing and paired-random sites ($t_{12} = 1.60$, $P = 0.136$). Visual obstruction was lower at brood-rearing sites than at paired-random sites ($t_{12} = -2.25$, $P = 0.044$) but did not differ between brood-rearing and random sites ($t_{24} = 1.87$, $P = 0.074$). Percent cover of bare ground was not different between used and paired-random sites ($t_{12} = -0.68$, $P = 0.510$), but was significantly lower at used sites compared with random sites ($t_{23} = -2.38$, $P = 0.026$). I did not detect any other vegetation differences among brood-rearing and random plots. There was no difference among used and paired-random or random plots in percent

canopy cover of shrub for the transformed data ($t_{12} = -1.13$, $P = 0.283$ and $t_{35} = -0.60$,

$P = 0.554$, respectively) or grass ($t_{12} = -0.76$, $P = 0.463$ and $t_{35} = -0.84$, $P = 0.405$). No

difference was detected between brood-rearing and paired-random sites for mean

maximum height of grass ($t_{12} = -0.65$, $P = 0.529$) or shrub ($t_{12} = 0.67$, $P = 0.515$).

Similarly, I did not detect differences between brood-rearing and random sites for mean

maximum height of grass for the transformed data ($t_{34} = -1.15$, $P = 0.257$) or shrub ($t_{27} =$

1.20, $P = 0.240$; Table 3-2).

Brood-rearing sites were located in GRMX (7.69%), SAGE (7.69%), and SAMX

(53.85%) habitat types (Fig. 3-2). Differences among the relative frequencies of habitat

types were not detected between brood-rearing and paired-random sites using χ^2 analysis

($\chi^2 = 0.253$, df = 2, $P = 0.881$).

Table 3-2. Vegetation characteristics ($\bar{x} \pm$ SE) at brood-rearing sites compared with random sites in the Bald Hills, Utah greater sage-grouse population (2011 and 2012).

Variable	Brood-rearing ($n = 13$)	Paired-Random[1] ($n = 13$)	Random[2] ($n = 25$)
Cover (%)			
Shrub	28.08 (2.84)	42.01 (7.37)	32.35 (3.00)
Forb	16.86 (3.68)	11.70 (2.69)	9.45 (2.18)*
Grass	12.72 (1.51)	15.61 (2.80)	17.65 (2.61)
Bare Ground	24.08 (3.32)	28.57 (3.86)	35.02 (2.37)*
Height (cm)			
Grass	33.97 (2.09)	36.11 (2.94)	41.85 (3.49)
Shrub	52.92 (7.61)	50.14 (8.25)	43.90 (4.50)
Visual Obstruction	22.02 (2.44)	29.42 (2.46)*	16.89 (1.79)

*Value is significantly difference ($P \leq 0.05$) from brood-rearing value.
[1]Paired-Random plots were conducted at a 90-m distance from the Brood-rearing plot in a random cardinal direction.
[2]Random plots were conducted at random locations throughout the study area.
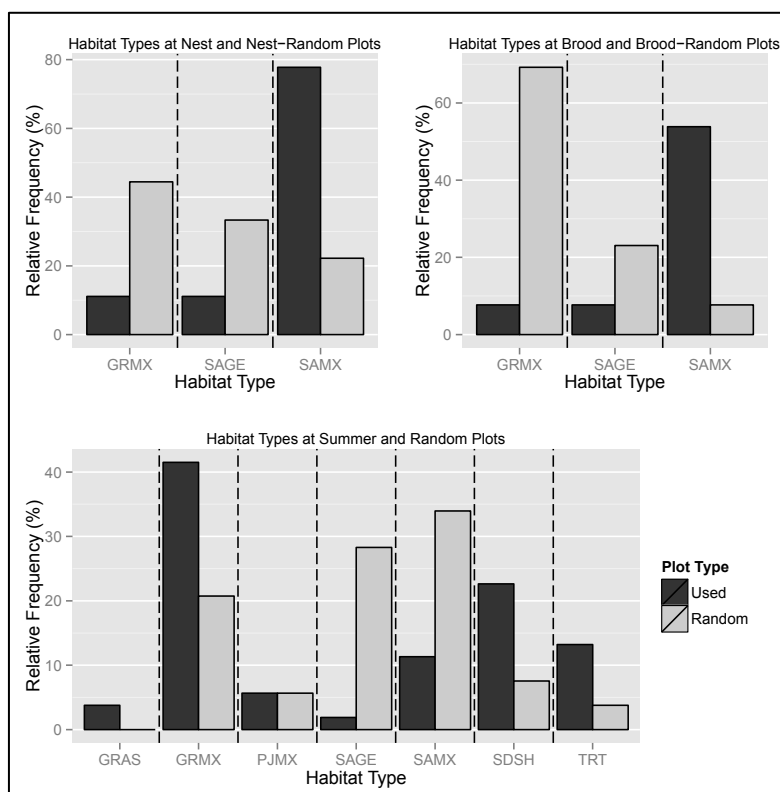
Figure 3-2. Relative frequency of plot habitat types[1] at all sites in the Bald Hills, Utah greater sage-grouse population (2011 and 2012).
[1]GRAS: grass, GRMX: grass mix, PJMX: pinyon-juniper mix, SAGE: sagebrush, SAMX: sagebrush mix, SDSH: salt-desert shrub, and TRT: post-fire rehabilitation treatment (Appendix Table A.2).

My sample size for summer plots surveyed from 7 June to 16 August 2011 and from 31 May to 14 August 2012 was $n = 53$ with an equal number of random plots ($n = 53$) surveyed. I detected differences in shrub canopy cover variances and distributions between summer and random sites (Table 3-3). Summer sites had smaller variance with a positively skewed distribution. Birds did not use shrub cover $\geq 35\%$ even though it was available and used $0 - 15\%$ shrub cover more than expected based on what was available (Fig. 3-3). I also detected differences between summer and random site distributions and variances for forb canopy cover (Table 3-3). The distribution of forb canopy cover in random plots shows that sites with $0 - 10\%$ forb canopy cover constitute the majority of

the landscape, with few sites containing greater quantities. Sage-grouse summer sites, however, are more evenly distributed from 0 – 50%. This suggests that birds use summer locations with ≥ 10% forb canopy cover more than would be expected and ≤ 10% less than what would be expected based on availability (Fig. 3-3). Grass canopy cover had no difference in variances between plot types but the distributions did vary between site types (Table 3-3). Birds did not use areas with 0 – 5% cover, which were available, and did use areas with 45 – 50% cover, which were not detected by the random plots (Fig. 3-3). Birds used areas with less bare ground (19.13% ± 1.72) as compared with random plots (31.85% ± 2.24). Mean maximum grass height had a different variance from random sites (Table 3-3) while the distributions did not vary. The violin plot shows that birds do not use extreme values (< 10% or > 60%) of available grass height in the study area (Fig. 3-3). I did not detect differences in the variances or distributions of shrub height or visual obstruction between used and random sites (Table 3-3).

Table 3-3. Vegetation characteristics at summer ($n = 53$) and random sites ($n = 53$) with comparisons of variable variances (F-test) and distributions (KS-test).

Variable	Summer	Random	F-test		KS-test	
	$\bar{x}$ (± 1 SE)		F	P	D	P
Cover (%)						
Shrub	9.21 (1.11)	18.17 (1.75)	0.40	0.001	0.45	≤ 0.001
Forb	16.19 (2.06)	6.28 (1.24)	2.76	≤ 0.001	0.43	≤ 0.001
Grass	21.71 (1.78)	15.25 (1.77)	1.01	0.960	0.28	0.029
Bare Ground	19.13 (1.72)	31.85 (2.24)	0.59	0.059	0.42	≤ 0.001
Height (cm)						
Grass	37.63 (1.62)	36.69 (2.33)	0.48	0.010	0.13	0.744
Shrub	40.02 (3.24)	44.70 (3.24)	1.00	0.997	0.21	0.204
Visual Obstruction	21.33 (0.92)	21.56 (1.13)	0.65	0.127	0.14	0.734
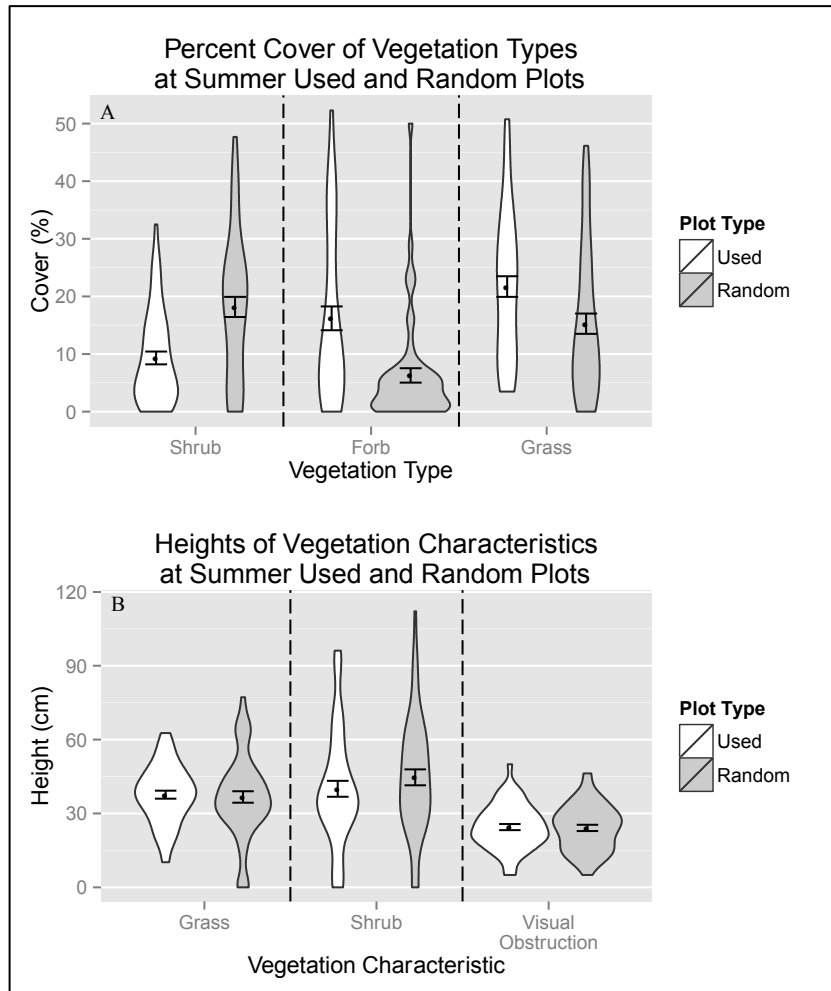
Figure 3-3. Mean, SE, and violin plot distributions of vegetation measurements for summer sites ($n = 53$) compared with random sites ($n = 53$).

Sage-grouse were found to use seven different habitat types during summer including: GRAS, GRMX, PJMX, SAGE, SAMX, SDSH, and TRT (Appendix Table A.2, Fig. 3-2). Using χ^2 analysis I detected differences in the distribution of habitat type frequencies among used and random plots ($\chi^2 = 30.69$, df $= 6$, $P \leq 0.001$). Further examination of the residuals revealed that this difference was caused by the greater frequency of SAGE habitat at random sites compared to used sites (residual $= [\pm]\ 2.47$). None of the residuals for the other habitat types were significant (> 1.96, at $\alpha = 0.05$).

I located 16 unique radio-collared birds (16.14% of all telemetry locations [$n =$ 508] during the time period that the summer plots were conducted) within private agricultural fields where I did not sample vegetation plots. Center pivot irrigation was used to grow alfalfa and corn at these sites. Dense forb habitat occurred at the pivot edges. Open water was available between planted rows, in the pivot wheel-wells, and in the drainage ditch associated with the pivot.

DISCUSSION

I quantified key habitat characteristics for the Bald Hills sage-grouse population at nest, brood-rearing, and summer locations. This was the first habitat assessment of a fringe population at the southern extent of the species distribution. I observed similar habitat use patterns at nest and brood-rearing sites. The overall trend of no differences among used and random sites could have multiple explanations including: 1) hens are selecting for measured habitat characteristics at a habitat-patch size other than 30-m^2, 2) hens are selecting for different habitat characteristics than the ones I measured, 3) hens are locating nest sites in the spring when the habitat is more uniform (predominantly snow and sagebrush) and then are limited by mobility to select for specific habitat characteristics post-hoc, during brood-rearing, 4) nest and brood habitat is uniformly distributed across the study area, or 5) birds are selecting nest and brood habitat at random. My results support the third explanation. Non-reproductive birds and brood-rearing hens are more mobile than nesting hens. Both non-reproductive birds and brood-rearing hens were found to select specific habitat characteristics from the available habitat. Non-reproductive birds selected for specific characteristics of the canopy cover of shrub (lower variance and different distribution), grass (different distribution), and

forb (higher variance and different distribution) as compared with random sites (Table 3-3, Fig. 3-3). Brood-rearing hens used habitats with greater forb canopy cover than expected when compared with random sites (Table 3-2). Multiple studies have shown that hens move towards mesic sites during brood-rearing for increased quantity and diversity of forb understory. Mobility of brood-rearing hens increases as the season progresses, allowing for greater habitat selection capability (Connelly et al. 2000b, Crawford et al. 2004, Rhodes et al. 2010). Birds in this population therefore have the capacity, along with other populations, to use their mobility to select for specific habitat attributes. If nesting hens were mobile, it is likely that they would also select for specific habitat characteristics as they changed with the seasonal progression.

Habitat characteristics used by reproductive hens differed from the Connelly et al. (2000b) guidelines for productive sage-grouse habitat at arid sites. Canopy cover of forbs (4.74%) and grasses (13.23%) at nest sites were lower than the reported guidelines (≥15% for both) while shrub canopy cover (36%) exceeded the reported guidelines (15-25%). At brood-rearing sites the canopy cover of grass (12.72%) was lower than the reported guidelines (≥15%) and shrub canopy cover (28.08%) exceeded the reported guidelines (10-25%). Grass height was reported as "variable" for brood-rearing habitat (Connelly et al. 2000b). In both nest and brood-rearing habitat shrub canopy cover was greater than recommended habitat while canopy cover of grass and forb was less than recommended habitat (canopy cover for forbs at brood-rearing locations was within the limits but at the low-end). Both nesting and brood-rearing hens used sites with less bare ground than random sites throughout the study area, suggesting that they are using areas with more cover (Table 3-1, Table 3-2).

At summer used sites the canopy cover of grass and forbs were within recommended values for productive habitat while the canopy cover of grass and forbs at summer random sites were lower than the recommended values. Summer habitat use included lower shrub and bare ground cover and higher forb and grass cover as compared with random sites. This suggests that the Bald Hills birds are selecting for higher quality summer habitat (more grass and forb understory) from the available habitat within the study area, where lower quality habitat is available (lower grass and forb understory). Overall, this suggests that this population occupies marginal or, according to Connelly et al. 2000b, unproductive sage-grouse habitat. This could explain the local adaptation of using agricultural fields for summer habitat in the absence of productive sage-grouse habitat throughout the study area. Agricultural fields may be providing a forb-rich habitat that is lacking in the native landscape during this time of year. Large seasonal home ranges in this population further suggest that the habitat is marginal; forcing birds to use a greater area in order to acquire all of their resources (see A. C. Burnett, Chapter 2).

It is not surprising that the habitat characteristics of this southern fringe population differed from the range-wide guidelines because habitat characteristics in other fringe populations differed from these guidelines as well (Connelly et al. 2000b, Aldridge and Brigham 2002, Kolada et al. 2009). Kolada et al. (2009) found that hens in a western fringe population selected nest sites with greater shrub cover then in other populations. Conversely, Aldridge and Brigham (2002) found that hens in a northern fringe population selected nest sites with less shrub cover than in other populations.

The relatively high percent cover of shrubs and bare ground with low percent cover of grass and forbs at nest, brood-rearing, and summer random sites may be indicative of the ecosystem dynamics in the Bald Hills. West and Young (2000) classified the Bald Hills area as Great Basin sagebrush, which is notably different from Sagebrush-steppe ecosystems. Great Basin sagebrush is characterized by desert shrub, sagebrush semi-desert, and woodland vegetation, which are similar attributes found in this study (Appendix Table A.2, Natural Resources Conservation Service [NRCS] 2012, West and Young 2000). Conversely, Sagebrush-steppe habitats are characterized by mountain shrub and sagebrush-grass vegetation, which are similar attributes found in non-fringe population habitat studies as well as some areas in the Bald Hills study area (Appendix Table A.2, NRCS 2012, West 2000). This may explain why the habitat characteristics of the Bald Hills population fall short of recommended guidelines for productive sage-grouse habitat; the ecosystem is inherently different from sagebrush-steppe habitats that large density sage-grouse populations occupy (Connelly et al. 2000b).

According to the Ecological Site Descriptions published by the Natural Resources Conservation Service (NRCS), the Bald Hills study area is within the Great Salt Lake Major Land Resource Area (MLRA) on the edge of the Wasatch Mountains South MLRA's semi-desert habitat which is comparable to arid sagebrush-steppe habitat (NRCS 2012). This could explain alternative or concurrent ecosystem effects occurring in the region. When stagnant sagebrush becomes dense and competitive, it can prevent perennial grasses and forbs from growing (West 2000). The high relative frequency of SAGE habitat (sagebrush dominated habitat with lack of understory) at random sites compared to used summer habitats provides evidence that this is occurring in the Bald

Hills (Fig. 3-2). While sagebrush is important, sage-grouse also rely on grass and forb understory for concealment and food. According to the West (2000) state and transition models of successional change in sagebrush steppe habitats, the Bald Hills habitat is consistent with Stage III (depauperate late seral sagebrush steppe) and Stage V (brush with only introduced annuals in understory) classification. In comparison, the guidelines for productive sage-grouse habitats describe sagebrush steppe systems that more closely resemble Stage II (late seral sagebrush steppe) and Stage III habitat (Connelly et al. 2000b). This distinction is important because the transition from Stage III to Stage IV represents a threshold by which managers' ability to restore habitat from Stage IV back to Stage III is questionable. It will be important to prevent conversion of habitat patches into Stage IV in the Bald Hills for the maintenance of viable habitat for sage-grouse as well as a suite of other sagebrush-obligate species (West 2000, Connelly et al. 2004, Rowland et al. 2006).

While the Bald Hills habitat would not be classified as productive sage-grouse habitat (Connelly et al. 2000b), data on the productivity of the Bald Hills sage-grouse population is lacking. Data on the reproductive success of this population at different stages (nesting, brood-rearing) will help distinguish if the marginal habitat conditions are limiting sage-grouse productivity or if the local population has adapted to local conditions and is stable or growing. If productivity is not sufficient to maintain a stable or increasing population then local habitat should be managed towards meeting sage-grouse habitat recommendations. Management goals would be to increase productivity and the likelihood of population persistence (Connelly et al. 2000b, Aldridge and Brigham 2002, UDWR 2009). If productivity is sufficient to maintain a stable or increasing population

then the population has likely adapted to local conditions and management should target the maintenance of and increased availability of habitat characteristics similar to what the grouse are using (Connelly et al. 2000b, Kolada et al. 2009, UDWR 2009). Gathering information about the reproductive success of this population may also help determine if seasonal carry-over effects are impacting this populations' productivity (Haramis et al. 1986, Saino et al. 2004, Norris 2005).

MANAGEMENT IMPLICATIONS

This study provides additional support to the mounting evidence that fringe sage-grouse populations use different habitat characteristics than non-fringe populations. Fringe populations that have adapted to marginal habitat conditions may indicate early stages of speciation. These populations would therefore provide important intra-species diversity, an important consideration for species in decline. Local variations are important and merit local management techniques and goals.

Local management techniques in southern Utah need to reflect current habitat use patterns as well as improved habitat if possible. At a minimum, grazing regimes, fire management, and habitat treatment techniques should be utilized to maintain habitat characteristics used by sage-grouse, indicated by this study. Traditional habitat treatments used for sage-grouse in mesic sagebrush-steppe habitats will not be applicable here (Beck et al. 2012). Management tools must reflect the arid and semi-arid nature of the ecosystem when employing management techniques. Wisdom and Chambers (2009) proposed a stepwise procedure to manage Great Basin shrub ecosystems that would benefit native vegetation that supports sage-grouse. This procedure helps mitigate the impacts of invasive annual grasses and woodland expansion to preserve sagebrush

resistance and resilience. Managers should also employ techniques to increase other types of understory such as native forbs and grasses, where possible given the sensitivity of arid ecosystems (Beck et al. 2012, West 2000, and Wisdom and Chambers 2009). This would include managing to maintain current Stage III habitat patches with the goal of moving towards Stage II, rather than Stage IV successional habitats (West 2000). This will result in increased availability of grasses and forbs on the landscape.

Agricultural fields in the Minersville area should be recognized as critical summer and brood-rearing habitat. Relying on agricultural fields can be problematic however because of the direct mortality threat from haying, mowing, or baling; exemplified by a hen and her brood that were killed by a baler in June 2012. In addition, any small disturbances to this habitat would have significant impacts on the large proportion of the Bald Hills population utilizing the small area of habitat. Management goals should focus on supporting sage-grouse in native habitats. I recommend that habitat patches adjacent to the agricultural fields be managed for wet meadow habitat to deter birds from inhabiting the agricultural fields while accommodating established migration patterns (A. C. Burnett Chapter 2). I also recommend establishing wet meadow habitat near current nesting habitat to decrease the need for reproductive birds to migrate long-distances to find suitable brood-rearing habitat (A. C. Burnett Chapter 2). Wet meadow habitats could be established using overflow water from well tanks for cattle dispersed throughout the study area.

Further management implications for the nest and brood-rearing habitat data will depend on the productivity of this population. If sage-grouse in the Bald Hills have high reproductive success, then management should focus on maintaining or increasing the

availability of habitat characteristics used by the birds. Conversely, if reproductive success is not sufficient to maintain the Bald Hills population, management should focus on greater increases in the abundance and availability of grass and forb cover (Stage II habitat).

LITERATURE CITED

Aldridge, C., and R. M. Brigham. 2002. Sage-grouse nesting and brood habitat use in southern Canada. The Journal of Wildlife Management 66:433-444.

Aldridge, C., R. Lee, P. Jones, and J. Nicholson. 2004. Winter habitat selection and survival by sage-grouse in southeastern Alberta. Final Project Report for 2003-2004 Sage-Grouse Funding Partners. Fort Collins, Colorado, USA.

Aldridge, C., S. E. Nielsen, H. L. Beyer, M. S. Boyce, J. W. Connelly, S. T. Knick, and M. A. Schroeder. 2008. Range-wide patterns of greater sage-grouse persistence. Diversity and Distributions 14:983-994.

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

Beck, J. L., J. W. Connelly, and C. L. Wambolt. 2012. Consequences of treating wyoming big sagebrush to enhance wildlife habitats. Rangeland Ecology and Management 65:444-455.

Beck, T. D. I. 1977. Sage grouse flock characteristics and habitat selection in winter. The Journal of Wildlife Management 41:18-26.

Black and Veatch Corporation. 2010. Utah renewable energy zone (UREZ) task force, phase 2; zone identification and scenario analysis. Utah Office of Energy Development. Salt Lake City, Utah, USA.

Bureau of Land Management [BLM]. 2011. The BLM's balancing act: Managing the needs of people and sage-grouse on public lands. <http://www.blm.gov/wo/st/en/prog/more/fish__wildlife_and/sage-grouse-conservation/energy.html> accessed 8/10/2012.

Brown, D. E., C. H. Lowe, and C. P. Pase. 1979. A digitized classification system for the biotic communities of North America, with community (series) and association examples for the southwest. Journal of the Arizona-Nevada Academy of Science 14:1-16.

Bunnell, K. D., J. T. Flinders, D. L. Mitchell, and J. H. Warder. 2004. Occupied and unoccupied sage grouse habitat in Strawberry Valley, Utah. Rangeland Ecology & Management 57:524-531.

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

Carbonell, R., J. Perez-Tris, and J. L. Telleria. 2003. Effects of habitat heterogeneity and local adaptation on the body condition of a forest passerine at the edge of its distributional range. Biological Journal of the Linnean Society 78:479-488.

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

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

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

Connelly, J. W., and C. E. Braun. 1997. Long-term changes in sage grouse *Centrocercus Urophasianus* populations in western North America. Wildlife Biology 3:229-234.

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

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

Connelly, J. W., W. L. Wakkinen, A. D. Apa, and K. P. Reese. 1991. Sage grouse use of nest sites in southeastern Idaho. Journal of Wildlife Management 55:521-524.

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

Crawford, J. A., R. A. Olson, N. E. West, J. C. Mosley, M. A. Schroeder, T. D. Whitson, R. F. Miller, M. A. Gregg, and C. S. Boyd. 2004. Ecology and management of sage-grouse and sage-grouse habitat. Rangeland Ecology & Management 57:2-19.

Dahlgren, D. K., R. Chi, and T. A. Messmer. 2006. Greater sage-grouse response to

sagebrush management in Utah. Wildlife Society Bulletin 34:975-985.

Daubenmire, R. 1959. A canopy-coverage method of vegetational analysis. Northwest

Science 50:431.

Doherty Jr., P. F., T. Boulinier, and J. D. Nichols. 2003. Local extinction and turnover

rates at the edge and interior of a species' range. Finnish Zoological and Botanical

Publishing Board 40:145-153.

Doherty, K. E., D. E. Naugle, and B. L. Walker. 2010. Greater sage-grouse nesting

habitat: The importance of managing at multiple scales. The Journal of Wildlife

Management 74:1544-1553.

Dunn, P. O., and C. E. Braun. 1986. Summer habitat use by adult female and juvenile

sage grouse. The Journal of Wildlife Management 50:228-235.

Eng, R. L. 1955. A method for obtaining sage grouse age and sex ratios from wings. The

Journal of Wildlife Management 19:267-272.

Fischer, R. A., K. P. Reese, and J. W. Connelly. 1996. Influence of vegetal moisture

content and nest fate on timing of female sage grouse migration. The Condor

98:868-872.

Haak, A. L., J. E. Williams, H. M. Neville, D. C. Dauwalter, and W. T. Colyer. 2010.

Conserving peripheral trout populations: the values and risks of life on the edge.

Fisheries 35:530-549.

Haramis, G. M., J. D. Nichols, K. H. Pollock, and J. E. Hines. 1986. The relationship

between body mass and survival of wintering canvasbacks. The Auk 103:506-

514.

Hintze, J. L., and R. D. Nelson. 1998. Violin plots: a box plot-density trace synergism. The American Statistician 52:181-184.

Holloran, M. J. 1999. Sage grouse (*Centrocercus Urophasianus*) seasonal habitat use near Casper, Wyoming. Thesis. University of Wyoming. Laramie, Wyoming, USA.

Holloran, M. J., and S. H. Anderson. 2005. Spatial distribution of greater sage-grouse nests in relatively contiguous sagebrush habitats. The Condor 107:742-752.

Klebenow, D. A. 1969. Sage grouse nesting and brood habitat in Idaho. The Journal of Wildlife Management 33:649-662.

Kolada, E. J., J. S. Sedinger, and M. L. Casazza. 2009. Nest site selection by greater sage-grouse in Mono County, California. Journal of Wildlife Management 73:1333-1340.

Lesica, P., and F. W. Allendorf. 1995. When are peripheral populations valuable for conservation? Conservation Biology 9:753-760.

Moynahan, B. J., M. S. Lindberg, and J. W. Thomas. 2006. Factors contributing to process variance in annual survival of female greater sage-grouse in Montana. Ecological Applications 16:1529-1538.

Natural Resources Conservation Service [NRCS]. 2012. Ecological Site Descriptions. <http://www.ut.nrcs.usda.gov/technical/technology/range/ecosites.html> accessed 12/2/2012.

Norris, D. R. 2005. Carry-over effects and habitat quality in migratory populations. Oikos 109:178-186.

Oyler-McCance, S. J., and P. L. Leberg. 2005. Conservation genetics in wildlife

    biology. Sixth edition. Pages 632-657 *in* C. E. Braun, editor. Techniques for

    wildlife investigations and management. The Wildlife Society, Bethesda,

    Maryland, USA.

Palmer, W. E., and S. D. Wellendorf. 2007. Effect of radiotransmitters on northern

    bobwhite annual survival. The Journal of Wildlife Management 71:1281-1287.

Patterson, R. L. 1952. The sage grouse in wyoming. Denver, Colorado, USA.

Rhodes, E. C., J. D. Bates, R. N. Sharp, and K. W. Davies. 2010. Fire effects on cover

    and dietary resources of sage-grouse habitat. Journal of Wildlife Management

    74:755-764.

Robel, R., J. Briggs, A. Dayton, and L. Hulbert. 1970. Relationships between visual

    obstruction measurements and weight of grassland vegetation. Journal of Range

    Management 23:295-297.

Rowland, M. M., M. J. Wisdom, L. H. Suring, and C. W. Meinke. 2006. Greater sage-

    grouse as an umbrella species for sagebrush-associated vertebrates. Biological

    Conservation 129:323-335.

Saino, N., T. Szep, R. Ambrosini, M. Romano, and A. P. Moller. 2004. Ecological

    conditions during winter affect sexual selection and breeding in a migratory bird.

    Proceedings of the Royal Society of London. Series B: Biological Sciences

    271:681-686.

Schroeder, M. A. 1997. Unusually high reproductive effort by sage grouse in a

    fragmented habitat in north-central Washington. The Condor 99:933-941.

Schroeder, M. A., J. R. Young, and C. E. Braun. 1999. Greater sage-grouse (*Centrocercus urophasianus*), the birds of North America Online (A. Poole, Ed.). Ithaca: Cornell Lab of Ornithology; Retrieved from the Birds of North America Online: http://bna.birds.cornell.edu/bna/species/425. Accessed 12 Oct 2012.

Sveum, C. M., W. D. Edge, and J. A. Crawford. 1998. Nesting habitat selection by sage grouse in south-central washington. Journal of Range Management 51:265-269.

U. S. Fish and Wildlife Service, Interior [USFWS]. 2010. Endangered and threatened wildlife and plants; 12-month findings for petitions to list the greater sage-grouse (*Centrocercus Urophasianus*) as threatened or endangered. 50 CFR Part 17. Department of the Interior; Federal Register, Washington D.C., USA.

Utah Division of Wildlife Resources [UDWR]. 2009. Utah greater sage-grouse management plan. Utah Department of Natural Resources, Division of Wildlife Resources Publication 09-17, Salt Lake City, Utah, USA.

Utah Division of Wildlife Resources [UDWR]. 2010. Utah Automated Geographic Reference Center [AGRC]. Spatial data for Utah, USA. <http://gis.utah.gov>. Accessed 2 April 2012.

Wakkinen, W. L. 1990. Nest site characteristics and spring-summer movements of migratory sage grouse in southeastern idaho.

Wallestad, R. 1975. Male sage grouse responses to sagebrush treatment. The Journal of Wildlife Management 39:482-484.

Wallestad, R. O. 1971. Summer movements and habitat use by sage grouse broods in central Montana. The Journal of Wildlife Management 35:129-136.

West, N. E. 2000. Synecology and disturbance regimes of sagebrush steppe ecosystems. *In* proceedings of the sagebrush steppe ecosystems symposium. Biose State University, Boise, Idaho, USA.

West, N.E., and J.A. Young. 2000. Ch. 7 (Intermountain Valleys and Lower Mountain Slopes). *In* M.G. Barbour and W.D. Billings, editors. North American terrestrial vegetation. 2nd Ed. Cambridge University Press, Cambridge, UK.

Western Regional Climate Center [WRCC]. 2012. Utah climate summaries. <http://www.Wrcc.Dri.Edu>. Accessed 20 November 2012.

Wisdom, M. J., M. M. Rowland, L. H. Suring, D. S. Dobkin, and B. Abbey. 2005. Habitat threats in the sagebrush ecosystem: Methods of regional assessment and applications in the great basin. Alliance Communications Group, Lawrence, Kansas, USA.

Wisdom, M. J., and J. C. Chambers. 2009. A landscape approach for ecologically based management of Great Basin shrublands. Restoration Ecology 17:740-749.

Young, J. R., C. E. Braun, S. J. Oyler-McCance, J. W. Hupp, and T. W. Quinn. 2000. A new species of sage-grouse (phasianidae: *Centrocercus*) from southwestern Colorado. The Wilson Bulletin 112:445-453.

CHAPTER 4

SPECIES DISTRIBUTION MODELING OF A FRINGE GREATER SAGE-GROUSE

POPULATION USING MAXENT

ABSTRACT Range-wide declines in greater sage-grouse (*Centrocercus urophasianus;* hereafter sage-grouse) populations have prompted extensive research on sage-grouse habitat use. Basic information about habitat use in southern periphery populations, such as in southern Utah, is still unknown. I developed seasonal distribution models (Nest, Brood, Summer, Winter) to predict and map the habitat use and potential distribution of sage-grouse in a southern periphery population using Maximum Entropy (MaxEnt) software. I developed the models using telemetry data collected in 2011 and 2012 from the Bald Hills, Utah population and projected the models to the Bureau of Land Management Cedar City Field Office (CCFO) area, which encompasses the Bald Hills population. Independently collected data from another population within the CCFO was used to assess similarities between the Bald Hills population and this other population in southern Utah. Nine predictor variables were examined including elevation, slope, aspect, landcover (major vegetation cover types), distance to nearest lek, distance to nearest road (high speed and low speed roads), distance to energy infrastructure, and local habitat treatments (wildfire, controlled broadcast burn, crushing, lop and scatter, mastication/mowing, seeding, thinning, or other) that occurred since 1992. All models produced excellent model fit (AUC > 0.900) for the telemetry data. The Nest model predicted where nest presences were located from the independently collected data, implying that hens in the Bald Hills population select for similar landscape-scale nest habitat characteristics as other populations within the CCFO. Landcover and distance to

lek were the top predictors in the Nest model. Elevation and habitat treatment were the

top predictors of the Brood model. The importance of habitat treatment may have caused

a lower predictive ability of this model within the CCFO because local management data

and was unavailable for the entire CCFO. The Summer model did not predict most

presence locations from the independently collected data, potentially indicating differing

landscape-scale habitat use patterns between populations within the CCFO. Distance to

lek and elevation were major predictors of summer habitat for the Bald Hills telemetry

data. The Winter model was able to predict winter habitat locations in other populations.

Major predictors for winter habitat were distance to active lek, distance to high speed

roads, and landcover. Predictive maps can be used to guide bird surveys, identify

potential habitat, identify similarities and differences between different populations, and

detect unidentified areas that may be occupied by the species of interest.

Greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse)

population declines and range contraction have been attributed to the loss of both quality

and quantity of sagebrush-steppe habitats in the western United States (Connelly and

Braun 1997, Schroeder et al.1999, Aldridge et al. 2008). While habitat quantity is

difficult to manage with continued infrastructure development, agricultural conversion,

and human encroachment, habitat quality (composition, connectivity, lack of disturbance)

can often be improved via management techniques (Dahlgren et al. 2006, Doherty et al.

2010, Bureau of Land Management [BLM] 2011, U S. Fish and Wildlife Service, Interior

[USFWS] 2010). Habitat quality can have direct impacts on sage-grouse productivity by

affecting nest success, brood success, and adult survival (Sveum et al. 1998, Aldridge et

al. 2004, Moynahan et al. 2006, Coates and Delehanty 2010). Declines in sage-grouse

productivity have led to the large-scale population declines over the past 30 years

(Connelly and Braun 1997). Understanding, maintaining, and restoring quality habitat at

a landscape scale is therefore a primary issue for sage-grouse conservation and

management (Connelly et al. 2000, Crawford et al. 2004, Utah Division of Wildlife

Resources [UDWR] 2009, USFWS 2010).

Fringe populations are those located at the geographic periphery of a species

range (Lesica and Allendorf 1995). Fisher (2011) predicted that declining species will

survive longer near the center of their range based on the premise that extinction rates are

highest at the periphery due to suboptimal habitat. Fringe populations often utilize

marginal habitats, which can lead to decreased success, unique adaptations to these

marginal habitats, and geographic isolation (Lesica and Allendorf 1995, Carbonell et al.

2003, Doherty et al. 2003, Haak et al. 2010). This is of consequence because unique

adaptations in small isolated populations can lead to genetic variation. Genetic variation

provides the population with phenotypic diversity, an integral consideration for the

recovery of declining species (Young et al. 2000, Oyler-McCance and Leberg 2005). The

Bald Hills sage-grouse population in southwestern Utah is a geographically isolated

peripheral population at the southern edge of the species range, and may exhibit these

fringe population attributes (see A. C. Burnett Chapter 2 and Chapter 3; Fig. 3-1; UDWR

2009).

A recent approach in examining landscape-scale habitat use in declining

populations is predicting and mapping species distributions (Elith et al. 2006, Aldridge

and Boyce 2007, Yost et al. 2008, Atamian et al. 2010). Species Distribution Modeling

(SDM) relates species-presence data to environmental variables in order to produce predictions of a species distribution as it relates to suitable habitat. The principle of SDM are based in ecological niche theory and habitat gradient analysis, given the assumption that species distributions can be predicted from the distributions of environmental variables that limit species occurrence (Soberón 2007, Yost et al. 2008). SDM is useful as a tool to project these predictive models into time (i.e. temporal forecast as it relates to climate change) or space (i.e. rediscovering species in areas that were not identified via telemetry; Fisher 2011, Schrag et al. 2011). SDMs have been used to model populations of various sizes, from continental distributions to small endemic populations (Franklin 2011).

Machine-learning methods have becoming increasingly useful for biologists to create and use SDMs (Franklin 2011). Maximum Entropy (Maxent; Version 3.3.3k, www.cs.princeton.edu/~schapire/maxent/, accessed 1 Oct 2012) has emerged as a popular machine-learning tool for modeling and mapping distribution predictions from incomplete information (Phillips et al. 2006, Yost et al. 2008, Franklin 2011). Maxent involves 3 main steps, starting with data collection (Yost et al. 2008). It is often difficult to obtain true absence data (locations that are available to, but not used by the target species), particularly with radio-telemetry studies (method of species presence data collection). Maxent is ideal for telemetry data because it uses presence-only data (collected with randomized sampling design) and randomly generates pseudo-absence (or background) data points of non-occurrences within the model extents to extract attribute data from the predictive landscape-scale variables (Phillips et al. 2006, Yost et al. 2008). The next step is selecting predictor variables and building the models. Maxent is capable

of incorporating linear, quadratic, product, and hinge functions for both continuous and categorical predictor variables (Phillips et al. 2006, Wisz et al. 2008, Smith 2012). The final step is to evaluate the models and project the data spatially or temporally. A good model fit will maximize sensitivity (proportion of actual presences that are accurately predicted) and specificity (proportion of actual absences that are accurately predicted; Franklin 2011, Smith 2012). Visual inspection is also useful when comparing model output with presence records. Visual assessment of model predictive ability depends on the question being asked. For example, the output would be interpreted differently if the goal is to "rediscover" species (want high threshold of what is predicted as suitable habitat to direct field surveys) as compared to the translocation of species (want low threshold of what is predicted as suitable habitat to ensure translocation success; Ikeda 2010, Fisher 2011). Variable contribution is estimated by Maxent using a jackknife test of variable importance by running the model with each variable in isolation and again with all variables excluding that one. The jackknife results are compared with the overall model predictability in the Maxent output (Pearson et al. 2007, Smith 2012). Several studies indicate that Maxent outperforms other presence-only species distribution modeling methods, especially when sample sizes are small (Elith et al. 2006, Phillips et al. 2006, Pearson et al. 2007, Phillips and Dudík 2008, Wisz et al. 2008, Yost et al. 2008, Baldwin 2009).

The goal of this study was to develop SDMs for a southern fringe sage-grouse population using Maxent. Separate models were developed based on biological seasons including nesting, brood-rearing, summer non-reproductive adults (hens that did not reproduce successfully that year and males), and winter. Models were developed with

radio-telemetry presence locations collected in the Bald Hills study area. These models

were projected to the Bureau of Land Management Cedar City Field Office(CCFO) with

the purpose of assisting local management agencies in identifying potentially un-

documented sage-grouse locations, identifying landscape-scale variables that influence

sage-grouse distributions, and determining if this fringe population occupies areas with

unique habitat characteristics as compared with other sage-grouse populations.

STUDY AREA

Located primarily on public land managed by the Bureau of Land Management

(BLM), the Bald Hills study area was delineated from the boundaries of the UDWR 2010

sage-grouse suitable brood-rearing habitat map (UDWR 2010). This area was designated

with the purpose of tracking birds radio-collared from the known leks (breeding areas)

encompassed by the area. Birds collared within the study area were tracked both inside

and outside of the original designated study area (Fig. 2-2).

The study area (1,250 km^2) covered portions of Iron and Beaver counties in Utah.

The southern edge of the study area was located 20 km north of Cedar City, and the

northeast corner was located 3 km south of Beaver (Fig. 2-2). State highway 130

(hereafter, HWY 130) bisected the study area from Cedar City to Minersville and

Interstate 15 from Cedar City to Beaver was east of the study area. The majority of the

study area was public land managed by the BLM (968 km^2), with some private (170 km^2)

and State Trust Lands (112 km^2; UDWR 2010). The elevation ranged from 1550 m to

2400 m. Average annual precipitation in Minersville (within low elevation portion of

study area) was 28.96 cm (11.4 in) (from 1948-2005) with mean annual total snowfall of

48.01 cm (18.9 in; Western Regional Climate Center [WRCC] 2012). Habitat types were

diverse yet characterized by Great Basin sagebrush (more arid and southerly as compared with sagebrush steppe; West and Young 2000), juniper forest, salt-desert shrub, and disturbed areas with invasive cheatgrass (*Bromus tectorum*), and annual mustard (*Brassicaceae* fam.). Dominant sagebrush species included mountain big sagebrush (*Artemisia tridentate vaseyana*) at high elevations, Wyoming big sagebrush (*Artemisia tridentata wyomingensis*) at intermediate elevations and overlapping with the other two species, and black sagebrush (*Artemisia nova*) at low elevations. During spring and summer, cattle and sheep grazing was common throughout the study area. Crop agriculture (primarily alfalfa and corn) was common in the northwest portion. The northeast portion had been re-seeded twice with a native and non-native mix of perennial grasses, forbs, and shrubs after the Greenville Bench wildfire (July 2007, 15.98 km^2; C.S. Pontarolo, Bureau of Land Management, unpublished data; Appendix Table A.1). The Wrangler (7 Aug 2011, 34.21 km^2) and Baboon (25 Jul 2012, 80.04 km^2) wildfires occurred during the study but did not burn areas where radio-collared sage-grouse were being tracked at those times (C.S. Pontarolo, Bureau of Land Management, unpublished data).

Eleven known leks (Horseshoe Flat, Jackrabbit, Little Horse Valley, Lost Spring, Minersville, Mud Springs, Parowan Gap, Poorman Flat, Poorman Jeff, Poorman Ridge, and Upper Long Hollow) were within the study area (Fig. 2-2). Of the 3 leks that were impacted by the Greenville Bench wildfire (Poorman Flat, Poorman Jeff, and Poorman Ridge) only the Poorman Jeff lek was active during this study. The Lost Spring lek was also inactive in 2011 and 2012. Two possible new leks were identified during the study period: Little Horse Valley (2012) and Upper Long Hollow (2011).

Figure 4-1. Bald Hills study area in southwestern Utah with dominant vegetation types and sage-grouse occupied habitat designated by the UDWR (UDWR 2010). The 1,250 km^2 area encompassed 11 known leks.

METHODS

Presence Data

I captured sage-grouse in 2011 and 2012 using spotlighting techniques on roosts surrounding 8 leks in the study area (Horseshoe Flat, Jackrabbit, Little Horse Valley, Minersville, Mud Springs, Parowan Gap, Poorman Jeff, and Upper Long Hollow; (Wakkinen 1990). My goal was to capture 60 sage-grouse over the study duration with a minimum of 40% hens and at least 2 birds from each active lek. For all captured birds, I weighed, collected a feather, and noted age class (sub-adult and adult) and sex (Eng 1955). All birds captured in 2011 were fitted with 24-g necklace VHF transmitters with

an 8-hr mortality switch (model A4060; Advanced Telemetry Systems, Isanti, MN).

Sage-grouse captured in 2012 were fitted with 19-g necklace VHF transmitters with an 8-

hr mortality switch (model A4050; Advanced Telemetry Systems, Isanti, MN). Larger

collars were used in 2011 to ensure battery life throughout the study duration. All capture

and handling procedures were approved through the Utah State University Institutional

Animal Care and Use Committee (Protocol #1322) and Certificate of Registration for

Banding, Collection, Depredation, and/or Salvage from the UDWR (R657-3). Prior to

this study, 15 male sage-grouse were radio-collared in 2010 by BLM personnel using the

same techniques and equipment as the 2011 capture operations; 9 of these birds were still

alive during my study and thus I incorporated them into my research. I assumed that the

radio-collared birds were a representative sample of the population and that the capture

event and transmitter attachment did not alter radio-collared bird behavior (Palmer and

Wellendorf 2007).

During the spring (Mar through May), summer (Jun through Aug), and fall (Sep

through Nov) I attempted to locate and flush each bird one time per week via VHF

ground telemetry (Beck et al. 2006). During nesting and brood-rearing (Apr through Aug)

I located nesting and brood-rearing hens without flushing them (Schroeder 1997). At

every ground telemetry location I recorded the bird identity, number of birds in the group,

habitat type (UDWR 2010), Global Positioning System (GPS) location, date, time, and

elevation (m). All Universal Transverse Mercator (UTM) coordinates were collected

using a handheld GPS with <5 m error (model eTrex Venture HC, Garmin International,

Inc., Olathe, KS). As weather permitted, I located missing birds via aerial telemetry using

a fixed-wing aircraft one time per month year-round. Flight locations were used to assist

with ground telemetry and were not used for analysis. This provided the potential to locate missing birds both within and outside of the study area.

I separated all of the telemetry presence locations (hereafter presence locations) into their respective seasons, excluding major migratory periods (see A.C. Burnett Chapter 2). Seasons included "Nest" (all nest locations) "Brood" (all brood-rearing locations), "Summer" (all non-reproductive adult locations from 1 Jun through 7 Oct), and "Winter" (all locations from 13 Nov through 9 Mar). Nest and Brood locations were excluded from the Summer model because nesting and brood-rearing hens may not select for the same landscape variables as non-reproductive adults (Crawford et al. 2004). I also modeled and reported Nest and Brood habitat separately due to differing habitat attributes associated with these reproductive phases (Connelly et al. 2000, Aldridge and Boyce 2007). By dividing Nest and Brood into separate models, I decreased my sample sizes for modeling reproductive hen habitat. Maxent is fairly insensitive to small sample sizes and has been shown to produce models with statistical significance when using sample sizes as small as 5 (Hernandez et al. 2006, Pearson et al. 2007, Wisz et al. 2008). With small sample sizes biologists must be cautious with model interpretation; however, these models can still be of great value. For example, these models can identify areas with similar environmental conditions as where the species was found to occur as well as target regions for field surveys (Pearson et al. 2007, Anderson and Raza 2010).

Model Extents

The original study area did not encompass all of the presence locations (see A.C. Burnett Chapter 2, UDWR 2010). Using Maxent, the training model needed to encompass all of the presence locations in order to extract habitat variable data for all of

the presence locations. I therefore needed to revise the study area extents. Small study

areas can be problematic for two reasons. If the study area is too small, the model will not

be able to differentiate between presence and background habitat types (Barbet-Massin et

al. 2012). Further, some habitat values in the projected area (BLM CCFO) may not be

represented in a small original study area, potentially leading to a truncated response

curve for those variables (Anderson and Raza 2010). Study areas that are too large can

also be problematic. If the environmental variables are too different between the study

area and the projected area then the model will not be informative because it will be over-

fit (Anderson and Raza 2010, Barbet-Massin et al. 2012). While the importance of study

area extent is crucial to a model's predictive ability, many studies choose arbitrary

extents and do not report on their decision process (Yost et al. 2008, Freese 2009, Schrag

et al. 2011). For example, Anderson and Raza (2010) vaguely reported that the study area

should be "immediately surrounding known localities".

For the Bald Hills sage-grouse population the study area needed to encompass all

of the presence locations. The furthest telemetry location from the study area boundary

was 2.5 km (see A.C. Burnett Chapter 2, UDWR 2010). The original study area was

relevant for management purposes because it was based on the UDWR sage-grouse

habitat maps (UDWR 2010). Using the guideline that the study area should surround all

presence locations, I placed a 5-km buffer around the original study area to create the

training model extents (2,240 km^2; Anderson and Raza 2010). The 5-km buffer was

chosen because it was double the distance of the furthest telemetry location from the

original study area, ensuring that the new study area would encompass an area of at least

2.5 km surrounding all telemetry locations.

Predictor Variables

Landscape-scale habitat variables were chosen *a priori* based on data availability, variables used in similar studies of sage-grouse, and what I believed would affect the species distribution based on their natural history (Phillips et al. 2006, Ikeda 2010). I included variables relating to human influences as well as environmental characteristics (Aldridge and Boyce 2007). In other studies that used Maxent to predict species distributions, the ratio of the number of variables to the number of presence points ranged from < 2% to > 200% with the number of variables ranging from 7 to 23 (Hernandez et al. 2006, Yost et al. 2008, Freese 2009, Anderson and Raza 2010, Ikeda 2010, Schrag et al. 2011). Having too few predictors makes it difficult to rule out absence areas while too many predictors can decrease the predicted presence areas (Phillips et al. 2006). I selected 10 variables to model the species distribution of the Bald Hills sage-grouse for each seasonal model (Table 4-1). All variables were processed at a 30-m resolution, which was greater than the GPS error (< 5m) when collecting the presence locations (Anderson and Raza 2010, Crabb and Black 2011).

While Maxent has the capacity to model complex variable interactions, I attempted to avoid using highly correlated variables (Phillips et al. 2006, Wisz et al. 2008). Environmental variables included elevation, slope, aspect, vegetation cover type, distance to lek, and fire year (Table 4-1). Elevation, slope, and aspect were obtained from a 10-m Digital Elevation Model (DEM; Utah Automated Geographic Reference Center [AGRC], www.gis.utah.gov, accessed 1 Oct 2012; Yost et al. 2008, Freese 2009, Atamian et al. 2010, Crabb and Black 2011). I used ArcGIS Desktop (Environmental Systems Research Institute, Redlands, CA) Spatial Analyst slope and aspect functions to

generate slope and aspect from the DEM, respectively. Vegetation cover type was

identified using the Southwest Regional Gap Analysis Project (SWReGAP) dataset

(SWReGAP Landcover and Related Datasets, www.earth.gis.usu.edu/swgap/index.html,

accessed 1 Oct 2012; Yost et al. 2008, Freese 2009, Atamian et al. 2010, Crabb and

Black 2011; Table 4-2). For the distance to nearest lek analysis I only included leks that

were active during the 2-year study (Euclidean Distance function; Freese 2009, Fedy et

al. 2012). Fire year represented the most recent year that an area burned within the past

20 years (Christine Pontarolo, BLM, unpublished data).

Anthropogenic predictors included distance to roads, distance to energy

development, and habitat management treatment types (Table 4-1). For the distance to

roads analysis I split roads into two different predictor variables based on posted speed

limits (Euclidean Distance function; Aldridge and Boyce 2007, Freese 2009, Atamian et

al. 2010). Speed was reported for all mapped roads (Road Centerlines, AGRC,

www.gis.utah.gov, accessed 1 Oct 2012). I classified low speed roads as those with speed

limits ≤ 56.33 km/hr (≤ 35 mph) and assumed that these represented roads with less

traffic, narrower widths, greater quantities of dirt roads, and therefore an overall

decreased disturbance to habitat and wildlife. I classified high speed roads as those with

speed limits ≤ 64.37 km/hr (≥ 40 mph) and assumed that these represented roads with

greater traffic volume, wider widths, greater quantity of paved roads, and therefore an

overall increased disturbance to habitat and wildlife. Distance to energy development

included oil and gas wells, oil and gas pipelines, and transmission lines (Euclidean

Distance function; AGRC, www.gis.utah.gov, accessed 1 Oct 2012; Aldridge and Boyce

2007). Habitat management treatment types included all vegetation treatments

conducted in the past 20 years (Christine Pontarolo, BLM, unpublished data).

Maxent Modeling

I used 10,000 randomly generated background pseudo-absence points weighted

equally to the presence points with random seed selection (Barbet-Massin et al. 2012).

This value was chosen because it is commonly used, provided a ratio > 10:1 of presence

to pseudo-absence points, and coupled well with the lack of sampling bias in the presence

data. The random seed option randomly selects different training presence points for each

run (Phillips and Dudík 2008, Wisz et al. 2008, Yost et al. 2008, Phillips et al. 2009,

Ikeda 2010, Barbet-Massin et al. 2012).

Table 4-1. Predictor variables selected *a priori* for maximum entropy modeling.

Variable	Type[1]	Description (units)
Environmental		
Elevation (dem_30m)	Continuous	calculated from 10 m DEM (m)
Slope (slope_30m)	Continuous	calculated from 10 m DEM (angle $^{\circ}$)
Aspect (aspect_30m)	Categorical	calculated from 10 m DEM (direction[2])
Vegetation Cover Type (landcover)	Categorical	SWReGAP[3]
Lek Distance (lek_dist)	Continuous	distance to nearest active lek (m)
Anthropogenic		
Road Distance (Slow Speed) (spd_low_dist)	Continuous	distance to $\leq$ 56.33 km/hr ($\leq$ 35 mph) roads (m)
Road Distance (Fast Speed) (spd_high_dist)	Continuous	distance to $\leq$ 64.37 km/hr ($\geq$ 40 mph) roads (m)
Energy Distance (energy_dist)	Continuous	distance to oil/gas wells, oil/gas pipelines, and transmission lines (m)
Habitat Treatment Type (fuels_fire) (not available for CCFO)	Categorical	if the area has had fuels treatment[4] or wildfire since 1992

[1]all variables assessed at 30m resolution
[2]1; N, 2; NE, 3; E, 4; SE, 5; S, 6; SW, 7; W, 8; NW
[3]refer to Table 4-2
[4]broadcast burn, crushing, lop and scatter, mastication/mowing, seeding, thinning, or other

Table 4-2. Vegetation cover types found within the Bald Hills model extents.

Class	Description
5	Rocky Mountain Cliff and Canyon
8	Inter-Mountain Basins Cliff and Canyon
9	Colorado Plateau Mixed Bedrock Canyon and Tableland
12	Inter-Mountain Basins Volcanic Rock and Cinder Land
14	Inter-Mountain Basins Playa
23	Rocky Mountain Bigtooth Maple Ravine Woodland
26	Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland
28	Rocky Mountain Subalpine Mesic Spruce-Fir Forest and Woodland
30	Rocky Mountain Montane Dry-Mesic Mixed Conifer Forest and Woodland
32	Rocky Mountain Montane Mesic Mixed Conifer Forest and Woodland
34	Rocky Mountain Ponderosa Pine Woodland
36	Colorado Plateau Pinyon-Juniper Woodland
37	Great Basin Pinyon-Juniper Woodland
38	Inter-Mountain West Aspen-Mixed Conifer Forest and Woodland Complex
41	Rocky Mountain Gambel Oak-Mixed Montane Shrubland
44	Inter-Mountain Basins Mountain Mahogany Woodland and Shrubland
48	Inter-Mountain Basins Big Sagebrush Shrubland
49	Great Basin Xeric Mixed Sagebrush Shrubland
50	Colorado Plateau Mixed Low Sagebrush Shrubland
58	Inter-Mountain Basins Mixed Salt Desert Scrub
62	Inter-Mountain Basins Montane Sagebrush Steppe
67	Inter-Mountain Basins Semi-Desert Shrub Steppe
70	Rocky Mountain Subalpine Mesic Meadow
71	Southern Rocky Mountain Montane-Subalpine Grassland
76	Inter-Mountain Basins Semi-Desert Grassland
79	Rocky Mountain Lower Montane Riparian Woodland and Shrubland
82	Inter-Mountain Basins Greasewood Flat
86	Rocky Mountain Alpine-Montane Wet Meadow
110	Open Water
111	Developed, Open Space - Low Intensity
112	Developed, Medium - High Intensity
114	Agriculture
116	Recently Burned
117	Recently Mined or Quarried
119	Invasive Perennial Grassland
121	Invasive Annual Grassland
122	Invasive Annual and Biennial Forbland
124	Recently Chained Pinyon-Juniper Areas

In order to validate the un-projected models, Maxent can partition the

presence data into training data (presence points used to generate the model) and test data

(presence points used to examine the model's predictive ability; Phillips et al. 2006). I

partitioned the data to use 70% of the presence points as train data and 30% as test data

(Ikeda 2010, Smith 2012). These points were selected at random by Maxent (Phillips et

al. 2006). To partition the Nest and Brood data, which had limited sample sizes, I used a

K-fold cross-validation equal to 5. This resulted in mean results from the combination of

the 5 models that were run using different train and test presence points (Smith 2012).

The default model output in Maxent is a species distribution map with values

ranging from 0 to 1 that denote the probability of species occurrence. I specified an

additional species distribution output for the Summer and Winter models based on a

threshold resulting in a presence/absence map. I defined the threshold rule as the equality

of the specificity and the sensitivity in the train data (Liu et al. 2005, Ikeda 2010, Smith

2012). For the Nest and Brood models, I classified the probability of occurrence maps by

the standard deviation of the mean value throughout the model extents. This allowed me

to calculate the areas (km^2) predicted as suitable habitat within the CCFO for each model

(reclassify function).

Projected Models

I projected the models that were trained on the Bald Hills dataset to the BLM

CCFO (15,195 km^2). The CCFO encompasses all of Iron and Beaver Counties and a

small portion of northern Washington County, Utah. There are two additional sage-

grouse occupied areas within the CCFO including Pine Valley and Hamlin Valley. Pine

Valley had 2 active leks during the study and Hamlin Valley had 4. Telemetry data

collected from the Hamlin Valley population during the same time period using

similar methods was used to independently validate the predictive ability of the projected

model (H. McPherron, Utah State University, unpublished data).

RESULTS

Presence Data

I captured 25 sage-grouse from 4 different leks in 2011. In 2012 I captured 25

sage-grouse ($n = 9$ hens, $n = 16$ males) from 6 leks. Of the 15 male sage-grouse

captured by the BLM in 2010, 4 died and 2 collars went offline prior to this study. I was

able to locate and track 9 of these birds during the study, increasing my total sample size

to 59 birds ($n = 17$ hens, $n = 42$ males) with 29% hens and all 8 active leks represented.

Over the study duration I detected 12 nest locations (Nest model $n = 12$) and 39

brood-rearing locations (Brood model $n = 39$). I obtained 581 presence telemetry

locations during the designated Summer season and 107 presence telemetry locations

during the designated Winter season. I partitioned the independently collected Hamlin

Valley data into seasons based on the same criteria as the Bald Hills data resulting in Nest

($n = 6$), Brood ($n = 7$), Summer ($n = 126$, 69 hen and 57 male locations), and Winter ($n =

8$, all hen locations) presence locations.

Predictor Variables

Within the 2,240 km^2 study extents for the initial Bald Hills models, the elevation

ranged from 1530 m - 2638 m and slope ranged from 0° - 70° where larger numbers

represented steeper slopes. Aspect represented the compass direction of the downslope

topography, segmented by direction to include North ($337.5^o – 22.5^o$), Northeast (22.5^o –

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°;

Table 4-1). I detected 38 vegetation cover types within the study extents (Table 4-2). The

distance to the nearest lek (0 m - 23,774 m), slow-speed roads (0 m - 2,660 m), fast-speed

roads (0 m - 14,754 m), and energy development (0 m - 14722 m) varied throughout the

study extents. Habitat treatment types included broadcast burn, crushing, lop and scatter,

mastication/mowing, other, seeding, thinning, and wildfire that occurred after 1992.

Data on habitat treatment types was not available for the entire CCFO. I

incorporated this predictor for the original Bald Hills model due to the relevance for local

management. I removed this predictor and developed a new model when projecting the

model to the CCFO.

Nest Models

I used a K-fold (K = 5) cross-validation sampling method for the Nest model so

all Nest model results represented the mean result over the 5 replicate-runs. Maxent

obtained the Receiver Operator Characteristic (ROC) curve by plotting the relationship

between Sensitivity and 1-Specificity (Fig. 4-2). I assessed the model predictive ability

using the Area Under the Curve (AUC) for the ROC plot, where a value of 0.5 would

indicate random prediction. The mean AUC for the Bald Hills Nest model (AUC = 0.944

± 0.032 [± 1 SD]) indicated excellent predictive ability, resulting in sensitivity and

specificity values that were much better than random (Fig. 4-2; Phillips et al. 2006).

Using the jackknife approach to assess variable contributions, 8 of the 9 variables

were found to contribute to the model. Using each variable separately, the variable

response curves displayed individual variable responses based on the Maxent model (Fig.

4-3). The top three predictors were landcover (56.79% [percent contribution]),

distance to nearest lek (21.80%), and habitat treatment type (9.84%; Table 4-3). Distance

to low-speed roads was not a significant predictor of suitable nest habitat.

Figure 4-2. Receiver Operator Characteristic (ROC) curve plot for the Bald Hills Nest model. Curves in top left corner indicate excellent model fit as compared with the black diagonal line indicating predictions that would be no better than random.

Table 4-3. Variable contributions for the Bald Hills and projected CCFO Nest models. Refer to Table 4-1 for variable descriptions.

Variable	Percent Contribution (%)	
	Bald Hills Model	Projected Model
Landcover	56.79	59.37
Distance to Lek	21.80	25.00
Habitat Treatment	9.84	N/A
Distance to Energy	4.60	2.85
Aspect	4.12	7.50
Distance to High Speed Roads	1.36	0.94
Elevation	1.15	3.59
Slope	0.35	0.74
Distance to Low Speed Roads	0.00	0.00

Nests were found disproportionately within inter-mountain basins montane
sagebrush steppe landcover type (landcover class 62; Table 4-2; Fig. 4-3A). The distance
to nearest lek had an inverse relationship to the probability of nest presence where larger
distances correlated with a smaller likelihood of nest occurrence. The probability of nest
presence decreased to 50% at a distance of approximately 2.5 km from the nearest lek
and decreased to < 30% at a distance of 5 km from the nearest lek (Fig. 4-3B). Birds were
more likely to be found in areas where habitat treatments or wildfire had occurred in the
past 20 years (since 1992; Fig. 4-3C).

Visual inspection of the model shows a good fit. All of the nest locations (as
determined via radio-telemetry) are within the high probability of presence areas
predicted by the model. The model also recognized other areas with similar habitat
attributes where no presence points were located (Fig. 4-4).

The nest model that was projected to the CCFO did not include the habitat
treatment (fuels_fire) variable. The resulting model still had excellent predictive ability
(AUC = 0.923 ± 0.051; Fig. 4-5). Landcover (59.37%) and distance to nearest lek
(25.00%) contributed the most to the model (Table 4-3). The variable response curves for
landcover and distance to nearest lek showed similar patters as the response curves for
the same variables in the Bald Hills nest model (Fig. 4-3). Distance to low speed roads
was not a significant contributor to the model (Table 4-3).
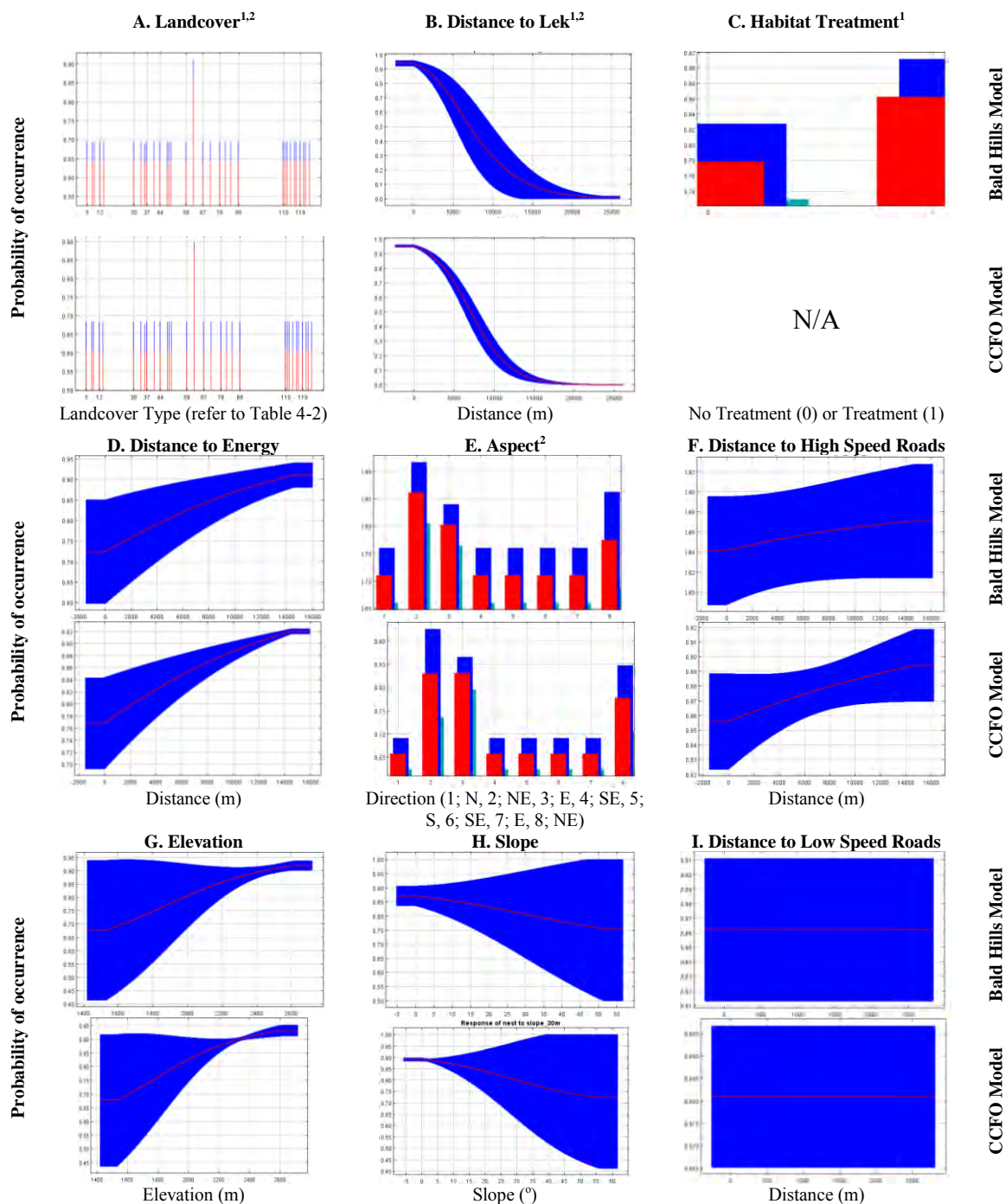
Figure 4-3. Variable response curves for the Bald Hills and projected CCFO Nest models. Mean response indicated in red with high and low standard error values in blue and green, respectively.

[1]The three predictor variables with the greatest percent contributions to the Bald Hills model.

[2]The three predictor variables with the greatest percent contribution to the CCFO model.

Figure 4-4. Predictive species distribution map for the Bald Hills Nest model with nest telemetry presence locations.
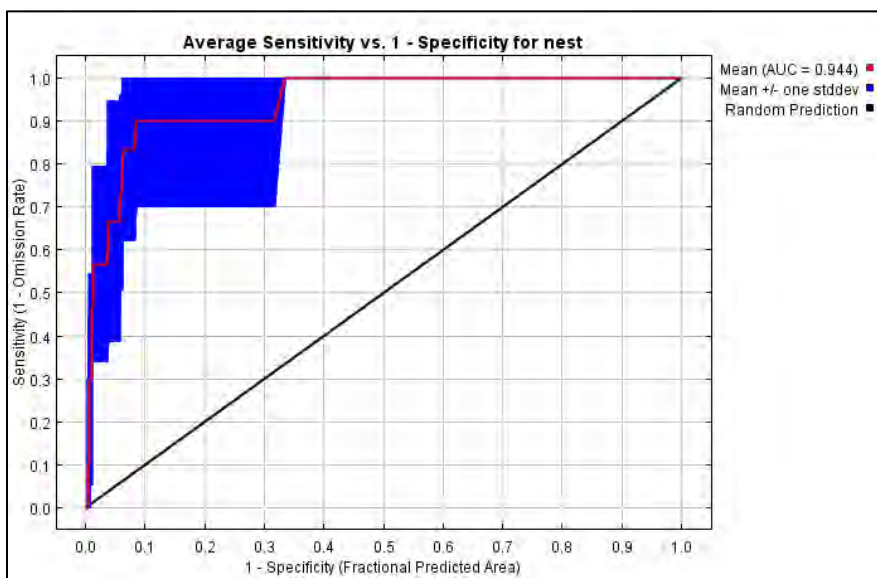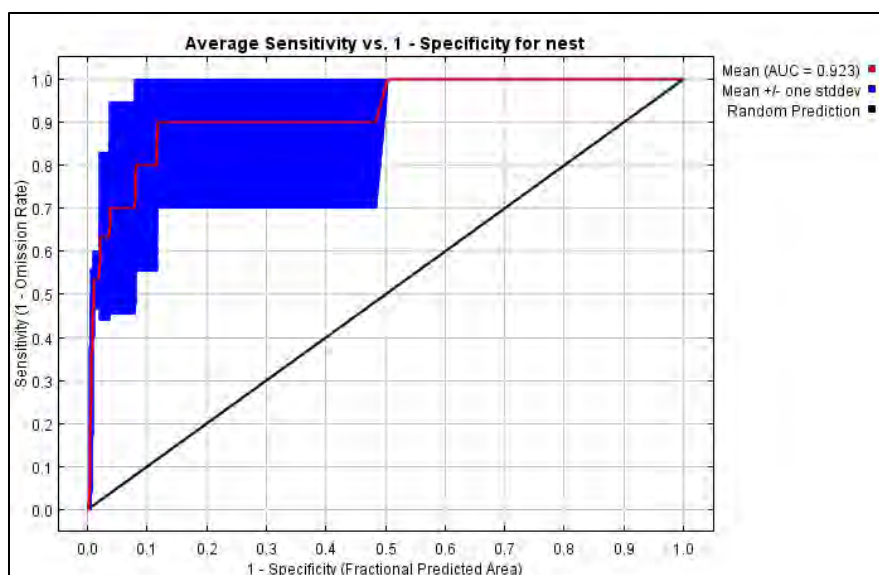

Figure 4-5. Receiver Operator Characteristic (ROC) curve plot for the projected CCFO Nest model. Curves in top left corner indicate excellent model fit as compared with the black diagonal line indicating predictions that would be no better than random.

Visual inspection of the model shows multiple areas outside of the Bald Hills extent with similar habitat attributes as the nest presence locations within the Bald Hills extents. The model predicted 13,395 km^2 of non-suitable habitat and 846 km^2, 410 km^2, and 543 km^2 of low, medium, and highly suitable habitat within the CCFO, respectively. There were 6 independently collected nest presence locations in Hamlin Valley. Five of the nests from Hamlin Valley were within the High probability of presence areas and 1 was within the medium probability of presence predicted area (Fig. 4-6).
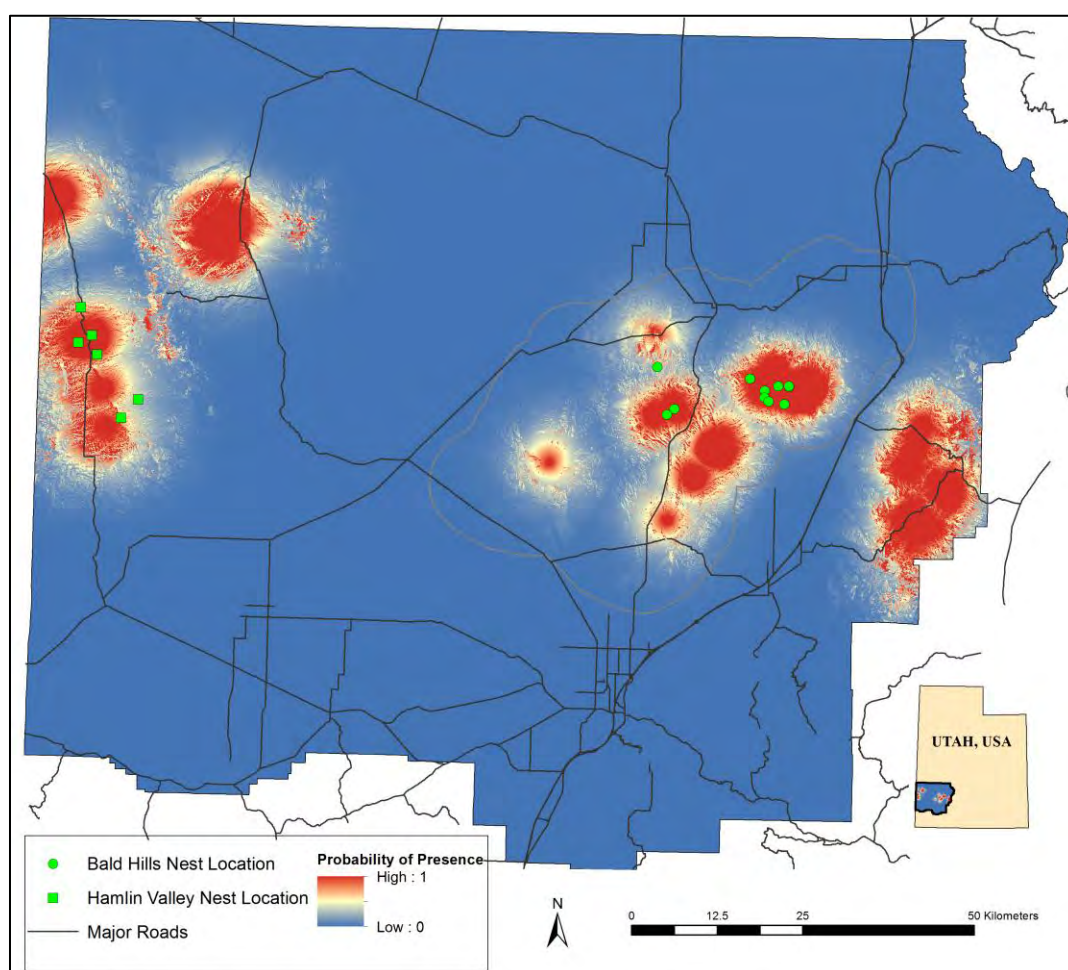
Figure 4-6. Predictive species distribution map for the projected CCFO Nest model with nest telemetry presence locations (Bald Hills Nest Locations) and independently collected nest presence locations for model validation (Hamlin Valley Nest Locations).

Brood Models

I used the same cross-validation sampling method for the Brood model as the

Nest model; all Brood model results represent the mean result over 5 replicate-runs. The

Bald Hills Brood model had excellent predictive ability (AUC = 0.963 ± 0.021; Fig. 4-7).

The jackknife test of variable importance resulted in all 10 variables contributing to the

model. The 3 variables that contributed most to the model were elevation (31.23%),

habitat treatment type (25.18%) and landcover (14.38%; Table 4-4).

The probability of presence decreased to < 30% when the elevation decreased to ≤

2,000 m (Fig. 4-8A). Habitat that was treated with fuels management techniques or

wildfire within the previous 20 years were used much more than areas that were not (Fig.

4-8B). Inter-mountain basins montane sagebrush steppe (landcover class 62), inter-

mountain basins semi-desert shrub steppe (landcover class 67), and rocky mountain

gambel oak-mixed montane shrubland (landcover class 41) landcover types were used

more than any other landcover types available (Fig. 4-8C, Table 4-2).

Visual examination of the Bald Hills Brood model shows some presence points

that are not represented by the model (Fig. 4-9). This could indicate that the model is

under-estimating suitable habitat in the Bald Hills area. Conversely, there are some areas

that were predicted as having high probability of presence that are not represented by

presence locations. Overall, the model appears to provide a good estimation of suitable

habitat when compared to the actual presence locations.

Table 4-4. Variable contributions for Bald Hills and projected CCFO Brood models.

Variable	Percent Contribution (%)	
	Bald Hills Model	Projected Model
Elevation	31.23	46.78
Habitat Treatment	25.18	N/A
Landcover	14.38	16.68
Distance to Energy	10.39	9.49
Distance to Lek	5.63	5.60
Distance to High Speed Roads	2.01	7.69
Aspect	4.96	7.22
Distance to Low Speed Roads	2.27	5.23
Slope	0.95	1.30
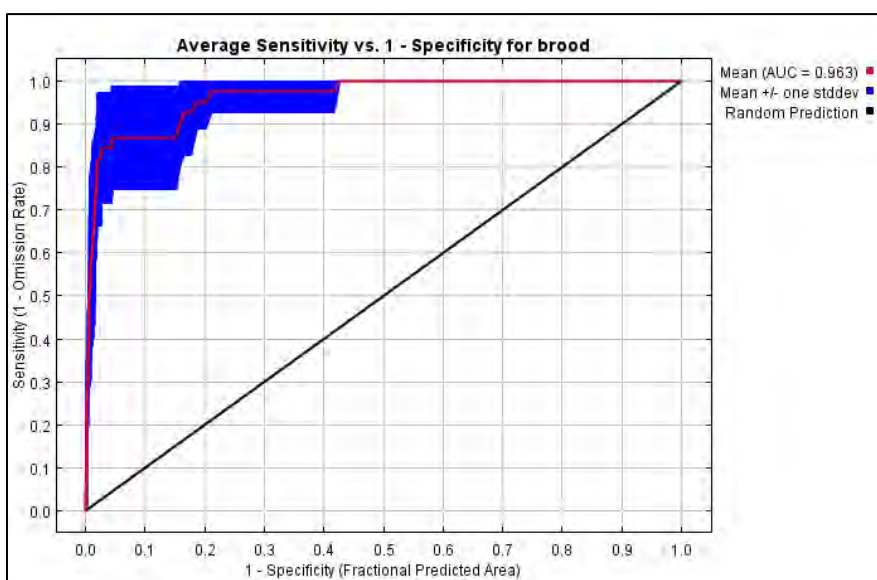
Figure 4-7. Receiver Operator Characteristic (ROC) curve plot for the Bald Hills Brood model. Curves in top left corner indicate excellent model fit as compared with the black diagonal line indicating predictions that would be no better than random.
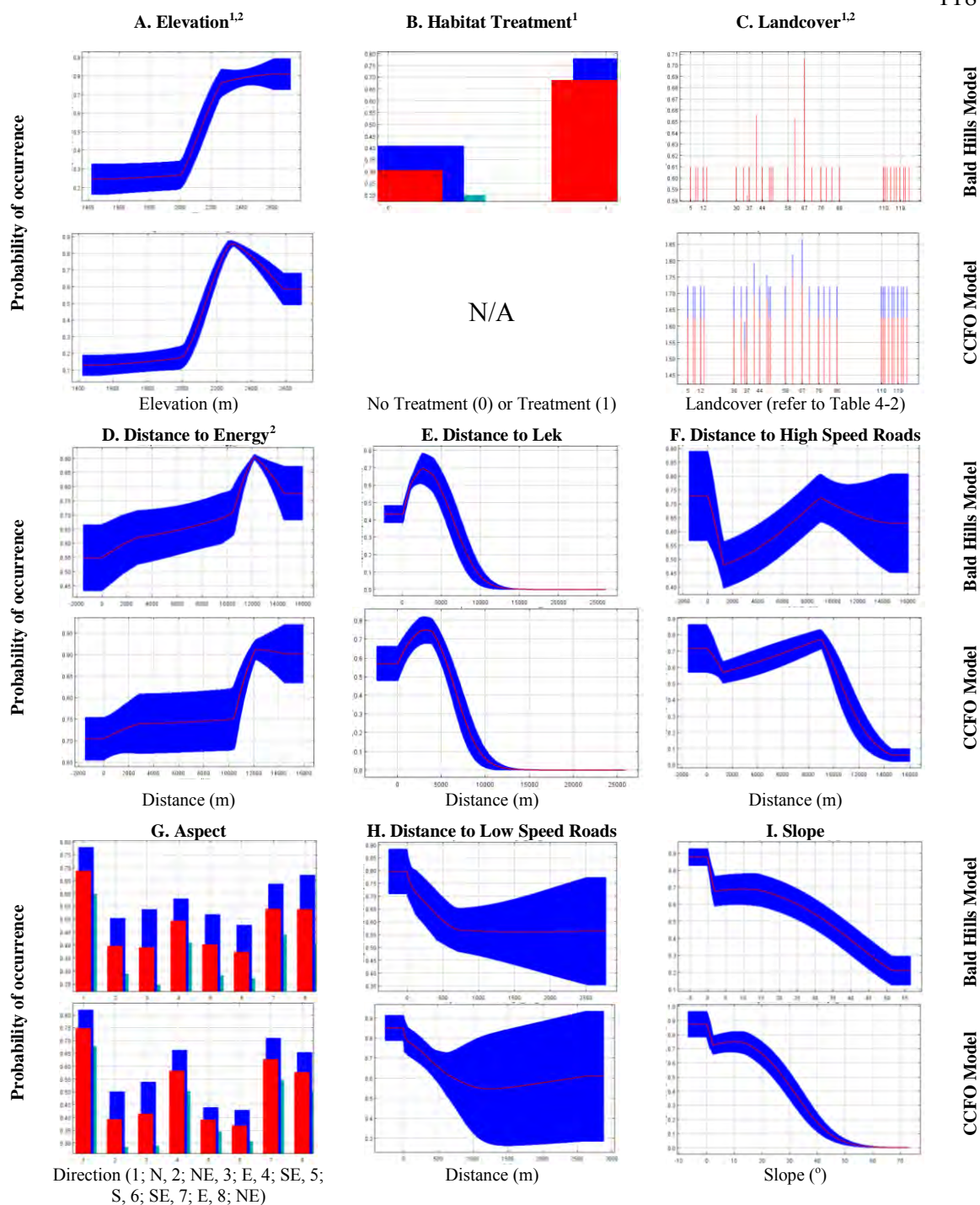
Figure 4-8. Variable response curves for the Bald Hills and projected CCFO Brood models. Mean response indicated in red with high and low standard error values in blue and green, respectively.

[1]The three predictor variables with the greatest percent contributions to the Bald Hills model.

[2]The three predictor variables with the greatest percent contribution to the CCFO model.
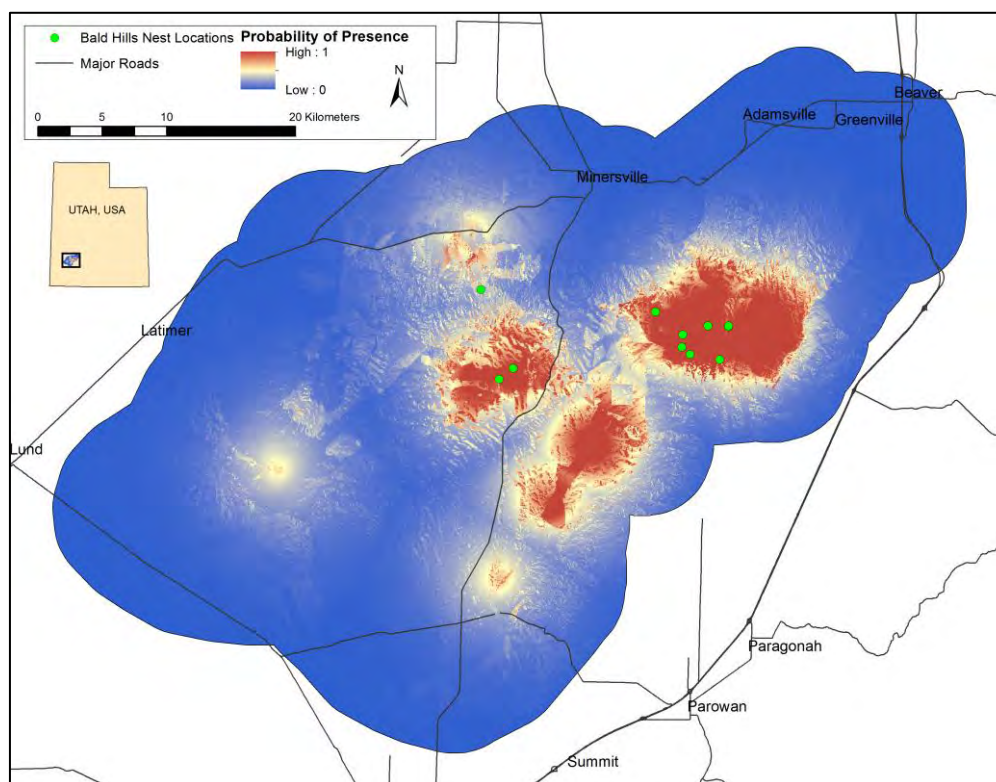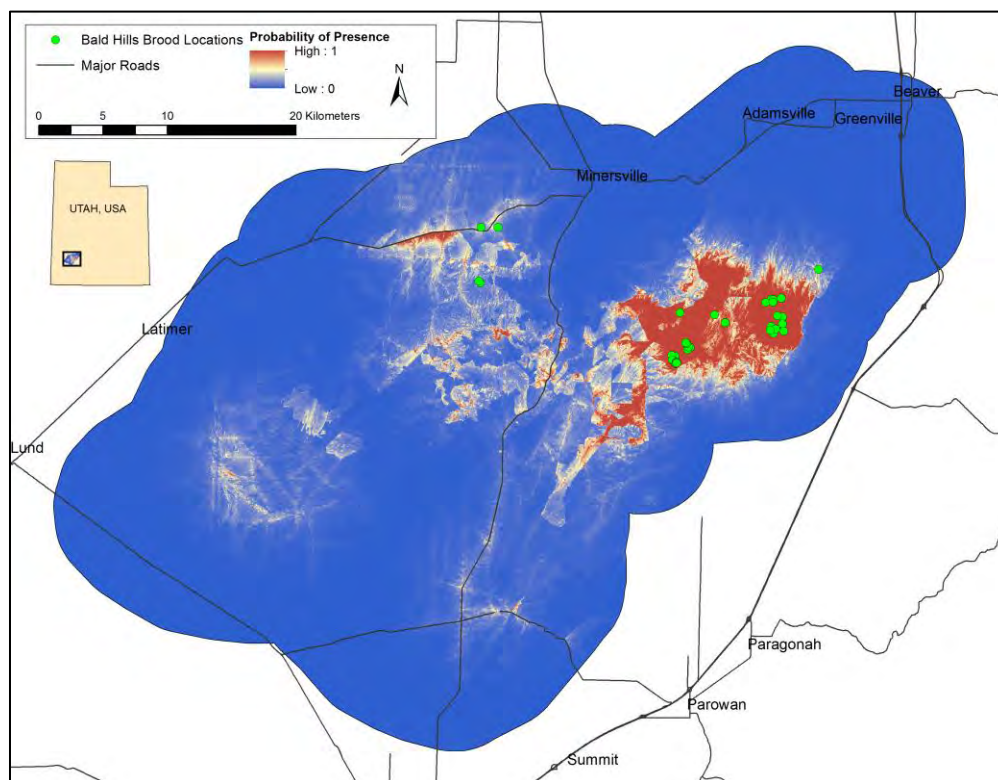
Figure 4-9. Predictive species distribution map for the Bald Hills Brood model with brood telemetry presence locations.

When I projected the Bald Hills Brood model to the CCFO area, I did not include habitat treatment type because the data was not available. The Brood model still had excellent predictive ability (AUC = 0.932 ± 0.041; Fig. 4-10). The most predictive variables for the CCFO Brood model were elevation (46.78%) and landcover (16.68%; Table 4-4). Elevation showed a similar pattern as the Bald Hills Brood model with the most suitable elevation > 2,200 m (Fig. 4-8A). Rocky mountain gambel oak-mixed montane shrubland (landcover class 41), inter-mountain basins montane sagebrush steppe (landcover class 62), and inter-mountain basins semi-desert shrub steppe (landcover class 67) provided the most suitable habitat compared with other landcover types (Table 4-2; Fig. 4-8C).
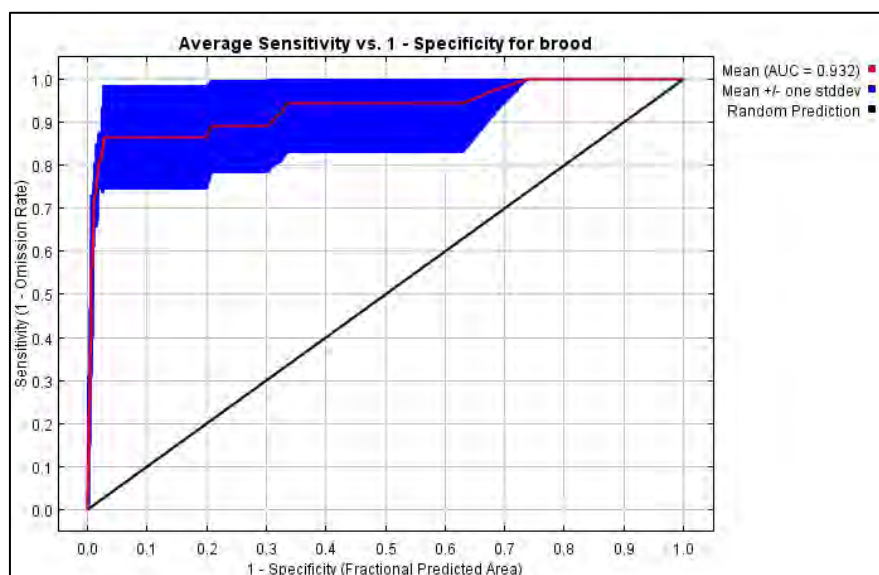
Figure 4-10. Receiver Operator Characteristic (ROC) curve plot for the CCFO Brood model. Curves in top left corner indicate excellent model fit as compared with the black diagonal line indicating predictions that would be no better than random.

The CCFO Brood model projected suitable brood-rearing habitat both east and west of the Bald Hills study area (Fig. 4-11). The model predicted 14,090 km^2 of non-suitable habitat and 543 km^2, 199 km^2, and 361 km^2 of low, medium, and high habitat suitability within the CCFO, respectively. Closer examination of the independently collected presence data shows that the model failed to predict most of the presences. While there are areas adjacent to the Hamlin Valley presence locations that were projected as presence areas, the model was not able to accurately predict these brood presence locations.

Summer Models

I partitioned the Summer model data into train (70%) and test (30%) data to develop and validate the Summer model. The Bald Hills Summer model had excellent predictive ability for both the training data (AUC = 0.966) and the test data (AUC =

0.953; Fig. 4-12). The jackknife test of variable importance resulted in all 9 variables contributing to the model. Distance from lek (57.66%) and elevation (22.15%) provided the highest predictive contribution to the model (Table 4-5).

The probability of presence decreased with increased distance from lek (Fig. 4-13A). The probability of presence decreased to < 15% at a distance of 2.5 km and decreased to <10% at a distance of 5 km. The response to elevation resulted in a bimodal distribution where 1,550 m and 2,400 m provided the most suitable habitat (Fig. 4-13B).
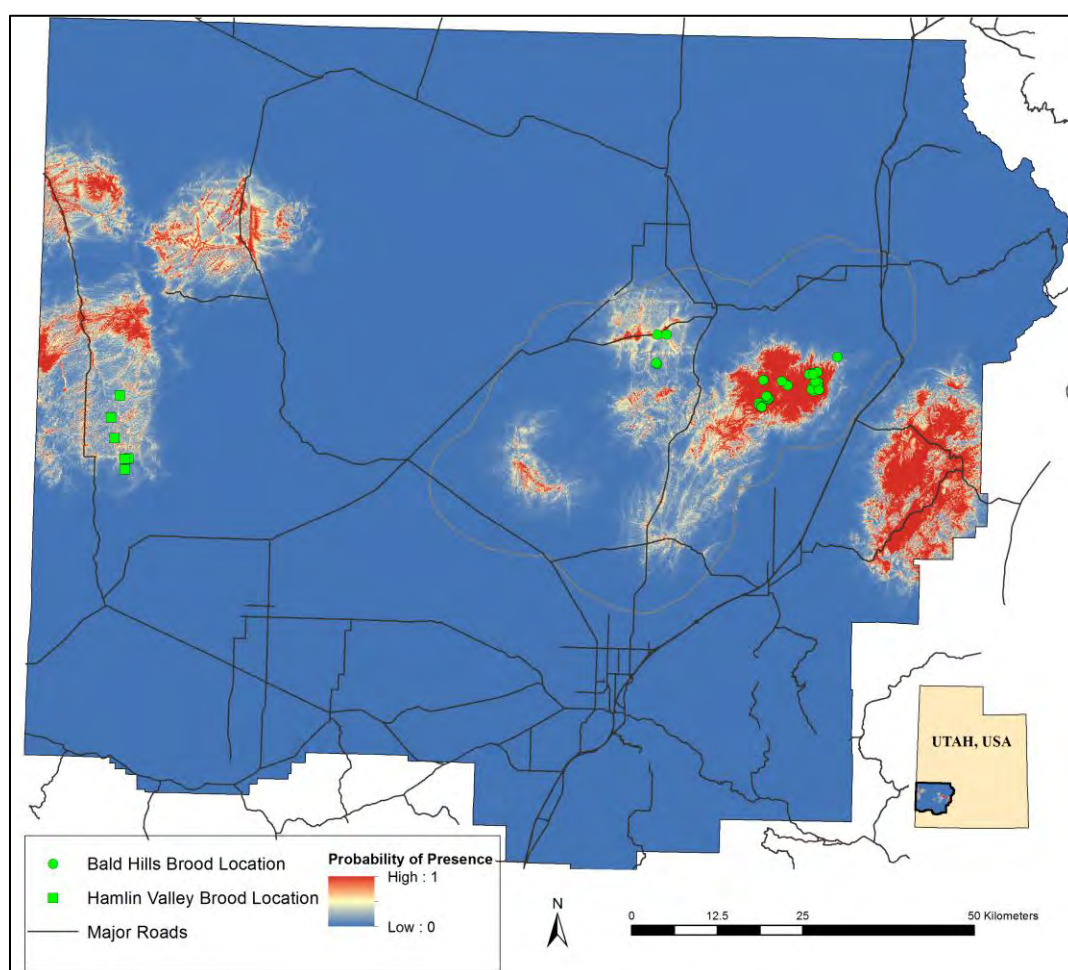
Figure 4-11. Predictive species distribution map for the projected CCFO Brood model with brood telemetry presence locations (Bald Hills Brood Locations) and independently collected nest presence locations for model validation (Hamlin Valley Brood Locations).

Further examination of the Bald Hills Summer model reveals that the model accurately predicted most of the presence locations (Fig. 4-14). There are some presence locations that were not predicted by the model and some areas without presence locations that were predicted as having a high probability of presence. Overall, visual inspection reveals a good model fit with > 98% of the presence points being located within the predicted suitable habitat.

The projected CCFO Summer model had an excellent fit for the training data (AUC = 0.968) and the test data (AUC = 0.936; Fig. 4-15). This model did not include habitat treatment type and maintained predictive ability much better than random. This model shared the same top predictor variables as the Bald Hills model; distance to lek (55.71%) and elevation (24.85%; Table 4-5). Also similar to the Bald Hills model, there was a negative relationship between the probability of presence and increased distance to lek (Fig. 4-13A). Elevation had a bimodal distribution for habitat suitability (Fig. 4-13B).

The projected CCFO Summer model predicted additional areas within the CCFO as having similar habitat attributes as the Bald Hills summer presence locations. Some areas are patchy with large distances between them and other high probability-of-presence areas (Fig. 4-16). Three presence areas (indicated by independently collected presence locations) in Hamlin Valley were accurately predicted as having suitable habitat. There was a large southern cluster of Hamlin Valley presence locations however, that were located in an area that was not predicted as suitable habitat.

Table 4-5. Variable contributions for the Bald Hills and projected CCFO Summer models.

Variable	Percent Contribution (%)	
	Bald Hills Model	Projected Model
Distance to Lek	57.66	55.71
Elevation	22.15	24.85
Distance to High Speed Roads	9.20	9.77
Aspect	5.23	6.69
Landcover	2.48	0.84
Habitat Treatment Type	1.66	N/A
Distance to Low Speed Roads	0.87	0.91
Slope	0.42	0.58
Distance to Energy	0.32	0.66

Figure 4-12. Operator Characteristic (ROC) curve plot for the Bald Hills Summer model. Curves in top left corner indicate excellent model fit as compared with the black diagonal line indicating predictions that would be no better than random.

A. Distance to Lek[1,2]

B. Elevation[1,2]

C. Distance to High Speed Roads[1,2]

Probability of occurrence

Bald Hills Model

CCFO Model

Distance (m)

Elevation (m)

Distance (m)

D. Aspect

E. Landcover

F. Habtiat Treatment Type

Probability of occurrence

Bald Hills Model

CCFO Model

N/A

Direction (1; N, 2; NE, 3; E, 4; SE, 5; S, 6; SE, 7; E, 8; NE)

Landcover (refer to Table 4-2)

No Treatment (0) or Treatment (1)

G. Distance to Low Speed Roads

H. Slope

I. Distance to Energy

Probability of occurrence

Bald Hills Model

CCFO Model

Distance (m)

Slope (°)

Distance (m)
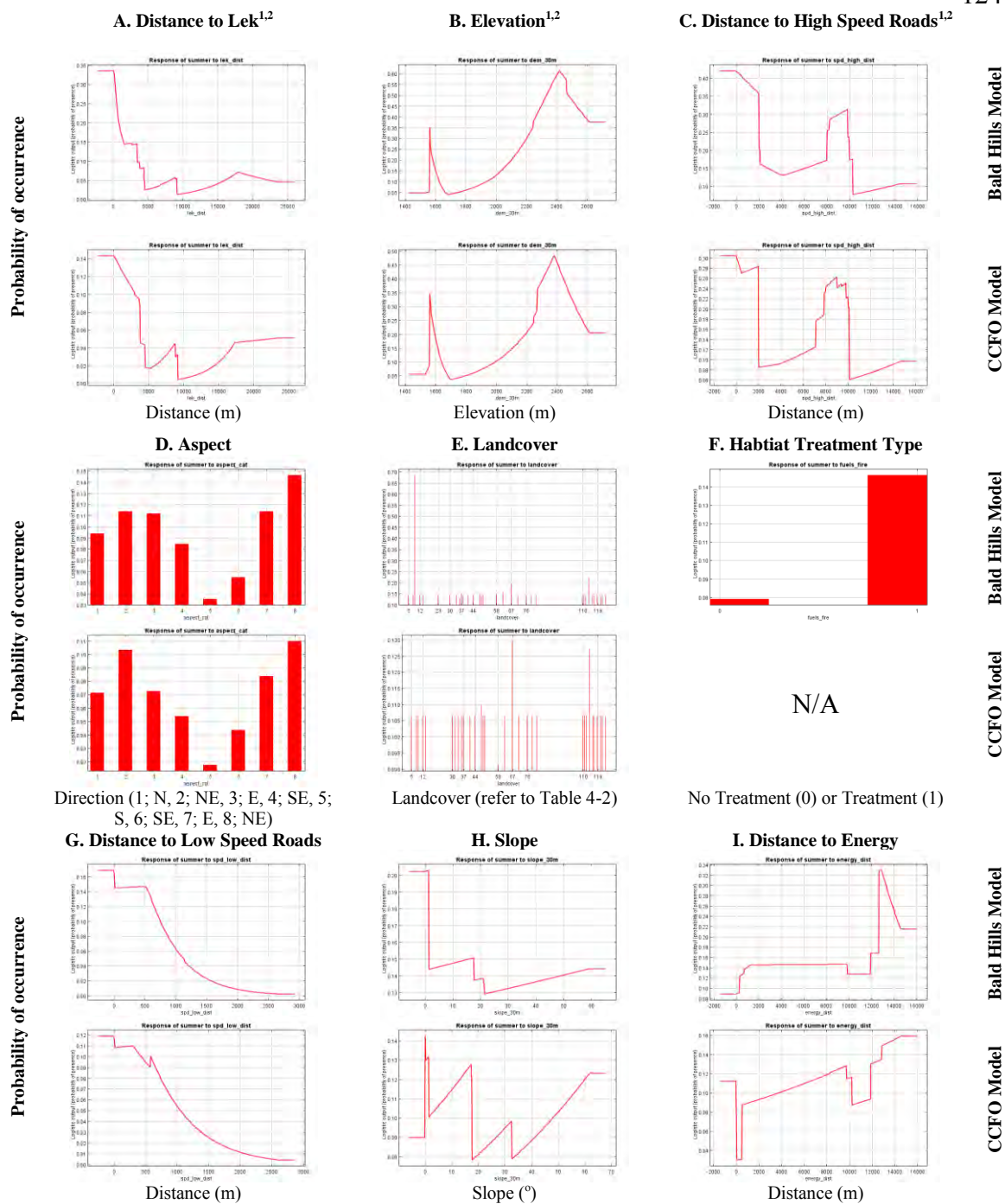
Figure 4-13. Variable response curves for the Bald Hills and projected CCFO Summer models. Mean response indicated in red with high and low standard error values in blue and green, respectively.

[1]The three predictor variables with the greatest percent contributions to the Bald Hills model.

[2]The three predictor variables with the greatest percent contribution to the CCFO model.
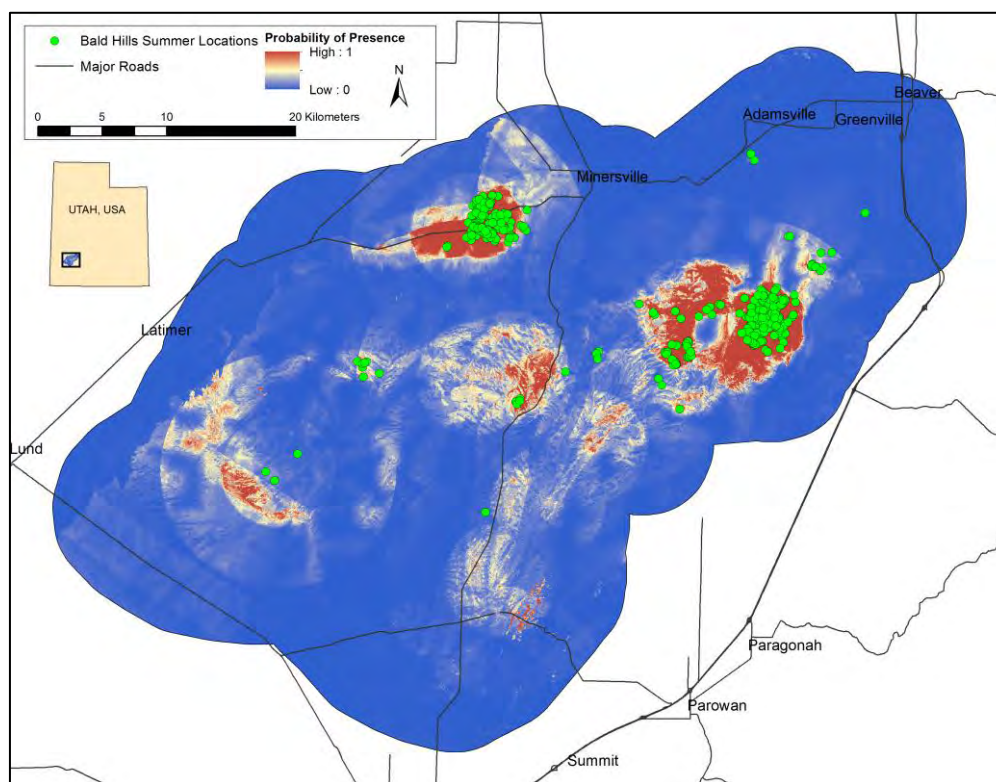
Figure 4-14. Predictive species distribution map for the Bald Hills Summer model with summer telemetry presence locations.
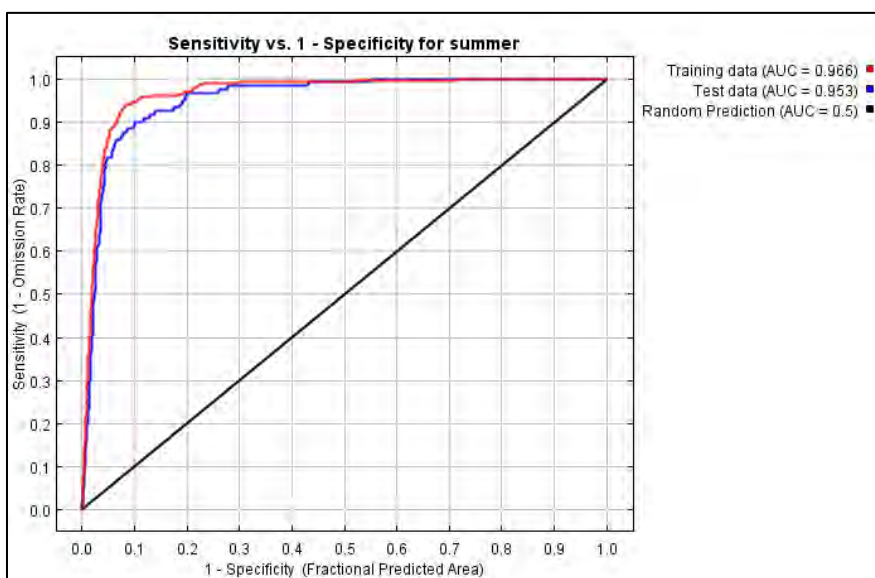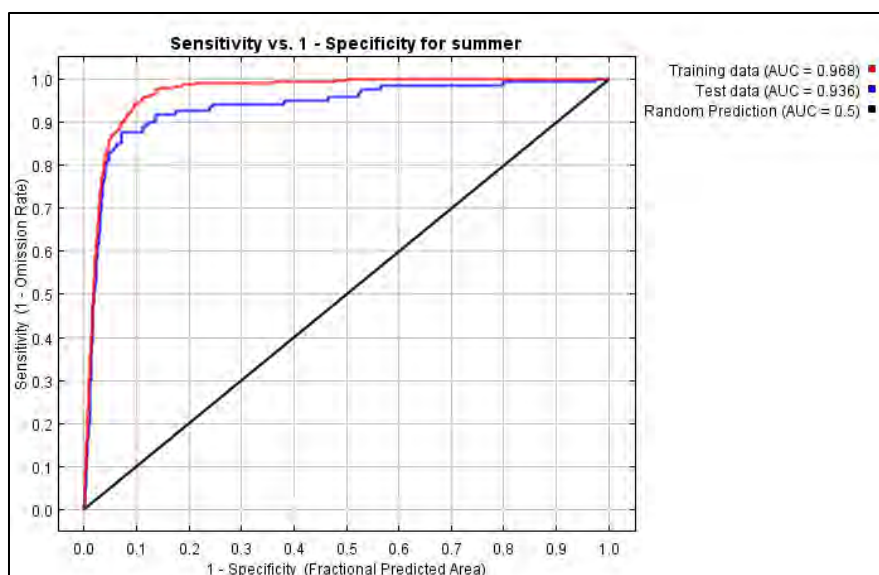

Figure 4-15. Receiver Operator Characteristic (ROC) curve plot for the CCFO Summer model. Curves in top left corner indicate excellent model fit as compared with the black diagonal line indicating predictions that would be no better than random.

The threshold used for the presence/absence map was the equality of the sensitivity and specificity for the train data and predicted 656 km^2 of suitable habitat within the CCFO (Fig. 4-17). With this threshold applied, there are fewer areas predicted as providing suitable summer habitat when compared with the probability of presence map (Fig. 4-17). Approximately 98% of the Bald Hills and approximately 87% of the Hamlin Valley presence points were within medium or high probability of presence areas before applying the threshold. After applying the threshold the percent accurately predicted decreased by > 5% for the Bald Hills population and > 10% for the Hamlin Valley population.

Winter Models

The model had excellent predictive ability for the training data (AUC = 0.966) and the test data (AUC = 0.960; Fig. 4-18). All 9 variables contributed to the model. Distance to nearest lek (42.96%), distance high speed roads (25.96%), and landcover (13.54%) contributed most to the model (Table 4-5). There was a negative relationship between probability of presence and distance to the nearest lek, with the probability of presence decreasing to < 35% at distances > 5 km (Fig. 4-19A). There was a positive relationship between distance to high-speed roads and probability of presence, with increasing probability at distances > 10 km (Fig. 4-19B). Colorado plateau mixed low sagebrush shurbland (landcover class 50), inter-mountain basins montane sagebrush steppe (landcover class 58), inter-mountain basins semi-desert shrub steppe (landcover class 67), and inter-mountain basins semi-desert grassland (landcover class 76) provided the landcover with the most suitable winter habitat (Fig. 4-19C and Table 4-2). Visual inspection of the predictive model shows excellent model fit. All of the telemetry

presence locations were in areas predicted as providing suitable winter habitat (Fig. 4-20).

The projected CCFO winter model had excellent fit for the training data (AUC = 0.963) and for the test data (AUC = 0.941; Fig. 4-21). This model predicted 347 km^2 of suitable winter habitat within the CCFO. Distance to lek (45.06%) and distance to high-speed roads (29.88%) were the greatest contributing variables to the model (Table 4-6). Both variables showed similar variable response curves as the Bald Hills model with a

Figure 4-16. Predictive species distribution map for the projected CCFO Summer model with summer telemetry presence locations (Bald Hills Presence Locations) and independently collected summer presence locations for model validation (Hamlin Valley Presence Locations).

negative relationship for lek distance (Fig. 4-19A) and a positive relationship for

distance to high-speed roads (Fig. 4-19B). The projected CCFO winter model shows an

excellent fit with the independently collected Hamlin Valley Data (Fig 4-22). The model

predicted additional areas with suitable habitat both east and west of the Bald Hills model

extents. The presence/absence map excluded some areas with medium probability of

presence values (Fig. 4-23). The resulting map excluded some telemetry presence points

from areas of presence in the Bald Hills and Hamlin Valley populations.

Figure 4-17. Predictive species presence/absence map for the projected CCFO Summer model based on a threshold of specificity and sensitivity equality for the model train data. Bald Hills Presence Locations represent all summer telemetry presence locations and the Hamlin Valley Presence Locations represent independently collected summer presence locations for model validation.

Table 4-6. Variable contributions for Bald Hills and projected CCFO Winter models.

Variable	Percent Contribution (%)	
	Bald Hills Model	Projected Model
Distance to Lek	42.96	45.06
Distance to High Speed Roads	25.96	29.88
Landcover	13.54	11.33
Elevation	7.73	4.64
Distance to Energy	5.04	2.82
Slope	1.83	2.39
Aspect	1.68	2.41
Distance to Low Speed Roads	1.37	1.48
Habitat Treatment	0.00	N/A
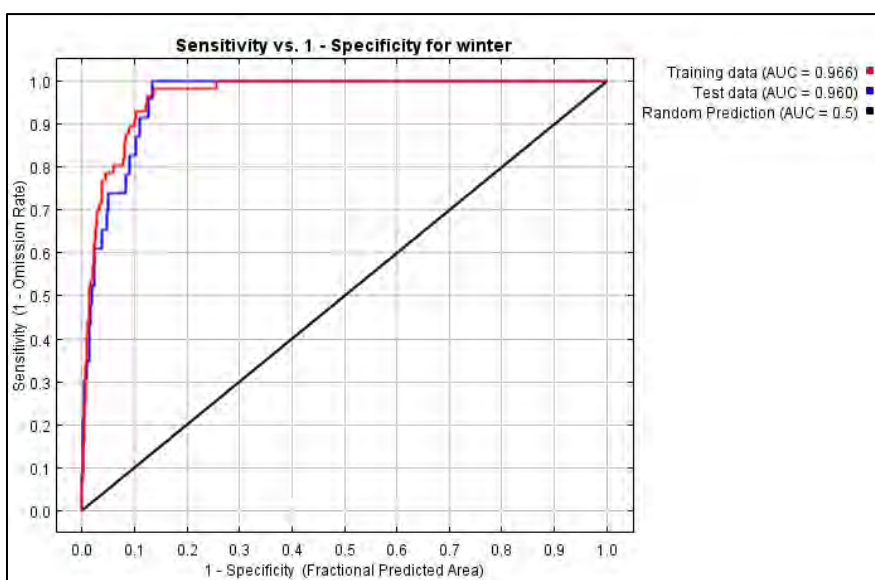
Figure 4-18. Receiver Operator Characteristic (ROC) curve plot for the Bald Hills Winter model. Curves in top left corner indicate excellent model fit as compared with the black diagonal line indicating predictions that would be no better than random.
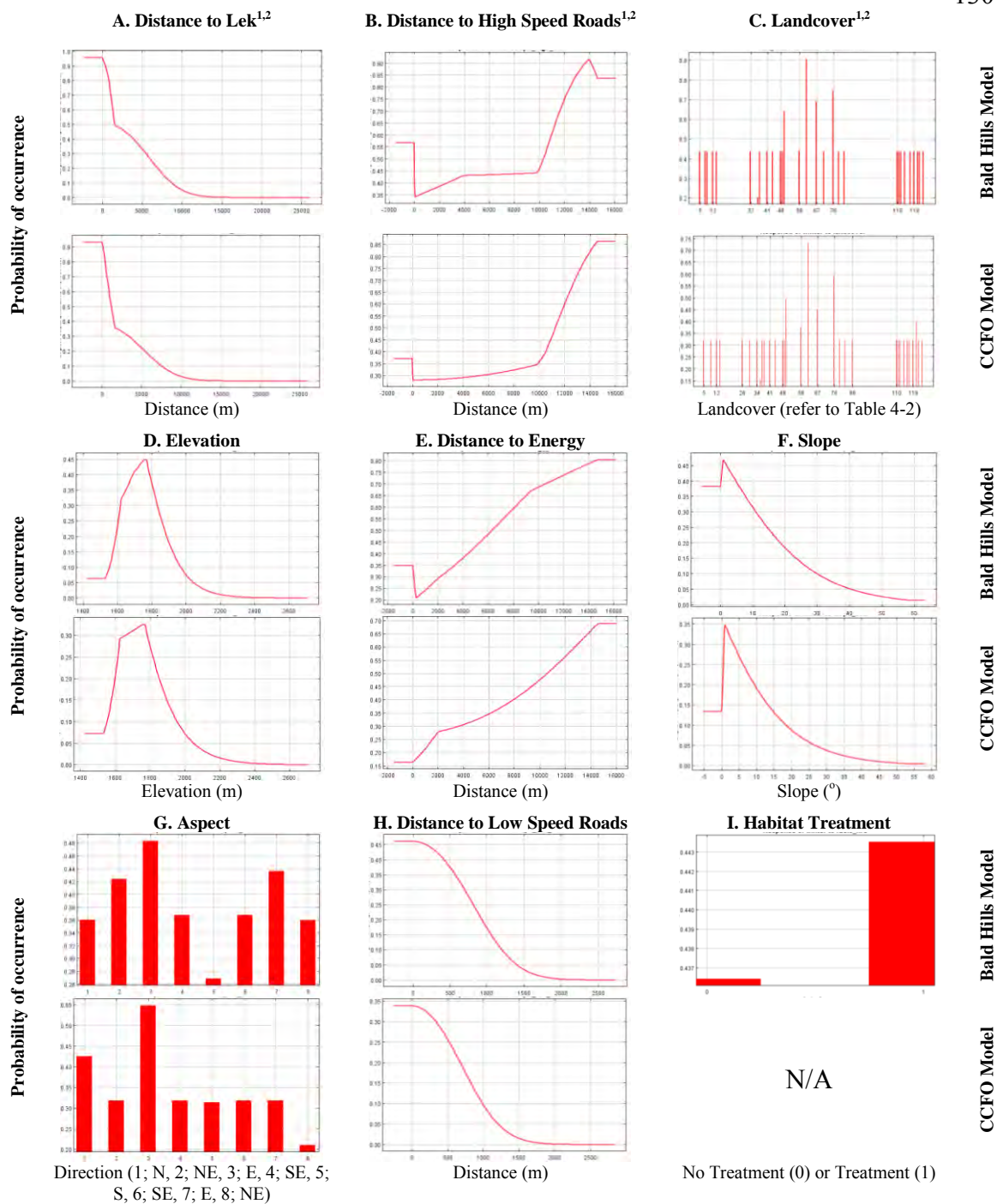
Figure 4-19. Variable response curves for the Bald Hills and projected CCFO Winter models. Mean response indicated in red with high and low standard error values in blue and green, respectively.
[1]The three predictor variables with the greatest percent contributions to the Bald Hills model.
[2]The three predictor variables with the greatest percent contribution to the CCFO model.
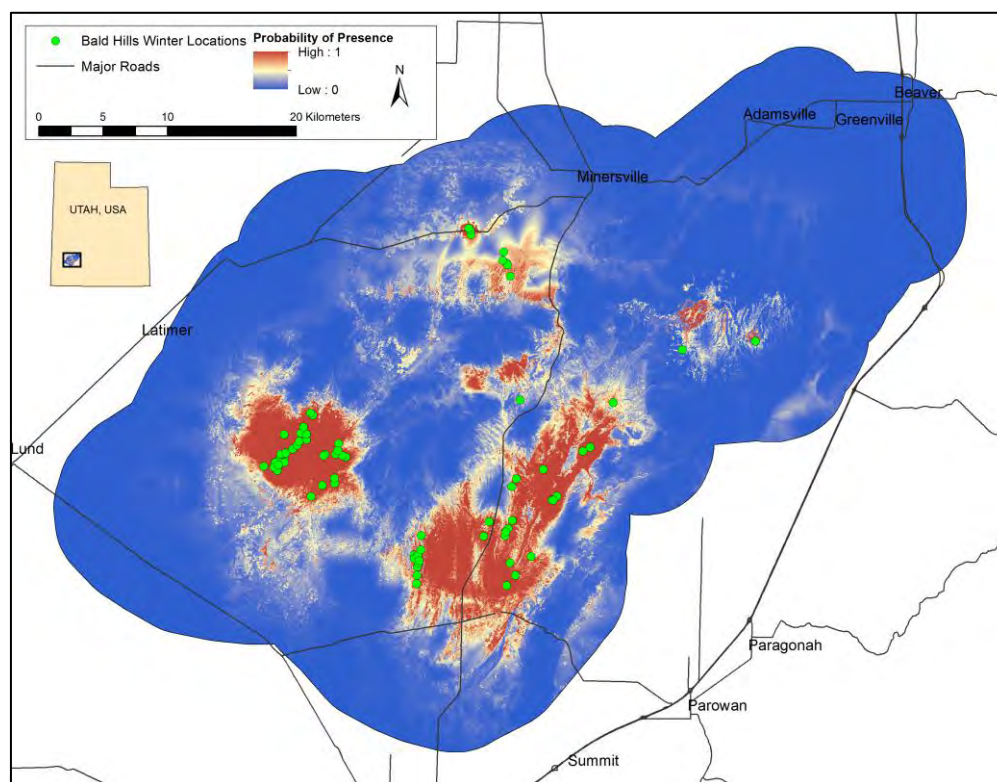
Figure 4-20. Predictive species distribution map for the Bald Hills Winter model with winter telemetry presence locations.
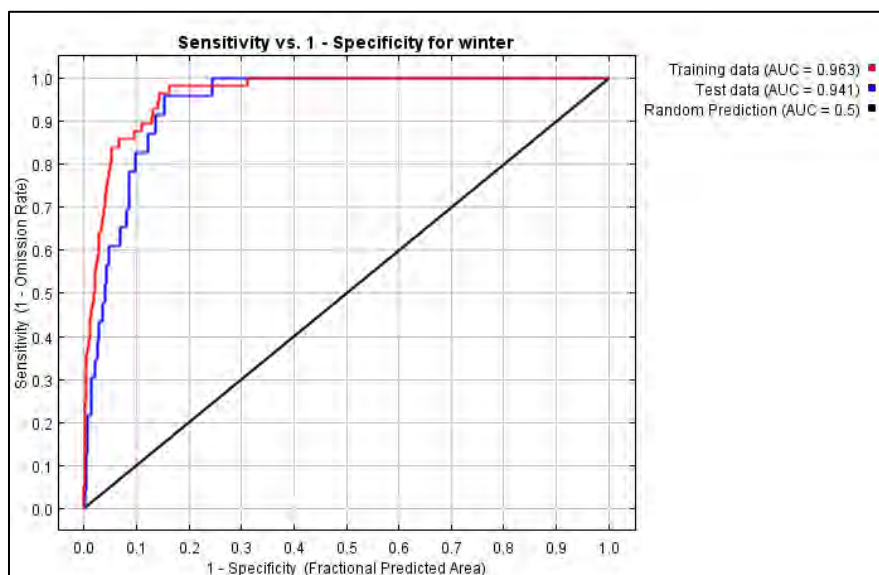
Figure 4-21. Receiver Operator Characteristic (ROC) curve plot for the CCFO Winter model. Curves in top left corner indicate excellent model fit as compared with the black diagonal line indicating predictions that would be no better than random.

DISCUSSION

Nest Models

Results from the Bald Hills Nest model indicate that landcover, distance to lek, and habitat treatment are the drivers of nest habitat suitability and therefore nest habitat selection in the Bald Hills sage-grouse population. Suitable nesting habitat was predicted
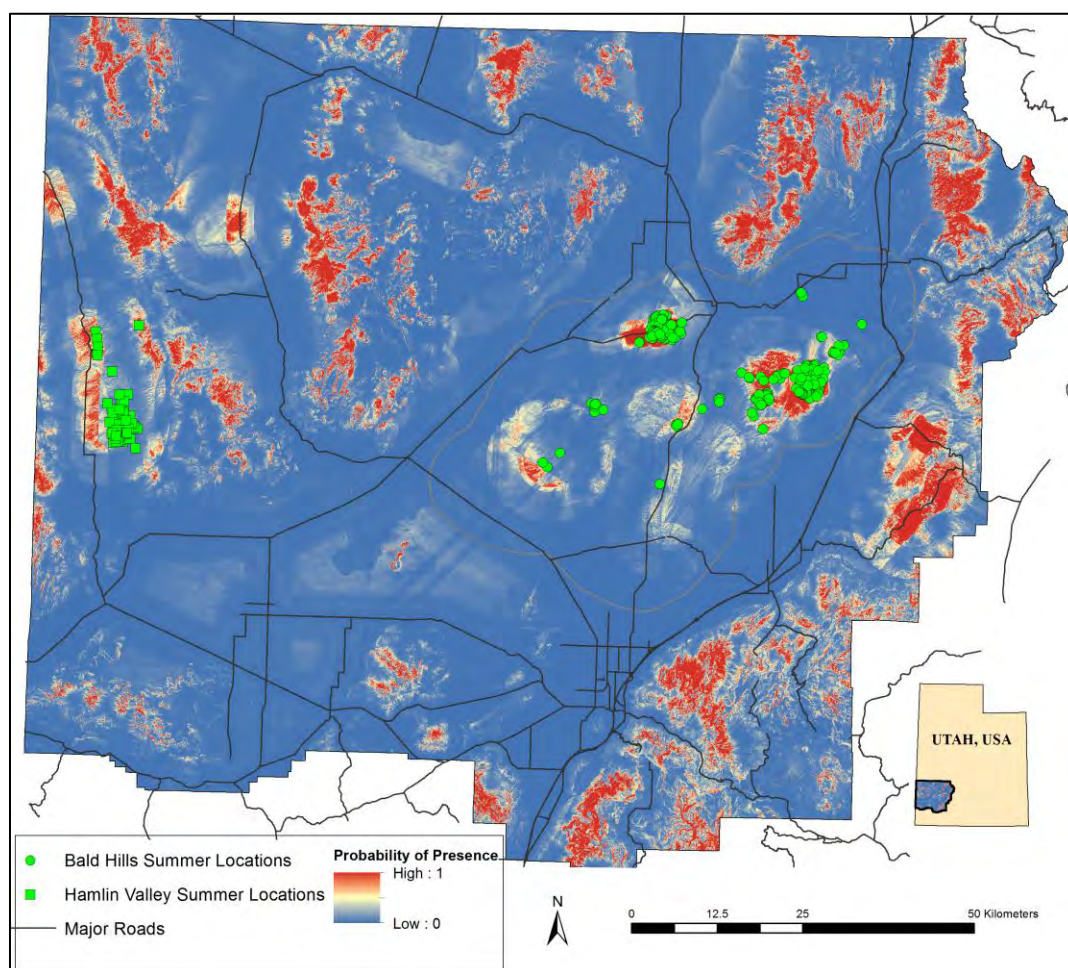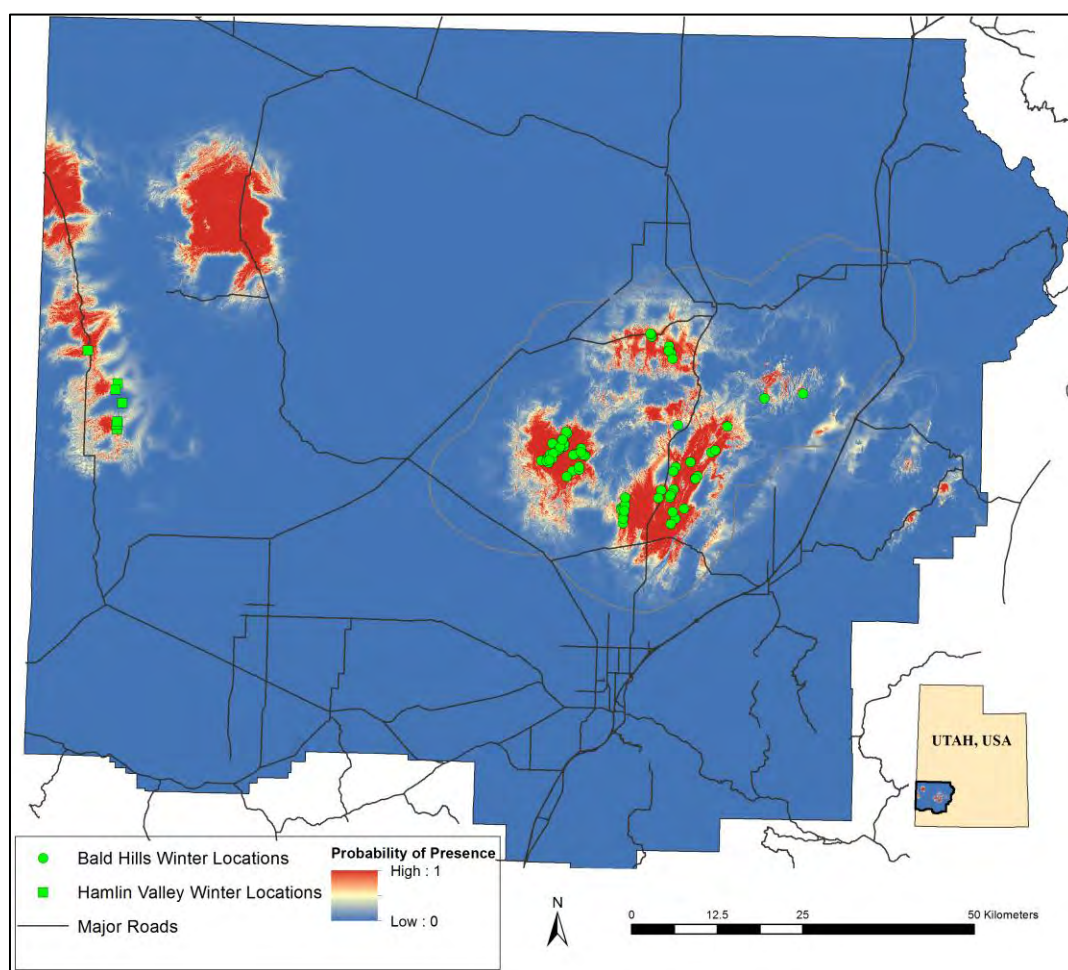

Figure 4-22. Predictive species distribution map for the projected CCFO Winter model with winter telemetry presence locations (Bald Hills Winter Locations) and independently collected winter presence locations for model validation (Hamlin Valley Winter Locations).

in areas of inter-mountain basins montane montane sagebrush steppe, < 5 km from an

active lek, and in areas that were treated or succumbed to wildfire within the previous 20

years. The importance of landcover and distance to lek was expected based on studies of

sage-grouse nesting habitat preferences in other populations; however, the strong

response to local habitat alterations (active management and wildfire) was not expected.
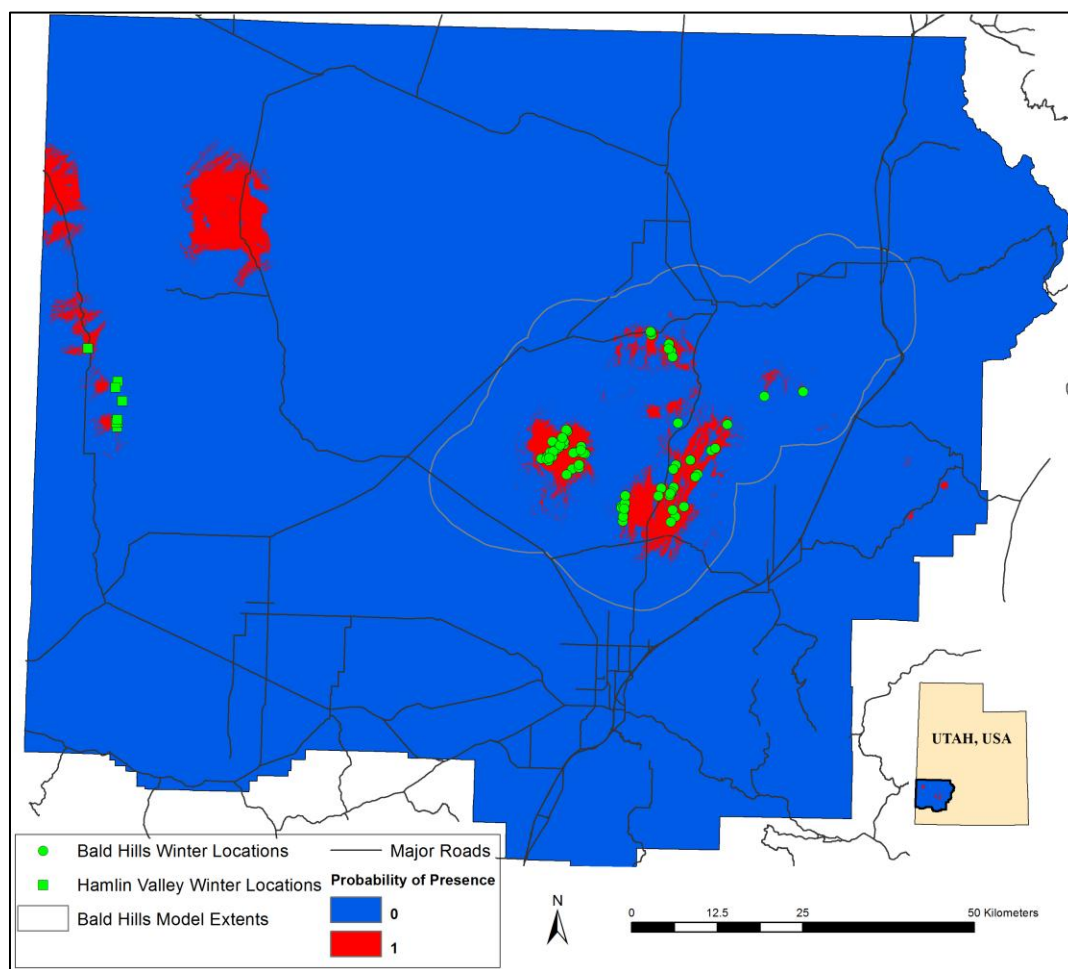
Figure 4-23. Predictive species presence/absence map for the projected CCFO Winter model based on a threshold of specificity and sensitivity equality for the model train data. Bald Hills Winter Locations represent all winter telemetry presence locations and the Hamlin Valley Winter Locations represent independently collected winter presence locations for model validation.

Yost et al. (2008) found that vegetation type was the most important predictor variable when using maxent to model nesting habitat in an Oregon population. Additionally, preference for inter-mountain basins montane sagebrush steppe in the Bald Hills population corroborates another Utah study that classified this landcover type as suitable habitat for sage-grouse (Crabb and Black 2011). This habitat type provides the most appropriate sagebrush overstory and grass/forb understory for nesting habitat compared with other landcover types available within the study area.

In Wyoming, nest locations were found to be spatially distributed relative to lek sites. A 5-km buffer was found to include over 60% of nest locations (Holloran and Anderson 2005). In Montana, Doherty et al. (2008) found that sage-grouse selected for winter habitat within 4 km^2 of leks. Identifying lek buffers as critical sage-grouse habitat during multiple seasons has become integral information for range-wide management efforts. The Utah Division of Wildlife Resources (UDWR 2010) has used this relationship to identify core populations based on 4.83 km (3 mi) lek buffers. In the Bald Hills population, the probability of nest occurrence decreased to < 70% at distances greater than 5 km from an active lek. This is indicative that the 5-km lek distance is an important threshold for the Bald Hills population.

Habitat alteration including habitat management techniques and fire regimes can have major impacts on sage-grouse habitat (Connelly et al. 2000, Crawford et al. 2004). Given the various factors that are associated with habitat alteration (size, intensity, duration, weather, time since previous alteration, number of previous alterations, etc.), it is difficult to determine the impacts of habitat management techniques and fire on sage-grouse habitat use. Here, I combined habitat management techniques with fire regimes as

a categorical variable to determine on a broad scale how sage-grouse respond to

habitat alteration. My results show that birds prefer areas that have been altered due to

wildfire, broadcast burning, crushing, lop and scattering, mastication/mowing, seeding, or

thinning and avoid habitat that has not been altered within the previous 20 years This is

the first study, to my knowledge, that incorporates local habitat management techniques

and fire history into predictive modeling of sage-grouse suitable habitat. By directly

examining these important landscape-scale habitat variables, these results can be used to

guide habitat management decisions. While large population-wide habitat suitability

models can be useful when examining population dynamics across multiple regions,

states, and countries, this study demonstrates that important local adaptations and

management techniques should not be overlooked.

The projected CCFO Nest model accurately predicted sage-grouse presences in

the Hamlin Valley population. This independent validation demonstrates that the Nest

model did an excellent job of predicting suitable nest habitat within the CCFO. This

result implies that hens in the Bald Hills population select for similar landscape-scale

habitat characteristics for nesting habitat as other populations within the CCFO. The sum

of the low, medium, and high probability predicted areas within the CCFO was 1,799

km^2. Further field validation should be conducted to determine if other areas predicted as

having high probabilities of nest presences actually contain sage-grouse nests. In

addition, projecting the Bald Hills model statewide would allow comparison between the

habitat preferences of southern Utah populations with populations in the rest of the state.

Management techniques designed to improve nesting habitat throughout the CCFO

should focus on maintaining and increasing inter-mountain basins montane sagebrush

steppe habitat, as classified by SWReGAP landcover data. Additionally, the model predicted sage-grouse would initiate nests more often in areas < 5 km of a known active lek. Therefore, disturbance such as infrastructure development should be avoided within 5 km of known active leks, especially during the nesting season.

Brood Models

Elevation and habitat treatment were the top predictors of the Bald Hills Brood model. The importance of fire regime and vegetation treatment types in both the Nest and Brood model emphasizes the importance of local management data on predicting reproductive habitat for sage-grouse in southern Utah. Suitable brood-rearing habitat was located in areas that had some form of habitat alteration in the previous 20 years. The management techniques and wildfire occurrences used in this dataset represent diverse habitat alteration types in a mosaicked landscape. Birds may avoid habitat that is un-altered for long periods of time because this can allow sagebrush to outcompete grass and forb species, decreasing available forage and cover for reproductive hens (A. C. Burnett Chapter 2, West 2000). Managing habitat for patchy and altered fire regimes would be beneficial to both nesting and brood-rearing hens. In general, sage-grouse have been found to respond favorably to habitat manipulations, including those employed in the BLM CCFO (Connelly et al. 2000, Crawford et al. 2004, Stringham 2010). Further research on local management techniques and wildfire should investigate effects of different habitat treatment types and fire intensities while accounting for overlapping areas, time-effects, climate, and other confounding variables.

Due to the small sample size of broods, it is difficult to determine the accuracy of the Bald Hills Brood model when examining the predictive map. There are 4 telemetry

locations that were not well predicted by the map and there are a lot of areas with no

predicted-presence that have similar habitat characteristics as the presence points. The

predictive ability of this model may be limited because of the small sample of hens that

the brood data came from. This may result in individual preferences that the model is

unable to account for. The model is still useful, however, in determining areas within the

model extents that have similar habitat attributes as the actual brood sites. Further field

studies should attempt to increase the sample size of brood-rearing hens monitored as

well as search the predicted high probability of presence areas for the presence of broods.

Additionally, broods are often associated with riparian habitat, which is not readily

available within the Bald Hills study area (Connelly et al. 2000, Crawford et al. 2004).

Incorporating an accurate moisture or soils dataset may further improve the predictive

ability of the Brood model. Current moisture and soils datasets are not fine-scale enough

to detect differences within the Bald Hills study area (UDWR 2010).

The projected CCFO Brood model had low sensitivity as a predictor of brood-

rearing habitat in other populations, exemplified by the low number of Hamlin Valley

presence points accurately predicted (Fig. 4-11). This is likely due to 1) different

elevation preferences in other populations; elevation was the top model contributor, 2)

other populations requiring smaller habitat patches; the model predicts small areas of

suitable brood-rearing habitat near the Hamlin Valley telemetry locations, and/or 3) local

habitat alteration is an important predictor of brood-rearing habitat in southern Utah;

removing the habitat treatment variable (second highest model contributor to the Bald

Hills model) resulted in a less predictive model. All of these factors are likely to

influence the predictive ability of projected habitat suitability models. Results such as this

further emphasize the influence of local management techniques and their importance

when considering suitable sage-grouse habitat. I was unable here, however, to assess

different habitat treatment types or fire intensities as covariates. I do not recommend

large-scale habitat alteration projects without further investigation about how specific

treatments impact sage-grouse in both short-term and long-term studies. I do suggest that

using larger-scale habit models to plan management actions might overlook the influence

of local habitat management techniques, resulting in the improper alteration or

conservation of habitat.

Summer Models

The main predictors of suitable summer habitat in the Bald Hills model were

distance to nearest lek and elevation. Sage-grouse prefer to be near leks (< 2.5 km)

regardless of reproductive status, and at either low or high elevations (1,550 m – 1,600 m

or 2,300 m – 2,500 m). These top model predictors are similar to suitable summer habitat

variables predicted in an Oregon population using maxent (Freese 2009). The bimodal

distribution of elevation is unique, however, and may be indicative of two sub-

populations within the Bald Hills population adapting differently to low-moisture habitat

conditions (A. C. Burnett Chapter 2). The low-elevation birds primarily utilize

agricultural fields and adjacent lowland habitats. These birds are likely utilizing this

habitat to compensate for a lack of riparian-like habitat in the area. The agricultural fields

provide open water, lots of forbs, and high insect abundance. The high-elevation birds

primarily utilize the area that burned in the 2007 Greenville Bench wildfire. This area has

been re-seeded multiple times and provides native grasses and forbs, another possible

substitute for the lack of sustainable riparian habitat (Appendix Table A.1; A. C. Burnett

Chapter 3). These local adaptations further emphasize the unique habitat preferences within the Bald Hills population and management should reflect these different strategies.

The Summer Bald Hills and CCFO models had the same 3 top predictor variables. The CCFO model had some minor sensitivity issues within the Bald Hills model extents. The non-predicted presence locations within the Bald Hills model extents likely represent outlier individuals, pre-migratory movements, and/or emigration attempts (A. C. Burnett Chapter 2). The sensitivity was more problematic in the Hamlin Valley area, indicated by many presence points in areas that were not predicted as having suitable habitat (Fig. 4-16). The non-predicted presence locations in the Hamlin Valley area may indicate differing landscape-scale habitat use patterns between the two populations. This could be from the Hamlin Valley birds selecting for 1) landscape-scale variables other than distance to lek, elevation, and distance to high speed roads, 2) different variable responses to the variables included in the model, or 3) variables at a different resolution than examined here. The Bald Hills population has already been found to have different vegetation use patterns as compared with other populations (A. C. Burnett Chapter 3). Isolation between the Bald Hills and other populations within the CCFO may have led to differences in landscape-scale summer suitable habitat, as well (A. C. Burnett Chapter 2).

The presence/absence threshold map was successful in removing many isolated patches of areas predicted as having medium/high probability of presence values. This increased the accuracy because many of these areas were likely too small and isolated for sage-grouse to occupy. The presence/absence map further decreased the model sensitivity, however. This threshold may therefore be too limiting when predicting areas with suitable summer habitat. It may be more effective to develop thresholds based on the

availability of suitable habitat on the landscape. I would suggest using thresholds based on the standard deviation of the mean probability of presence value within the model extents, similar to the methods used to calculate low, medium, and high probability of presence areas for the Nest and Brood models. This method would also help managers prioritize habitat based on their classification as low, medium, or high habitat suitability.

While caution should be used when selecting management actions based on this model for areas outside of the Bald Hills, the model is still a useful tool. For example, based on my results, management techniques for sustaining and improving summer habitat that minimize disturbance within 5 km of known-active leks would have a high probability of success for sage-grouse conservation. In addition, the development of new high-speed roads should be limited.

Winter Models

I expected landcover and/or elevation to provide the greatest contributions to the Winter model based on other studies that have shown the importance of sagebrush height and cover (habitat attributes associated with landcover and elevation) on winter sage-grouse habitat (Connelly et al. 2000, Crawford et al. 2004, Doherty et al. 2008). Landcover and elevation were the 3rd and 4th top contributors to the model, respectively, with distance to lek and distance to high-speed roads providing the most predictive contributions. To my knowledge, this is the first study to examine the effect of road speed on winter habitat use. Sage-grouse in the Bald Hills population avoid high-speed roads in the winter and utilize habitat > 10 km from high-speed roads. The preference for wintering sage-grouse to be near leks is not unique, and was also found to influence

winter habitat selection in a Montana population (Battazzo 2007). The Bald Hills
Winter model predicted every presence location, indicating that variables such as
proximity to high-speed roads and leks should be examined when predicting winter
habitat in other sage-grouse populations.

The projected Winter CCFO model did an excellent job of predicting presence
locations from both the Bald Hills and Hamlin Valley data. The fit with the Hamlin
Valley data indicates that both populations share suitable habitat attributes during winter.
The good model fit (all but 1 independent presence location accurately predicted) to the
independently collected data suggests that the projected Winter CCFO model has good
predictive ability throughout the entire CCFO model extents. Conversely, the
presence/absence map increased the number of presence points that were inaccurately
predicted for both the Bald Hills and Hamlin Valley. Similar to the Summer model, the
threshold is too limiting with the goal of predicting potentially suitable habitat within the
CCFO. I would make the same suggestion for the Winter model as for the Summer model
and use a relative threshold based on the standard deviation of the mean probability of
presence value in order to designate areas as providing no, low, medium, or high quality
winter habitat.

Management goals for the conservation of winter habitat should have very similar
techniques as for the management of summer habitat. Disturbances within 5 km of
known-active leks should be avoided and the development of new high-speed roadways
should be conducted > 10 km from current winter habitat. While these parameters
provided the most predictive ability to the model, landcover was still an important
variable for winter habitat. Local management should focus on maintaining and

increasing the availability of inter-mountain basins big sagebrush shrubland,

Colorado Plateau mixed low sagebrush shrubland and inter-mountain basins semi-desert

grassland. While invasive annual grassland was used as suitable winter habitat,

management should consider other impacts of invasive grass species and focus efforts on

re-establishing native grass habitats where there is currently non-native grass habitats.

Important Predictor Variables of Sage-Grouse Habitats

While each projected CCFO model had different top predictor variables,

landcover, elevation, distance to nearest lek, and distance to high-speed roads where the

most predictive variables across all CCFO models. These variables should be paid close

attention when developing management strategies within the CCFO, as well as in

southern Utah. Managing for particular landcover types and minimizing disturbances

year-round within 5 km of known-active leks is the most direct way to address these

predictors of suitable habitat.

Landcover use for all models indicated that inter-mountain basins montane

sagebrush steppe (landcover class 62), inter-mountain basins semi-desert shrub steppe

(landcover class 67), and rocky mountain gambel oak-mixed montane shrubland

(landcover class 41), Colorado plateau mixed low sagebrush shurbland (landcover class

50), inter-mountain basins montane sagebrush steppe (landcover class 58), and inter-

mountain basins semi-desert grassland (landcover class 76) provided the most suitable

winter habitat (Table 4-2). These landcover types indicate that the Bald Hills sage-grouse

inhabit habitat more similar to the Great Basin ecosystem as compared with sagebrush

steppe ecosystems (A. C. Burnett Chapter 3, West 2000). This would cause inherently

different habitat use patterns in southern Utah populations as compared with higher

density populations that occupy sagebrush steppe habitats (A. C. Burnett Chapter 3).

The distance to lek variable may be indicative that the Core Regions Concept may

be an effective method of managing southern Utah sage-grouse populations year-round

(Holloran and Anderson 2005, Fedy et al. 2012, UDWR 2009). This strategy has already

been used to develop the Core Regions Concept in Utah, as well as other states, where lek

density circles are developed using a lek buffer and density information about every lek

in the state. The result is a representation of "hot-spots", where core populations that

represent the greatest percentages of the state's breeding populations are identified. These

core areas have become the focus for mitigation and habitat restoration efforts (UDWR

2009). The results of this research suggest that protecting Core Regions, as defined by a

5-km buffer around all known-active leks is applicable to Utah populations as well as

southern fringe populations year-round. By providing greater protections for higher

density leks, the Core Regions Concept may not adequately protect fringe popultions,

however. Fringe populations, such as the Bald Hills population, often persist at lower

densities than more central populations, which would decrease the protection status

afforded to important fringe populations (Lesica and Allendorf 1995). I therefore suggest

that when employing the Core Regions Concept, densities be assessed relative to

neighboring populations, rather than relative to the meta-population.

Distance to slow-speed roads, slope, and aspect were consistently poor predictors

across all of the CCFO models. This affirms my assumption that low-speed roads ($\leq$ 35

mph) represent roads with decreased disturbance to habitat and wildlife because they had

less traffic, narrower widths, and greater quantities of dirt roads. This study provides a

unique look at the effects of different road types, classified by speed, on sage-grouse habitat utilization. Slope and aspect have provided greater predictive contributions in other studies as compared with this study (Yost et al. 2008, Freese 2009, Atamian et al. 2010, Crabb and Black 2011). The low predictive contribution of these variables in this study supports the hypothesis that the southern Utah fringe populations may have unique behaviors. This result also indicates that the variables included in this study that have not previously been used in sage-grouse habitat models are biologically significant and should be accounted for in future sage-grouse habitat modeling.

Habitat treatment was an important variable in the majority of the Bald Hills models. By combining all habitat management techniques employed in the Bald Hills region with all wildfires that occurred within the previous 20 years I was unable to determine impacts of individual habitat alteration types. Habitat alteration is very complex to examine because of confounding variables such as patch size, intensity, duration, climatic variables, time since previous alteration, number of previous alterations, and others. I have shown, however, that habitat alteration is an important predictor have sage-grouse habitat use in southern Utah with birds selecting for areas that have been altered within the previous 20 years. Because specific impacts of different habitat treatment types (broadcast burning, crushing, lop and scattering, mastication/mowing, seeding, or thinning) and wildfires (size, duration, intensity, year) could not be examined here, it is important that the results of this study are not misinterpreted and that managers do not use these techniques indiscriminately. The results of this study do suggest that local habitat management techniques are an important driver of sage-grouse habitat selection and should be considered when predicting suitable

sage-grouse habitat. While many sage-grouse habitat improvement projects have been conducted throughout sage-grouse habitat, more long-term studies need to be conducted in order to determine the most effective short-term and long-term habitat management techniques.

While it was not a top contributor to any model, distance to energy development was an important predictor variable (0.32% – 10.39% contribution, 4th – 10th contributor) of suitable sage-grouse habitat for all of the seasonal models. All of the models showed a positive relationship where the probability of presence increased to > 50% at distances > 8 km indicating avoidance, which is consistent with other studies (Walker et al. 2007, Doherty et al. 2008, Holloran et al. 2009, Harju et al. 2010). I was unable to examine any time-effect which would detect any ability of birds to acclimate to energy infrastructure. Further examination of potential mechanisms for sage-grouse acclimation to energy infrastructure, including a potential time-lag effect, will have broader implications for sage-grouse populations in the face of increased energy development pressures population-wide (BLM 2011). For management of sage-grouse habitat in the CCFO, a conservative strategy would avoid developing additional energy projects < 8 km from current habitat, particularly for nesting and brood-rearing habitat because reproductive birds are less likely to acclimate to the disturbance (Harju et al. 2010).

This was the first study to produce a SDM for a southern fringe sage-grouse population. All models produced habitat suitability maps with high predictive ability for the Bald Hills population. Local management strategies were found to play an important role in sage-grouse habitat selection in the Bald Hills region. The models were projected to the CCFO with mixed results. This is suggestive that habitat use in the Bald Hills

population is more similar to other CCFO populations during nesting and winter and more unique during brood-rearing and summer. In addition, projected CCFO models predicted less accurately when local management techniques were top predictors in the corresponding Bald Hills models, further implicating the importance of local management. This study provides evidence that while useful, population-wide SDMs are not able to incorporate important local adaptations and management techniques. SDMs produced within management areas are more effective in determining any unique population behaviors as well as sage-grouse responses to local management techniques.

MANAGEMENT IMPLICATIONS

Using Maxent to develop species distribution models at a local scale is a useful technique when focusing on fringe populations of decreasing populations. Fringe populations may select for different habitat attributes resulting in unique definitions of suitable habitat as compared with other populations. Differences in landscape-scale habitat preferences may not be universal across all seasons, exemplified by the Bald Hills population. This information is essential when managing fringe populations and using SDMs are useful in identifying if landscape-scale habitat preference differences are occurring. We now know, for example, that summer habitat in the Bald Hills population varies from summer habitat in the Hamlin Valley population, which corroborates previous results showing that habitat in the Bald Hills population varied from species habitat guidelines (A. C. Burnett Chapter 3; Connelly et al. 2000).

SDMs can also be useful in guiding field surveys to detect the extent of sage-grouse population presence. Since distance to lek was a predictor in all of the seasonal models, areas with high probability of presence values that were not associated with

known leks should be surveyed with the goal of identifying potentially new and unknown leks. Additional presence/absence field surveys can also act as another independent model validation method.

Further research should develop methods to examine how different habitat alteration types impact habitat selection patterns of local populations. Local habitat management techniques should be considered when developing habitat suitability models for sage-grouse at small and large scales. Threshold maps are the most effect maps to determine low, medium, and high probability of presence areas for sage-grouse. Thresholds should be determined by the standard deviation of the mean probability of presence value within the model extents rather than the equality of sensitivity and specificity thresholds.

In order to manage for sustained sage-grouse populations in southern Utah, disturbances should not be allowed within 5 km of leks year-round. Habitat alterations should be employed in order to maintain and increase landcover types that are selected for by the Bald Hills population (inter-mountain basins montane sagebrush steppe (landcover class 62), inter-mountain basins semi-desert shrub steppe, and rocky mountain gambel oak-mixed montane shrubland, Colorado plateau mixed low sagebrush shurbland, inter-mountain basins montane sagebrush steppe, and inter-mountain basins semi-desert grassland; A. C. Burnett Chapter 3). Development of renewable energy resources should be avoided within high probability of presence areas, within migration cooridors, and within 5 km of active leks, year round (A. C. Burnett Chapter 3). By incorporating new information into current management practices, managers will be more able to sustain

and increase the quantity and quality of sage-grouse habitat locally and throughout

the sage-grouse distribution.

LITERATURE CITED

Aldridge, C., and M. S. Boyce. 2007. Linking occurence and fitness to persistence: Habitat-based approach for endangered Greater sage-grouse. Ecological Applications 17:508-526.

Aldridge, C., R. Lee, P. Jones, and J. Nicholson. 2004. Winter habitat selection and survival by sage-grouse in southeastern Alberta. Final Project Report for 2003-2004 Sage-Grouse Funding Partners. Fort Collins, Colorado, USA.

Aldridge, C., S. E. Nielsen, H. L. Beyer, M. S. Boyce, J. W. Connelly, S. T. Knick, and M. A. Schroeder. 2008. Range-wide patterns of greater sage-grouse persistence. Diversity and Distributions 14:983-994.

Anderson, R. P., and A. Raza. 2010. The effect of the extent of the study region on GIS models of species geographic distributions and estimates of niche evolution: Preliminary tests with montane rodents (genus *Nephelomys*) in Venezuela. Journal of Biogeography 37:1378-1393.

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

Baldwin, R. A. 2009. Use of maximum entropy modeling in wildlife research. Entropy 11:854-866.

Barbet-Massin, M., F. Jiguet, C. H. Albert, and W. Thuiller. 2012. Selecting pseudo-absences for species distribution models: how, where and how many? Methods in Ecology and Evolution 3:327-338.

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

Battazzo, A. M. 2007. Winter survival and habitat use by female greater sage-grouse in South Phillips County, Montana 2004-2006. Thesis. University of Montana, Missoula, Montana, USA.

Bureau of Land Management [BLM]. 2011. The BLM's balancing act: managing the needs of people and sage-grouse on public lands. <http://www.blm.gov/wo/st/en/prog/more/fish__wildlife_and/sage-grouse-conservation/energy.html> accessed 8/10/2012.

Carbonell, R., J. Perez-Tris, and J. L. Telleria. 2003. Effects of habitat heterogeneity and local adaptation on the body condition of a forest passerine at the edge of its distributional range. Biological Journal of the Linnean Society 78:479-488.

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

Connelly, J. W., and C. E. Braun. 1997. Long-term changes in sage grouse *centrocercus urophasianus* populations in western North America. Wildlife Biology 3:229-234.

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

Crabb, B., and T. A. Black. 2011. Development of statewide 30 meter winter sage-grouse
habitat models for Utah. Utah State University Cooperative Extension. Logan,
Utah, USA.

Crawford, J. A., R. A. Olson, N. E. West, J. C. Mosley, M. A. Schroeder, T. D. Whitson,
R. F. Miller, M. A. Gregg, and C. S. Boyd. 2004. Ecology and management of
sage-grouse and sage-grouse habitat. Rangeland Ecology & Management 57:2-19.

Dahlgren, D. K., R. Chi, and T. A. Messmer. 2006. Greater sage-grouse response to
sagebrush management in Utah. Wildlife Society Bulletin 34:975-985.

Doherty Jr., P. F., T. Boulinier, and J. D. Nichols. 2003. Local extinction and turnover
rates at the edge and interior of a species' range. Finnish Zoological and Botanical
Publishing Board 40:145-153.

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

Doherty, K. E., D. E. Naugle, and B. L. Walker. 2010. Greater sage-grouse nesting
habitat: the importance of managing at multiple scales. The Journal of Wildlife
Management 74:1544-1553.

Elith, J., C. H. Graham, R. P. Anderson, M. Dudík, S. Ferrier, A. Guisan, R. J. Hijmans,
F. Huettmann, J. R. Leathwick, A. Lehmann, J. Li, L. G. Lohmann, B. A.
Loiselle, G. Manion, C. Moritz, M. Nakamura, Y. Nakazawa, J. McC. M.

Overton, A. Townsend Peterson, S. J. Phillips, K. Richardson, R. Scachetti-Pereira, R. E. Schapire, J. Soberón, S. Williams, M. S. Wisz, and N. E. Zimmermann. 2006. Novel methods improve prediction of species' distributions from occurrence data. Ecography 29:129-151.

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

Fedy, B. C., C. L. Aldridge, K. E. Doherty, M. O'Donnell, J. L. Beck, B. Bedrosian, M. J. Holloran, G. D. Johnson, N. W. Kaczor, C. P. Kirol, C. A. Mandich, D. Marshall, G. McKee, C. Olson, C. C. Swanson, and B. L. Walker. 2012. Interseasonal movements of greater sage-grouse, migratory behavior, and an assessment of the core regions concept in Wyoming. The Journal of Wildlife Management 76:1062-1071.

Fisher, D. O. 2011. Trajectories from extinction: where are missing mammals rediscovered? Global Ecology and Biogeography 20:415-425.

Franklin, J. 2011. Mapping species distributions: spatial inference and prediction. Cambridge University Press, Cambridge, UK.

Freese, M. T. 2009. Linking greater sage-grouse habitat use and suitability across spatiotemporal scales in central Oregon. Thesis. Oregon State University, Corvallis, Oregon, USA.

Haak, A. L., J. E. Williams, H. M. Neville, D. C. Dauwalter, and W. T. Colyer. 2010. Conserving peripheral trout populations: the values and risks of life on the edge. Fisheries 35:530-549.

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

Hernandez, P. A., C. H. Graham, L. L. Master, and D. L. Albert. 2006. The effect of sample size and species characteristics on performance of different species distribution modeling methods. Ecography 29:773-785.

Holloran, M. J., and S. H. Anderson. 2005. Spatial distribution of greater sage-grouse nests in relatively contiguous sagebrush habitats. The Condor 107:742-752.

Holloran, M. J., R. C. Kaiser, and W. A. Hubert. 2009. Yearling greater sage-grouse response to energy development in Wyoming. Journal of Wildlife Management 74:65-72.

Ikeda, D. H. 2010. The conservation ecology of *Cynomys parvidens*: predicting potential species distribution and the impact of climate change. M.S. Thesis, Northern Arizona University, Flagstaff, AZ.

Lesica, P., and F. W. Allendorf. 1995. When are peripheral populations valuable for conservation? Conservation Biology 9:753-760.

Liu, C., P. M. Berry, T. P. Dawson, and R. G. Pearson. 2005. Selecting thresholds of occurrence in the prediction of species distributions. Ecography 28:385-393.

Moynahan, B. J., M. S. Lindberg, and J. W. Thomas. 2006. Factors contributing to process variance in annual survival of female Greater sage-grouse in Montana. Ecological Applications 16:1529-1538.

Oyler-McCance, S. J., and P. L. Leberg. 2005. Conservation genetics in wildlife biology. Sixth edition. Pages 632-657 *in* C. E. Braun, editor. Techniques for wildlife investigations and management. The Wildlife Society, Bethesda, Maryland, USA.

Palmer, W. E., and S. D. Wellendorf. 2007. Effect of radiotransmitters on northern bobwhite annual survival. The Journal of Wildlife Management 71:1281-1287.

Pearson, R. G., C. J. Raxworthy, M. Nakamura, and A. Townsend Peterson. 2007. Original article: Predicting species distributions from small numbers of occurrence records: A test case using cryptic geckos in Madagascar. Journal of Biogeography 34:102-117.

Phillips, S. J., R. P. Anderson, and R. E. Schapire. 2006. Maximum entropy modeling of species geographic distributions. Ecological Modelling 190:231-259.

Phillips, S. J., and M. Dudík. 2008. Modeling of species distributions with maxent: new extensions and a comprehensive evaluation. Ecography 31:161-175.

Phillips, S. J., M. Dudík, J. Elith, C. H. Graham, A. Lehmann, J. Leathwick, and S. Ferrier. 2009. Sample selection bias and presence-only distribution models: implications for background and pseudo-absence data. Ecological Applications 19:181-197.

Schrag, A., S. Konrad, S. Miller, B. Walker, and S. Forrest. 2011. Climate-change impacts on sagebrush habitat and west nile virus transmission risk and conservation implications for greater sage-grouse. GeoJournal 76:561-575.

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

Schroeder, M. A., J. R. Young, and C. E. Braun. 1999. Greater sage-grouse
(*Centrocercus urophasianus*), the birds of North America Online (A. Poole, Ed.).
Ithaca: Cornell Lab of Ornithology; Retrieved from the Birds of North America
Online: http://bna.birds.cornell.edu/bna/species/425. Accessed 12 Oct 2012.

Smith, A. 2012. An introduction to best practices in species distribution modeling in
conservation; a short course. 2012 Society for Conservation Biology's North
American Congress for Conservation Biology July 14, 2012.

Soberón, J. 2007. Grinnellian and eltonian niches and geographic distributions of species.
Ecology Letters 10:1115-1123.

Stringham, R. B. 2010. Greater sage-grouse response to sagebrush reduction treatments
in Rich County, Utah. Thesis. Utah State University, Logan, Utah, USA.

Sveum, C. M., W. D. Edge, and J. A. Crawford. 1998. Nesting habitat selection by sage
grouse in south-central Washington. Journal of Range Management 51:265-269.

U. S. Fish and Wildlife Service (USFWS). 2010. Endangered and threatened wildlife and
plants; 12-month findings for petitions to list the Greater sage-grouse
(*Centrocercus urophasianus*) as threatened or endangered. 50 CFR Part 17.
Department of the Interior; Federal Register, Washington, D.C., USA.

Utah. Division of Wildlife Resources (UDWR) 2009. Utah greater sage-grouse
management plan. Utah Department of Natural Resources, Division of Wildlife
Resources Publication 09-17, Salt Lake City, Utah, USA.

Utah Division of Wildlife Resources (UDWR). 2010. Utah Automated Geographic
Reference Center (AGRC). Spatial data for Utah, USA.
<http://gis.utah.gov/download>. Accessed 2 April 2012.

Wakkinen, W. L. 1990. Nest site characteristics and spring-summer movements of migratory sage grouse in southeastern Idaho.

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

West, N. E. 2000. Synecology and disturbance regimes of sagebrush steppe ecosystems. *In* proceedings of the sagebrush steppe ecosystems symposium. Biose State University, Boise, Idaho, USA.

West, N.E., and J.A. Young. 2000. Ch. 7 (Intermountain Valleys and Lower Mountain Slopes). *In* M.G. Barbour and W.D. Billings, editors. North American terrestrial vegetation. 2nd Ed. Cambridge University Press, Cambridge, UK.

Western Regional Climate Center [WRCC]. 2012. Utah climate summaries. <http://www.Wrcc.Dri.Edu/>. Accessed 20 November 2012.

Wisz, M. S., R. J. Hijmans, J. Li, A. T. Peterson, C. H. Graham, A. Guisan, and N. P. S. D. W. Groups. 2008. Effects of sample size on the performance of species distribution models. Diversity and Distributions 14:763-773.

Yost, A. C., S. L. Petersen, M. A. Gregg, and R. F. Miller. 2008. Predictive modeling and mapping sage grouse (*Centrocercus urophasianus*) nesting habitat using maximum entropy and a long-term dataset from southern Oregon. Ecological Informatics 3:375-386.

Young, J. R., C. E. Braun, S. J. Oyler-McCance, J. W. Hupp, and T. W. Quinn. 2000. A new species of sage-grouse (phasianidae: *Centrocercus*) from southwestern Colorado. The Wilson Bulletin 112:445-453.

CHAPTER 5

SUMMARY

Greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse) have been studied extensively over the past 15 years. Few studies have examined population dynamics at the periphery of the sage-grouse distribution and this was the first study of a fringe population at the southern edge of the species distribution. This study has added to the increasing literature that indicates peripheral populations as occupying marginal habitat compared with more central populations with greater connectivity. The importance of this study is compounded by the high potential for wind, solar, and/or geothermal energy development in the Bald Hills study area. Results presented here lay the groundwork for the potential of future post-development studies on this sage-grouse population. In order to examine the spatial and habitat use patterns of the Bald Hills population I tracked 66 birds (17 females & 49 males) via VHF telemetry in 2011 and 2012.

The first objective of my research was to establish basic information about the Bald Hills population's seasonal movements, distributions, and home ranges. My results indicated the population was primarily 1-stage migratory (80%), with some birds exhibiting non-migratory (10%) or 2-stage migratory (10%) patterns. Migratory movement dates varied more in the spring than in the fall, with a spring migratory period of 10 March to 30 May, and a fall migratory period of 8 October to 12 November. Population-wide seasonal distributions for nest and brood-rearing (225 km2), summer (869 km2), and winter (603 km2) varied from the Utah Division of Wildlife suitable

habitat maps for the area. Mean home range sizes for individuals in summer (82 km2,

95% CI = 38.84-125.16) and winter (157.82 km2, 95% CI = 76.95-238.69) may provide

new information about seasonal habitat patch size requirements for the species.

I examined habitat use in the Bald Hills population at multiple spatial scales,

using measured vegetation characteristics then using habitat characteristics obtained from

GIS. First, I surveyed vegetation plots at nest ($n = 9$), brood-rearing ($n = 13$), summer (n

$= 53$), and random ($n = 75$) locations in 2011 and 2012. Nest sites were characterized by

$36.00 \pm 5.86\%$ ($\bar{x} \pm$ SE) shrub, $4.74 \pm 2.67\%$ forb, and $13.23 \pm 1.62\%$ grass canopy

cover. Brood-rearing sites were characterized by $28.08 \pm 2.84\%$ shrub, $16.86 \pm 3.68\%$

forb, and $12.72 \pm 1.51\%$ grass canopy cover. Nesting and brood-rearing hens only

selected for greater forb cover at brood-rearing sites as compared with random sites

within the study area. Summer sites were characterized by $9.21 \pm 1.11\%$ shrub cover,

16.19 ± 2.06 forb cover, 21.71 ± 1.78 grass cover, and 37.63 ± 1.78cm mean maximum

grass height. Birds at summer sites selected for different distributions and variances of

multiple habitat variables from random sites. For all plot types, shrub canopy cover was

greater than in other populations while canopy cover of grasses and forbs were lower.

In my last chapter, I developed seasonal distribution models (nesting, brood-

rearing, summer, and winter) to predict and map the habitat use and potential distribution

of sage-grouse in the Bald Hills population using habitat characteristics from GIS. I

developed the models with Maximum Entropy (maxent) software using telemetry data

collected from the Bald Hills population and projected the models to the Bureau of Land

Management Cedar City Field Office (CCFO). Independently collected data from another

population within the CCFO was used to assess similarities between the Bald Hills

population and this other population in southern Utah. Nine predictor variables were examined including elevation, slope, aspect, landcover, distance to nearest lek, distance to nearest road (high speed and slow speed roads), distance to energy infrastructure, and habitat treatment type (including wildfire and habitat management techniques). All models produced excellent model fit (AUC > 0.900) for the telemetry data. Local management strategies had high predictive ability during all seasons in the Bald Hills region. Other variable responses were also similar among seasons. Distances to leks > 5 km decreased the probability of presences for all seasons. Distance to high-speed roads had a positive relationship with suitable habitat, while distance to low-speed roads was not as correlated. Similarly, the probability of sage-grouse presences increased as distances to energy infrastructure increased. The models were projected with mixed results, suggesting that habitat use in the Bald Hills population is more similar to other CCFO populations during nesting and winter and more unique during brood-rearing and summer. In addition, projected CCFO models predicted less accurately when local management techniques were top predictors in the corresponding Bald Hills models, further implicating the importance of local management techniques.

This was the first study of the Bald Hills population, a fringe and isolated sage-grouse population at the southern periphery of the population distribution. By quantifying basic seasonal space use patterns exhibited by this population, I was able to develop more complex seasonal habitat models for this population. My results show this population as having large home ranges (Chapter 2), migratory behavior (Chapter 2), occupying marginal habitat based on measured vegetation characteristics (Chapter 3), and using habitat attributes varied from other populations based on landscape-scale GIS habitat

characteristics (Chapter 4). All of these results indicate that the Bald Hills population has developed some unique behaviors to compensate for occupying marginal habitat. As an isolated population (Chapter 2), this population exhibits many characteristics of peripheral populations that increase their extinction risk. This data will help inform local management techniques so that current habitat conditions are maintained while the quantity and quality of grasses, forbs, and riparian habitat are increased. Future work should focus on the reproductive success of this population in order to determine if this population has adapted to local habitat conditions or if the local habitat conditions are limiting sage-grouse productivity.

Management goals for sage-grouse, and other declining species, focus on maximizing results for minimal cost and effort resulting in focused efforts on large and more central populations with high connectivity. These techniques may disregard the unique habitat requirements of southern and other peripheral populations. Developing species distribution models for declining species is a useful management tool to mitigate these threats to fringe populations. Predictive maps can be used to guide fieldwork, identify similarities and differences between different populations, and detect unidentified areas that may be occupied by species of concern. In the Bald Hills population, for example, we can now provide local managers with specific recommendations for optimizing sage-grouse habitat as well as identifying new habitat, such as potential unidentified leks. I hope that the increasing literature on the uniqueness and importance of fringe populations in declining species will prompt more management efforts focused on mapping and managing specifically for these populations to ensure their persistence.

APPENDICES

Table A.1. Composition of seed mix for the Greenville Bench wildfire treatment (July 2007, C.S. Pontarolo, Bureau of Land Management, unpublished data).

Seed Type	Common Name	Scientific Name
Native grass	Bluebunch wheatgrass	*Pseudoroegneria spicata*
Native grass	Thickspike wheatgrass	*Elymus lanceolatus*
Native grass	Intermediate wheatgrass	*Thinopyrum intermedium*
Native grass	Western wheatgrass	*Pascopyrum smithii*
Native grass	Indian ricegrass	*Achnatherum hymenoides*
Native forb	Alfalfa	*Medicago sativa*
Native forb	Palmers penstemon	*Penstemon palmeri*
Non-native forb	Western yarrow	*Achillea millefolium*
Non-native forb	Small burnet	*Sanguisorba minor*
Non-native forb	Sainfoin	*Onobrychis vicifolia*
Non-native forb	Ladak alfalfa	*Medicago ladak*
Non-native forb	Lewis flax	*Linum lewisii*
Native shrub	Antelope bitterbrush	*Purshia tridentate*
Native shrub	Wyoming big sagebrush	*Artemisia tridentata wyomingensis*
Native shrub	Mountain big sagebrush	*Artemisia tridentata vaseyana*

Table A.2. Dominant plant species found in vegetation plots with associated habitat classification types (UDWR 2010).

Habitat Classification Type	Definition	Plant Type	Common Name	Scientific Name
Grass	Landscape dominated by grass species	Grass	Cheatgrass	*Bromus tectorum*
			Crested Wheatgrass	*Agropyron cristatum*
			Indian Ricegrass	*Achnatherum hymenoides*
			Intermediate Wheatgrass	*Thinopyrum intermedium*
			Needle and Thread Grass	*Hesperostipa comate*
			Squirreltail	*Elymus elymoides*
			Thickspike Wheatgrass	*Elymus lanceolatus*
Grass Mix	Landscape dominated by mixture of grass species and another habitat classification type	Shrub	See Shrub species under Sagebrush Habitat Classification Type	
		Forb	Alfalfa	*Medicago sativa*
			Annual Mustard	*Brassicaceae* spp.
			Field Bindweed	*Convolvulus arvensis*
			Scarlet Gilia	*Ipomopsis aggregate*
			Scarlet Globemallow	*Sphaeralcea coccinea*
			Hood's Phlox	*Phlox hoodia*
			Lupine	*Lupinus* spp.
			Mountain Dandelion	*Agoseris glauca*
			Mojave Sandwort	*Arenaria macradenia*
			Small Burnet	*Sanguisorba minor*
			Milkvetch	*Astragalus* spp.
			Blue Flax	*Linum perenne*
			Woolly Groundsel	*Packera cana*
			Common Yarrow	*Achillea millefolium*

		Grass	See Grass species under Grass Habitat Classification Type	
Pinyon-Juniper Mix	Landscape dominated by mixture of Utah Juniper (*Juniperus osteosperma*) and another habitat classification type	Shrub Forb Grass	See Shrub species under Sagebrush Habitat Classification Type See Forb species under Grass Mix Habitat Classification Type See Grass species under Grass mix Habitat Classification Type	
Sagebrush	Landscape dominated by sagebrush species	Shrub	Mountain Big Sagebrush Bitterbrush Black Sagebrush Utah Juniper Gambel Oak Rubber Rabbitbrush Greasewood Halogeton Russian Thistle Shadscale Snakeweed Wyoming Big Sagebrush	*Artemisia tridentata vaseyana* *Purshia tridentate* *Artemisia nova* *Juniperus osteosperma* *Quercus gambelii* *Ericameria nauseosa* *Sarcobatus vermiculatus* *Halogeton glomeratus* *Salsola tragus* *Atriplex confertifolia* *Gutierrezia sarothrae* *Artemisia tridentata wyomingensis*
Sagebrush Mix	Landscape dominated by sagebrush species and another habitat classification type	Shrub Forb Grass	See Shrub species under Sagebrush Habitat Classification Type See Forb species under Grass Mix Habitat Classification Type See Grass species under Grass Habitat Classification Type	
Salt-desert Shrub	Landscape dominated by salt-desert shrub species (greasewood, shadescale, rabbitbrush, Russian thistle)	Shrub Forb Grass	See Shrub species under Sagebrush Habitat Classification Type See Forb species under Grass Mix Habitat Classification Type See Grass species under Grass Habitat Classification Type	

Post-fire Rehabilitation Treatment	Area re-seeded after Greenville Bench wildfire (Appendix Table A.1)	Shrub	Antelope bitterbrush	*Purshia tridentate*
			Wyoming big sagebrush	*Artemisia tridentata wyomingensis*
			Mountain big sagebrush	*Artemisia tridentata vaseyana*
		Forb	Alfalfa	*Medicago sativa*
			Palmers penstemon	*Penstemon palmeri*
			Western yarrow	*Achillea millefolium*
			Small burnet	*Sanguisorba minor*
			Sainfoin	*Onobrychis vicifolia*
			Ladak alfalfa	*Medicago ladak*
			Lewis flax	*Linum lewisii*
		Grass	Bluebunch wheatgrass	*Pseudoroegneria spicata*
			Thickspike wheatgrass	*Elymus lanceolatus*
			Intermediate wheatgrass	*Thinopyrum intermedium*
			Western wheatgrass	*Pascopyrum smithii*
			Indian ricegrass	*Achnatherum hymenoides*