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Greater Sage-Grouse Vital Rate and Habitat Use Response to Landscape Scale Habitat Manipulations and Vegetation Micro-Sites in Northwestern Utah

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GREATER SAGE-GROUSE VITAL RATE AND HABITAT USE RESPONSE TO LANDSCAPE SCALE HABITAT MANIPULATIONS AND VEGETATION MICRO-SITES IN NORTHWESTERN UTAH

by

Charles P. Sandford

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

MASTER OF SCIENCE

in

Wildlife Biology

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UTAH STATE UNIVERSITY
Logan, Utah

2016
ABSTRACT

Greater Sage-grouse Vital Rate and Habitat Use Response to Landscape Scale Habitat Manipulations and Vegetation Micro-Sites in Northwestern Utah

by

Charles P. Sandford, Master of Science
Utah State University, 2016

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

The greater sage-grouse (Centrocercus urophasianus; sage-grouse) has been a species of conservation concern since the early 20th century due to range-wide population declines. To contribute to knowledge of the ecology of sage-grouse populations that inhabit the Box Elder Sage Grouse Management Area (SGMA) in northwestern Utah and quantify their responses to landscape scale habitat manipulations, I monitored vital rates and habitat selection of 45 female sage-grouse from 2014 to 2015. Using telemetry locations of female sage-grouse with known nest and brood fates, I created Generalized Linear Mixed Models to estimate the influence of proximity to pinyon (Pinus spp.) and juniper (Juniperus spp.; conifer) encroachment, and removal projects may have on sage-grouse reproductive fitness in the Box Elder SGMA. The best fit model suggested that for every 1 km a nest was located away from a conifer removal area, probability of nest success was reduced by 9.1% ($\beta = -0.096$, $P < 0.05$). Similarly, for every 1 unit increase in the log-odds of selection for distance to treatment, probability of brood success
declined by 52.6% ($P = 0.09$). The probability of brood success declined by 77.2% ($P < 0.05$) as selection for conifer canopy cover increased.

To evaluate sage-grouse habitat use, I used fecal pellet surveys to estimate relative pellet density in conifer encroachment, removal, and undisturbed sagebrush areas. Sage-grouse pellet densities were estimated at 4.6 pellets/ha (95% CI = 1.2, 10.9), 8.6 pellets/ha (95% CI = 3.8, 15.2), and 50.6 pellets/ha (95% CI = 36.8, 69.6), in conifer encroachment, removal, and undisturbed sagebrush areas respectively. Density estimates did not statistically differ between conifer encroachment and removal areas.

To determine if vegetation micro-site characteristics at sage-grouse use sites influenced nest or brood fate, I recorded standard vegetation measurements for all radio-marked sage-grouse nests and a stratified random sample of brood-use sites from 2014-2015 and compared them to random sites. Micro-site vegetation characteristics measured did not differ for successful and unsuccessful nests. Many characteristics differed between micro-sites used by successful broods and those used by unsuccessful broods. Sites used by successful broods also differed from random sites.
The greater sage-grouse (Centrocercus urophasianus; sage-grouse) has been a species of conservation concern since the early 20th century. The decline of populations has largely been attributed to loss and degradation of sagebrush (Artemisia spp.) habitats. To contribute to the knowledge of sage-grouse ecology and quantify the effectiveness of landscape scale habitat manipulations intended to benefit sage-grouse, I monitored habitat use and vital-rates (i.e., nest and brood success) of 45 sage-grouse females in the Box Elder Sage-Grouse Management Area (SGMA) in northwestern Utah. Using telemetry locations of sage-grouse females with known nest and brood fates, I generated statistical models to estimate the influence of proximity to conifer encroachment and conifer removal projects on sage-grouse reproductive fitness. The probability of nest success declined as sage-grouse females selected areas further from conifer removal areas. Similarly, probability of brood success declined as sage-grouse selected for areas further from conifer removal areas. The probability of brood success also declined as sage-grouse females selected sites closer to conifer encroachment areas.

To evaluate sage-grouse habitat-use responses to mechanical conifer removal treatments, I used fecal pellet surveys to estimate relative densities of sage-grouse pellets in conifer encroachment, removal, and undisturbed sagebrush habitats. Sage-grouse pellet densities were highest in undisturbed sagebrush habitats than conifer removal
treatments or conifer encroachment. Sage-grouse pellet densities were not statistically
different in areas where conifer treatments where completed than conifer encroached
areas.

To investigate whether micro-site vegetation characteristics influenced sage-
grouse nest or brood success, I analyzed standard vegetation measurements (i.e., Visual
Obstruction Reading (VOR), percent shrub canopy, sagebrush canopy, forb canopy, grass
canopy, litter, bare ground, and rock cover, and shrub, sagebrush, forb, and grass height)
recorded at all radio-marked sage-grouse nests and stratified brood sites from 2014-2015.
I also compared these data to vegetation micro-site characteristics collected at random
sites. The vegetation micro-site characteristics recorded did not differ between successful
and unsuccessful sage-grouse nests. Many vegetation characteristics differed between
sites used by successful broods compared to unsuccessful broods. Many vegetation
characteristics also differed between sites used by successful broods, and random sites.
ACKNOWLEDGMENTS

I would like to start by thanking Dr. Terry Messmer, my major advisor, for being such an influential person to Utah’s sage-grouse conservation and research. He has been critical to coordinating and implementing research, and building strong connections in the rural communities most affected by the sage-grouse’s sensitive status. As a student of Terry’s I have not only learned a great deal of sage-grouse ecology, but I have also learned about the social and political aspects of wildlife management. I would also like to thank my committee members, Eric Thacker for his rangeland expertise, and Tom Edwards for his statistical and programming advice. I also thank Dave Dahlgren for his input across all aspects of my research.

Thanks to Joe Smith and Mark Szczypinski for getting me started in the sage-grouse world, and helping me make the connections necessary to further my education. Thanks to Avery Cook and Brian Wing for establishing a working relationship with landowners in my study area. Thanks to Leah Lewis, Jeff Schick, and the landowners of west Box Elder County for their help acquiring and protecting private property information. Thanks to Mary Conner for her assistance as I explored data in MARK. Jason Carlisle stepped up with very short notice to help me navigate the world of distance sampling. Michael Guttery was patient with me as I leapt into analyses and got instantly lost. Thanks to Nathan Dulfon for keeping our office lively, and helping work though analyses while encouraging some goofing off every now and then. Thanks to Michael Kohl and Peter Mahoney for sharing their extensive knowledge of Resource Selection Functions and data interpretation. Without these people and many others my transition into and completion of my research would not have been possible.
My research would not have been completed without the help of field technicians who tolerated adverse field conditions, long days, and unpredictable bird behavior. My thanks to Amanda Reininger, Kenneth Loonam, Rachel Keller, Emilia Breitenbach, Emily Prosser, and Aaron Tietjen. Thanks also to Brian Wing, Avery Cook, Brandon Flack, Skyler Farnsworth, Wayne Smith, and Chris Bryan and his wife for staying up well into many frigid nights to help me trap sage-grouse.

The landowners of western Box Elder County also deserve a huge and sincere thanks. I understand that letting someone run around and collect data on your property can make many people nervous, but the landowners of west Box Elder County were incredibly supportive. These landowners are phenomenal examples of proper habitat stewardship, with healthy and productive rangelands constantly managed to meet the needs of both livestock and wildlife. I owe a very special thanks to Jay and Holly Carter for their friendship throughout my research. The Carters provided a house for myself and my technicians, invited myself and my technicians to participate in family and community events, and allowed me free range of their property.

A very special thank you is dedicated to my family who supported me throughout this journey. Thank you to my grandfather Charles Ray, who encouraged me to pursue a graduate degree, but passed away before seeing me earn it. To my mom and dad who despite my stubbornness, supported me though my early education, and pushed me to continue in to graduate school. To my sister who has tolerated my absence at both my nephew and niece’s births; I’ll make it up to them. And to my extended family and friends who have supported and encouraged my dreams; thank you.
This project would not have been possible without funding from our partners including the Ruby Pipeline and El Paso Corporation, Utah Division of Wildlife, Utah’s Watershed Restoration Initiative, U.S. Bureau of Land Management, the Jack H. Berryman Institute, the Quinney Professorship for Wildlife Conflict Management at Utah State University. I thank everyone for making my research and education possible.

Charles P. Sandford
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The greater sage-grouse (*Centrocercus urophasianus*; sage-grouse), is the largest grouse species in North America, and has been recognized as an indicator species of the condition of sagebrush (*Artemisia* spp.) ecosystems (Knick et al. 2013). Occupied sage-grouse range has declined by nearly 600,000 km² since pre-European settlement as of 2000 (Schroeder et al. 2004). In Utah, sage-grouse populations are estimated to be just 41% of historic levels (Beck et al. 2003). Large scale research on the species has led to conclusions that conservation is still possible due to current widespread distribution of the species, and relatively large areas of remaining sagebrush habitats (Messmer 2013).

In 2010, the sage-grouse was designated as a candidate species by the U.S. Fish and Wildlife Service (USFWS) for protection under the Endangered Species Act of 1973 (ESA) due to range-wide population declines and long-term habitat losses (USFWS 2010). In 2015, the USFWS reversed its previous decision when it announced sage-grouse no longer warranted ESA protection. Their 2015 decision was based on a determination that range wide conservation efforts had mitigated species conservation threats (USFWS 2015).

**History**

Population declines are nothing new to sage-grouse; declines have been recognized for nearly a century (Hornaday 1916). Market hunting, combined with the false belief that that populations were inexhaustible, led to sage-grouse hunting
restrictions in Colorado as early as the 1910’s (Rogers 1964). As populations continued
to decline, hunting was completely prohibited in both Wyoming and Colorado in 1937
(Patterson 1952, Rogers 1964). Nearly 20 years later, with research indicating that the
prohibition of sage-grouse hunting had not had any effect on sage-grouse population
sizes, a hunting season was reinstated. However, continued concern over declining
populations led private citizens, wildlife managers, industry members, sportsman’s
groups, and other non-governmental organizations to address and implement
conservation actions to benefit sage-grouse (Stiver et al. 2006). These actions include
habitat restoration and protection, as well as political recognition. In 2008, members of
the Western Association of Fish and Wildlife Agencies (WAFWA), as well as the U.S.
Forest Service (USFS), Bureau of Land Management (BLM), USFWS, U.S. Geological
Survey (USGS), Natural Resources Conservation Service (NRCS), and Farm Service
Agency (FSA) signed a Memorandum of Understanding, agreeing to cooperatively
address sage-grouse conservation at all levels, and across jurisdictional boundaries
(Stiver 2011).

Conservation Status

In 1999, the USFWS was petitioned to list an individual population of greater
sage-grouse for protection under the ESA (USFWS 2001). The USFWS determined that
though protection was warranted, the sage-grouse was precluded by other species with
greater protection priority. Multiple other petitions were filed in the early 2000’s, but all
were dismissed due to either other species of greater concern, or a finding that protection
was not warranted (Stiver 2011). A 2005 decision (USFWS 2005) was challenged in
federal court due to errors in how the listing decision was handled, and the USFWS was
ordered to restart the process. In 2010, the USFWS came to the same conclusion as 2001: protection of the sage-grouse was warranted but precluded by other species of greater concern (USFWS 2010). Multiple organizations sued the USFWS for failing to reach a satisfactory decision, arguing that labeling them a “candidate species” offered no legal protection. In September 2015, as instructed by a federal judge, the USFWS made a final decision not to list the greater sage-grouse for ESA protection, citing increased regulatory mechanisms, unprecedented habitat restoration, and implementation of state and region specific management plans as well as other factors, as sufficient progress to ensure the species conservation (USFWS 2015).

Individual states where the species occurs have completed plans that will guide species conservation in each respective state (State of Wyoming Game and Fish Commission 2003, Montana Sage Grouse Work Group 2005, Idaho Sage-grouse Advisory Committee 2006, Utah Governor’s Office 2013, State of Nevada Sagebrush Ecosystem Council 2014). These plans recognize the diversity of ecological habitats required to sustain this and other landscape species. In Utah, conservation plans are even created by some counties, to address specific needs of fine scale geographic areas. The West Box Elder Adaptive Resource Management Local Working Group (BARM) for example, refined the Utah conservation plan to address specific threats and management options for sage-grouse in Box Elder County (BARM 2007). However, to continue to conserve sage-grouse, better information is needed regarding population response to landscape scale management and conservation strategies. Specifically, managers need better information regarding sage-grouse nest initiation rates, nest and brood success, survival, recruitment, production (i.e., vital rates) and seasonal movement and habitat-use
patterns in response to mechanical conifer removal, sagebrush thinning, and disturbance mitigation (landscape management).

**Greater Sage-grouse Ecology**

**Breeding**

Sage-grouse are polyandrous species, with males competing to mate with as many females as possible (Scott 1942, Patterson 1952). For up to 5 months in the spring, male sage grouse gather in open areas, termed leks, to attract females to breed using elaborate strutting behavior and secondary sexual traits (fanned feathers and inflated neck sacs). Lek locations are generally stable through time, but can move in response to changes in vegetation, snow cover, disturbance, or expansion (Connelly et al. 2011a). There are examples of all of these behaviors, as well as lek extirpation in my study area. Initiation of lekking generally begins in February, and can extend as late as the first weeks of June (Connelly et al. 2011a). About half of the males in a population can be seen on leks shortly after initiation of lekking season (Eng 1963, Jenni and Hartlzer 1978). About 1 month later, peak female attendance occurs for up to two weeks (Eng 1963). Male peak attendance usually occurs about 3 weeks after peak female attendance, when dominant males begin to allow sub-dominant males to enter the lek (Eng 1963, Connelly et al. 2011a). In northwestern Utah, lekking typically occurs from early March through the first week of June (BARM 2007). Peak lek counts in the area occur from the last week of March, and into the second week of April (Knerr 2007). However, all timing is dependent on weather conditions, and can be shifted anywhere from a matter of days, to weeks (Schroeder 1997, Connelly et al. 2011a).
Nesting

Nest locations can range from 1 to over 20 km from the lek where a female bred (Connelly et al. 2000). However, nests are typically within 5 km of a lek (Braun et al. 1977, Holloran et al. 2005). Because hens may visit multiple leks in a breeding season, determining which lek a female bred at can be very difficult, and it would be unwise to assume that she bred at the lek closest to her nest (Connelly et al. 2011a, Schroeder and Robb 2003). Site fidelity also contributes to where a female will nest. Females that successfully hatched a nest in the previous year are likely to nest within 1600m of the previous year’s nest (Berry and Eng 1985, Fischer et al. 1993, Holloran et al. 2005, Schroeder and Robb 2003). Females that had unsuccessful nest(s) in the previous year will move their nest an average of 5.2km away from the previous year’s location(s) (Schroeder and Robb 2003).

In their western distribution, sage-grouse nest initiation averages 78% (Connelly et al. 2011a). Approximately 10 days after peak female attendance on leks, egg-laying begins (Schroeder 1997). During the egg-laying period, females deposit one egg approximately every 24 hours (Patterson 1952). Incubation of the nest begins after the final egg is deposited, and occurs for 27 days (Schroeder 1997). Clutch sizes in Utah range from 6 (Dahlgren 2006) to 10 eggs (Knerr 2007), which fits in the average of 7.1 eggs observed in their western distribution (Connelly et al. 2011a). Connelly et al. (2011a) reported that over a large sample of studies in different areas and habitat conditions, nest success can range from 15-85%.
Brood-Rearing

Immediately after her nest hatches, the female will move her brood away from the nest, and will not return. This initial movement is typically restricted to within 3km of the nest site, due to mobility of chicks, and available habitat (Berry and Eng 1985). Chicks are immediately exposed to, and prefer a variety of habitat types (Schroeder et al. 1999). They also face the highest risk of death (Gregg et al. 2007) in the first 2-3 weeks post-hatch. Due to timing of nesting, most chicks are hatched during a flush of growth in or following spring rains. The female and chicks actively seek out areas with succulent forbs and abundant insects that are rich in protein (Patterson 1952, Klebenow and Gray 1968, Johnson and Boyce 1990).

As chicks mature, and xeric conditions begin to intensify, broods begin to seek areas with higher moisture and forb content, which in the western United States, generally means moving up in elevation (Connelly et al. 2011b). This movement between early brood-rearing sites and late brood-rearing sites can vary greatly in distance, from none in areas with constant moisture and forb abundance to up to a known 82km (Connelly et al. 1988 and Connelly et al. 2011b).

Winter

As implied by their name, sage-grouse are tied very intimately to sagebrush habitats (Baruch-Mordo et al. 2013, USFWS 2010, Patterson 1952). During the winter months, sage-grouse are almost entirely dependent on sagebrush extending through snow for winter forage as well as cover (Patterson 1952, Braun et al. 1977, Crawford et al. 2004). Therefore, sage-grouse are also extremely dependent on weather patterns and snow depth to maintain exposed sagebrush (Patterson 1952, Beck 1977).
Survival during the winter months is typically extremely high, even with extremely low temperatures and moderate to extreme weather events (Connelly et al. 2004). However, periods of deep snow and extreme lows can compound to negatively affect survival (Moynahan et al. 2006). Adult sage-grouse can experience winter survival rates of between 82 and 100% (Hausleitner 2003, Wik 2002). Juvenile sage-grouse survival can vary more than adults, with survival in moderate elevations at 84% and survival at high elevation sites at as low as 64% (Beck et al. 2006).

**Historic and Current Management**

Much of the western United States has experienced a variety of farming and grazing practices since the middle of the 19th century (BARM 2007). From 1910 through the 1920’s, spurred by the Homestead Act of 1862 and the Enlarged Homestead Act of 1909, Euro-American settlement in western Utah was intense (Morris 2011). This settlement also brought dry farming and grazing livestock to areas. This intense level of dry farming has resulted in lower total forb cover and increased squirreltail (*Elymus elymoides*) and mixed shrubland (Morris et al. 2011). The effects of such intense farming and grazing practices have remained for over 100 years, with many areas still visible on many landscapes in present-day.

In western Utah, livestock production has taken over as the dominant land use over crop production. Most livestock production is involved with multiple varieties of cattle (*Bos taurus*). However, there is also a great deal of sheep (*Ovis aries*) production (BARM 2007). Because of the high demand for grazing land and forage, there is a great interest in maximizing productivity while maintaining sustainability in the area. Productivity in this case not only includes forage for livestock, but also habitat and
resources for native flora and fauna. Cooperation between landowners and university researchers to investigate best land use practices extend back for nearly 40 years (Ralphs and Busby 1978, 1979). Private landowners near the study area have recently participated in research investigating the effects of sagebrush treatments (mechanical, chemical, and prescribed fire for the reduction of sagebrush cover) on sage-grouse (Thacker 2010). Other research includes the effect of green stripping with forage kochia (Kochia prostrata) to mitigate fire risk on sage-grouse (Graham 2013) and the role of vegetation structure, composition, and nutrition in sage-grouse ecology (Wing 2014).

The Sage Grouse Initiative, started in 2010 by the NRCS in response to the potential endangered listing of the sage-grouse by the USFWS (2010) has dramatically increased the amount of research and conservation aimed at sage-grouse. The NRCS uses this program, along with its existing relationships with landowners to find and implement practices that benefit livestock producers, as well as the sage-grouse. Utah’s Watershed Restoration Initiative (WRI) has also funded projects that benefit sage-grouse and livestock. Federal agencies, including the BLM and USFS have also began project implementation on the lands they manage to maximize benefits across ownership boundaries. Projects led by these organizations include habitat improvement by means of conifer removal, sagebrush thinning, and burned area rehabilitation. Private landowners have also completed projects without partnering with an organization, however projects in this category are rarely recorded and often unavailable due to privacy rights.

**Conservation Threats**

Crawford et al. (2004) concluded that the major factors of the decline of sage-grouse populations has been due primarily to habitat loss and fragmentation, excessive
livestock grazing, conversion to agricultural production, and a change in plant communities in historic sage-grouse habitat over the past century. The USFWS cited habitat loss and fragmentation of habitat as key causes of sage-grouse population declines (USFWS 2010). Habitat loss and fragmentation may occur in many forms, including fire, invasive plants, roads, fences and powerlines, and encroachment of pinyon and juniper (hereafter conifer). Climate change may intensify many of the threats, particularly encouraging conifer expansion (Knapp et al. 2001, Bradley and Fleishman 2008), and increasing fire frequency and West Nile infection rates (USFWS 2010).

In western Box Elder County, Utah, sage-grouse face many of the recognized threats, including wildfire, urban development, conversion of sagebrush habitat to agriculture, disease, altered water distribution, pinyon-juniper encroachment, and predation (BARM 2007, 2012). Currently, land managers focus on invasive weed management, reservoir sustainability analyses, winter rangeland improvement, and reducing conifer encroachment (Cirrus Ecological Solutions and Logan Simpson Design 2013).

A change in dominant plant communities over the past century has greatly reduced the sagebrush habitat in the Box Elder Sage-Grouse Management Area. In particular, managers are concerned about the conifer encroachment in sagebrush habitat (BARM 2007). The expansion of conifers, in particular native pinyon pine (*Pinus* spp.) and juniper (*Juniperus* spp.) into sagebrush ecosystems has been implicated as a species conservation threat (BARM 2007, USFWS 2010, Utah Governor’s Office 2013). As pinyon and juniper invade sagebrush habitats, they close the canopy, out-compete sagebrush, and convert the micro-climate to a more xeric condition that is uninhabitable
for greater sage-grouse (Miller 2005, Miller and Eddleman 2000). The encroachment of conifers is often broken into 3 semi-subjective phases: Phase I - conifers are present but shrubs, forbs, and grasses remain the dominant vegetation community, Phase II – conifers are co-dominant with shrubs, and are influencing ecological processes, and Phase III – conifers are the dominant vegetation influencing ecological processes, and shrubs, forbs, and grasses are suppressed (Miller 2005). Restoration from a Phase III conifer landscape to sagebrush steppe becomes labor intensive and costly (Miller et al. 2000).

While Phase I conifer encroachment may not be sufficient to change vegetative interactions, it can be more than enough to displace sage grouse. Baruch-Mordo et al. (2013) reported that sage-grouse leks in Oregon were extirpated when juniper canopy cover exceeded 4% within 1000m of a lek. The occurrence of juniper canopy cover near or greater than 4% within 1000m of an active lek in Management Area 1 has been observed (Cook 2015), illustrating the need for immediate management, or a site specific measurement of sage-grouse conifer cover tolerance. The presence of conifers also offers perches and nest sites for avian predators (Commons et al. 1999). Further, Doherty et al. (2008, 2010) found that sage-grouse avoid conifer in habitats at a 650 m$^2$ scale and when selecting nest sites. Frey et al. (2013) noted that sage-grouse in southern Utah used agricultural land as much as sagebrush habitat, an indication of insufficient forbs in the sagebrush habitat (Connelly and Doughty 1989). The reduced available forbs could be due to suppressed vegetation communities in conifer areas (Miller 2005, Miller et al. 2000). This would further compound the negative effects of conifer on sage-grouse habitat use. Frey et al. (2013) also found that when conifers were removed, sage-grouse selected for mulched and seeded conifer removal sites over previously favored
agricultural areas. Cook (2015) analyzed pellet surveys and sage-grouse telemetry locations in west Box Elder County to determine factors that influence sage-grouse use of conifer removal areas. They found that sage-grouse use of conifer removal sites was positively associated with proximity to mesic habitat and proximity to an existing sage-grouse population, and negatively associated with proximity to remaining conifer canopy cover.

However, not all recent research supports the idea that conifer removal benefits sage-grouse in a timeframe that is meaningful to wildlife managers. Knick et al. (2014) studied sagebrush bird community response to prescribed fire and mechanical conifer removal in Utah, Nevada, Idaho, and Oregon. They concluded that conifer removal was unlikely to increase available habitat for the entire sagebrush bird community, including sage-grouse.

**Vital Rate Responses to Habitat Manipulation**

Evidence of sage-grouse using conifer removal areas (Frey et al. 2013, Cook 2015, Sandford et al. 2015) suggests that these populations may respond to an increase in usable space (Dahlgren et al. 2016). However, despite the growing amount of research regarding the relationship between sage-grouse and conifers, there has been no investigation as to whether the selection of reopened habitat directly benefits sage-grouse fitness (i.e., increased nest and brood success).

Resource selection is the product of decisions in which animals consider the cost-benefit of competing demands such as forage acquisition and predator avoidance in an effort to maximize fitness (Manly et al. 2002, Beyer et al. 2010, Leclerc et al. 2015). Resource selections by animals are therefore linked to individual fitness (DeCesare et al.
As such, resource selection is a multi-dimensional ecological process that occurs across both time and space (DeCesare et al. 2012). Resources are not distributed evenly across the landscape (Mysterud and Ims 1998), and therefore individual variation in resource selection is likely to occur. This variation is referred to as a resource selection functional response (Mysterud and Ims 1998). This multi-dimensional process, depending on resource importance and availability, may drive individual differences in nest and brood success in sage-grouse females.

In ecological systems with anthropogenic influence, functional responses in resource selection have been directly linked to reduced fitness (Hebblewhite and Merrill 2008, Benson et al. 2015). Wildlife managers are therefore increasingly implementing landscape-scale habitat manipulation projects as a strategy to improve habitat and slow or reverse population declines (Williams et al. 2004, Fedy et al. 2014). However, it is uncertain whether wildlife populations actually respond to habitat manipulations on temporal and spatial scales that are relevant to managers (Frey et al. 2013, Knick et al. 2014, Cook 2015). Although wildlife may exhibit increased use of habitat improvement projects, there are questions about whether the perceived increase in habitat availability or quality actually translates to changes in individual fitness and population abundance (Guthery 1997, Harrington et al. 1999, Cain et al. 2008).

Micro-site Vegetation Characteristics

Much of the sage-grouse literature has investigated the effects and influence of vegetative characteristics on sage-grouse habitat selection. Stiver et al. (2015) synthesized available literature and provided recommendations for site-specific vegetation characteristics. This synthesis is used by the BLM and other agencies when
surveying and describing range conditions and making recommendations for habitat management for the benefit of sage-grouse.

Shrub, forb, and grass cover and height have been reported as important factors in determining nest and brood site selection and success (Hagen et al. 2007, Connelly et al. 2011b, Utah Governor’s Office 2013, Wing 2014, Stiver et al. 2015). Previous research in the study area described nest, brood, and available habitat vegetation characteristics, and their effect on nest and brood success (Wing 2014). This previous research also compared vegetation characteristics of the study area to neighboring populations (Knerr 2007), and populations in other areas of Utah (Dahlgren 2006, Duvuvuei 2013). Because the landscape of the study area are dynamic, it is important to continue recording vegetative characteristics to detect and describe potential shifts that may affect the local sage-grouse population.

**Study Site**

The study area was located in western Box Elder County, Utah (Fig. 1-1). This area is classified locally as the Box Elder Sage-grouse Management Area (SGMA; Utah Governor’s Office 2013), and range wide, as the southeast corner of the Snake River Plain Management Zone (Stiver et al., 2006). Geographically, the core study area is bounded to the north by the Raft River Mountains, to the West by the Grouse Creek Mountains, to the south by salt flat desert, and to the east by the Great Salt Lake and its extensive mud and salt flats. The focal area covers approximately 103 600 ha$^2$ in the vicinity of the towns of Park Valley (lat. 41°49’16”N, long. 113°24’03”W) and Rosette, and former towns of Rosebud and Dove Creek in western Box Elder County, Utah. The area is a mix of private and public land, and predominantly used for cattle and sheep, and
alfalfa (*Medicago sativa*) hay production. The Box Elder SGMA encompasses one of the largest and most stable sage-grouse populations in Utah; 577 male sage grouse were counted on 42 leks in 2013 (Utah Division of Wildlife Resources [UDWR] unpublished data; Western Association of Fish and Wildlife Agencies 2015).

Vegetation communities in the study area display a strong elevational gradient. Lower elevation sites were composed of salt desert scrub. These sites transitioned into sagebrush and juniper communities as elevation increased, and finally became sagebrush, mahogany (*Cercocarpus ledifolius*), spruce (*Picea* spp.) and fir (*Abies* spp.) woodlands, and aspen (*Populus tremuloides*) communities at high elevations. Elevation ranged from 1350 to 3000 m above sea level.

Mean annual precipitation in the study area was approximately 29.3 cm between 1990 and 2015 (1706 m. elevation). Most precipitation occurred between December and Jun, averaging 2.8 cm per month. Mean temperature ranged from -9.4 °C in December to 30.3 °C in July (Western Regional Climate Center 2015). Higher elevations remain colder and receive more precipitation, and elevations >2400 m may retain snow well into summer months. Snow was observed at 2800 m until early July in 2014 and 2015. The 2014 field season was characterized a dry winter, warm spring, unusually wet summer, and average fall. The 2015 season was characterized by a dry winter, extremely early spring, unusually wet and early summer, and average fall.

**Study Purpose**

The information base regarding sage-grouse response to conifer encroachment into sagebrush habitats and subsequent mechanical removal has increased in the last decade (Commons et al. 1999, Baruch-Mordo et al. 2013, Frey et al. 2013, Knick et al.
2014). In western Box Elder County, recent research has documented positive individual sage-grouse use responses to conifer removal (Wing 2014, Cook 2015, Sandford et al. 2015). My research builds on previous research in the Box Elder SGMA (Cook 2015) in that it describes increased fitness effects (i.e., nest and brood success) for sage-grouse that select areas to nest and raise broods near areas were conifers have been mechanically removed.

This research addresses knowledge gaps primarily outlined in Strategy 1 of the BARM’s (2007) conservation plan, and address others that have arisen since completion of the BARM conservation plan (Utah Governor’s Office 2013). This research also completes 2nd and 3rd order (Johnson 1980) habitat assessments of the Raft River subunit of the Utah Division of Wildlife Resources (UDWR) Sage-Grouse Management Area 1 (UDWR 2002). My research describes the effects of conifer encroachment and removal at the landscape level on sage-grouse vital rates and habitat selection. This research will assist land managers and state and federal government agencies on local and regional levels to identify management actions and areas that are critical to conservation of the sage-grouse.

Chapter 2 investigates the fitness effects experienced by sage-grouse that select nest and brood sites in proximity to conifer encroachment and removal using a Resource Selection Function. Chapter 3 compares relative sage-grouse use densities in sagebrush habitats where conifer removal projects have been completed, sites exhibiting conifer encroachment, and sagebrush sites exhibiting no conifer encroachment. Chapter 4 examines the relationship between vegetation micro-site characteristics at nest, brood, and random sites, and nest and brood success. The appendix contains a published novel
observation of a sage-grouse female selecting a nest site in an ongoing conifer
mastication site, despite proximity to mechanical disturbances.

This thesis is written in a multiple paper format. Chapters 1, 3, and 5 follow
format guidelines for the Journal of Wildlife Management. Chapters 2 and 4 follow
format guidelines for the Journal of Rangeland Ecology and Management, and the
Appendix follows format guidelines for The Prairie Naturalist.

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Figure 1-1. Western Box Elder County study area within the Box Elder Sage Grouse (*Centrocercus urophasianus*) Management Area (SGMA) as defined by the Conservation Plan for Greater Sage-grouse in Utah (Utah Governor’s Office 2013). Though the SGMA boundaries remain unchanged, this map represents the most current habitat labeling scheme, as determined by the Utah Division of Wildlife Resources (UDWR 2014). Sage-grouse Management Areas encompass areas with the highest sage-grouse breeding densities, and together support more than 94% of Utah’s sage-grouse population. The areas within SGMAs are classified as habitat, non-habitat, and opportunity areas. Habitat areas are further classified as nesting, brood-rearing, winter, and other available habitat.
CHAPTER 2

GREATER SAGE-GROUSE RESOURCE SELECTION DRIVES REPRODUCTIVE FITNESS IN CONIFER REMOVAL SYSTEM

ABSTRACT

The link between individual variation in resource selection (e.g., functional response) and fitness serves as the foundation in our understanding of wildlife-habitat relationships. Many anthropogenic activities are known to adversely affect these relationships, yet it is largely unknown whether projects implemented to benefit wildlife populations actually achieve this outcome. For sagebrush (Artemisia spp.) obligate species such as the greater sage-grouse, (Centrocercus urophasianus; sage-grouse), expansion of juniper (Juniperus spp.) and pinyon-pine (Pinus spp.; conifers) woodlands into sagebrush dominated landscapes has been identified as conservation threat. Previous research indicates that sage-grouse may abandon leks in areas where conifer canopy cover exceeds 4% within 1km of the lek. To mitigate the effects of conifer expansion on sage-grouse and their habitats, federal and state agencies have implemented range wide landscape level management actions that have removed conifers on hundreds of thousands of hectares of pinyon-juniper cover. The effect of these habitat management strategies on individual sage-grouse fitness (i.e., nest and brood success) is largely unknown. We evaluated if sage-grouse nest and brood success was affected by proximity to conifer removal treatments completed in sagebrush-steppe habitat. To complete this analysis, we linked sage-grouse resource use to individual nest and brood success by incorporating random-slope Resource Selection Functions as explanatory predictors in a

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logistic survival model. Using this novel approach, we demonstrated that the probability of individual nest and brood success declined ($P < 0.05$ and $P = 0.09$, respectively) as sage-grouse females selected sites farther from conifer removal areas. This research provides the evidence that conifer removal treatments completed adjacent to occupied sage-grouse habitats in addition to increasing habitat availability, may also have a positive effect on individual female nest and brood survival rates.

INTRODUCTION

The link between resource selection and individual fitness is a key tenet in ecology (DeCesare et al. 2014). Resource selection is the product of trade-off decisions in which animals address competing demands such as forage acquisition and predator avoidance in an effort to maximize fitness (Beyer et al. 2010; Leclerc et al. 2015). As such, resource selection is a multi-dimensional ecological process that occurs across both time and space (DeCesare et al. 2012). Furthermore, environmental resources are not distributed evenly across the landscape (Mysterud and Ims 1998), therefore individuals are likely to vary in their selection of resources, referred to as a resource selection functional response (Mysterud and Ims 1998). This multi-dimensional process, depending on resource importance and availability, may drive individual differences in fitness.

In human-altered systems, functional responses in resource selection have been directly linked to reduced fitness (Benson et al. 2015; Hebblewhite and Merrill 2008). As such, wildlife managers are increasingly implementing large-scale habitat improvement projects as a strategy to reduce population declines (Fedy et al. 2014; Williams et al. 2004). However, it is uncertain whether wildlife populations respond to habitat
manipulations on temporal and spatial scales that are relevant to managers (Cook 2015; Frey et al. 2013; Knick et al. 2014). Although wildlife may exhibit increased use of habitat improvement projects, little is known how the increased habitat availability will affect individual fitness or population abundance (Cain et al. 2008; Guthery 1997; Harrington et al. 1999).

The greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse), has been recognized as an indicator of the condition of sagebrush (*Artemisia* spp.) ecosystems and as such is considered an umbrella species for other sagebrush obligates (Hanser and Knick 2011; Knick et al. 2013). In 2010, the sage-grouse was designated as a candidate species by the U.S. Fish and Wildlife Service (USFWS) for protection under the Endangered Species Act (ESA) of 1973 due to range-wide population declines that were attributed to long-term habitat losses (USFWS 2010). The expansion of conifers, in particular native pinyon pine (*Pinus* spp.) and juniper (*Juniperus* spp.) into sagebrush ecosystems has been implicated as a species conservation threat (Commons et al. 1999; USFWS 2013; Utah Governor’s Office 2013). Stiver et al. (2006) estimated that 60,000-90,000 ha of sagebrush habitat across the range of sage-grouse is lost annually to conifer encroachment. An estimated 90% of this expansion has occurred in areas that were previously sagebrush ecosystems (Miller et al. 2011).

Because of the impact of conifer expansion on sage-grouse, managers have increasingly implemented management actions designed to remove or reduce conifer canopy cover in sagebrush habitats. The Natural Resources Conservation Service (NRCS), through its Sage-grouse Initiative (www.sagegrouseinitiative.com), has provided cost-share to landowners to mechanically remove or reduce thousands of
hectares of conifer on private lands in the western U.S. Similar projects have been implemented range wide on Bureau of Land Management (BLM) and U.S. Forest Service (USFS) administered lands. In Utah alone, conifers have been removed from > 200,000 hectares of sagebrush landscapes since 2006 under the Utah Department of Natural Resources (UDNR) Watershed Restoration Initiative (WRI; UDNR 2014).

Connelly et al. (2011) concluded that to effectively mitigate sage-grouse conservation threats, managers will need better information regarding sage-grouse nest initiation rates, nest and brood success, survival, recruitment, production and seasonal movement and habitat-use patterns in response to management actions. Dahlgren et al. (2006) and Thacker (2010) both found that sage-grouse used manipulated habitats more than expected. Baruch-Mordo et al. (2013), Frey et al. (2013), and Commons et al. (1999) reported the negative impact of increased conifer canopy cover, as well as a positive response following conifer canopy reduction by sage-grouse and suggested management practices to target conifer removal for the benefit of sage-grouse. In contrast, Knick et al. (2014) concluded that the use of prescribed fire and small scale mechanical conifer removal projects (< 27 ha) would not benefit sagebrush obligates including sage-grouse over the short-term. Frey et al. (2013), Cook (2015), and Sandford et al. (2015) documented immediate sage-grouse presence in plots > 57 ha where conifers were removed using mechanical methods (i.e., Fecon Bull Hog, Lebanon, OH; and chaining, Cain, 1972).

Large-scale mechanical conifer reduction projects are relatively low cost on a per hectare basis, and may have potential for increasing usable habitat space for sage-grouse and other sagebrush obligate species (Baruch-Mordo et al., 2013; UDWR, 2009).
Multiple sage-grouse management plans recognize that conifer encroachment is a threat to sage-grouse populations (Idaho Sage-grouse Advisory Committee 2006; Montana Sage Grouse Work Group 2005; State of Nevada Sagebrush Ecosystem Council 2014; State of Wyoming Game and Fish Commission 2003; Utah Governor’s Office 2013). However, beyond observations of sage-grouse avoiding conifer canopy cover and using areas of recent conifer removal (Baruch-Mordo et al. 2013; Commons et al. 1999; Cook 2015; Doherty et al. 2008; Frey et al. 2013), little is known about how sage-grouse proximal habitat-use of conifer removal sites may affect individual fitness.

We used a Resource Selection Function (RSF) framework (Manly et al. 2002) to determine individually-marked female sage-grouse resource selection during the reproductive period (nesting and brood-rearing). From this, we extracted the functional response coefficient estimates for individual female sage-grouse, and inserted these estimates into a logistic survival model to determine how functional responses in resource selection influenced individual nest and brood success. We hypothesized that sage-grouse females that selected sites in close proximity to conifer removal areas would experience higher nest and brood success indicating increased individual fitness.

**METHODS**

**Study Area**

Our study area was located in the Box Elder Sage-grouse Management Area (SGMA; Fig. 2-1; Utah Governor’s Office 2013), and the southeast corner of the Snake River Plain Management Zone (Stiver et al. 2006). The Box Elder SGMA encompasses one of the largest and most stable sage-grouse populations in Utah; 577 male sage grouse were counted on 42 leks in 2013 (Utah Division of Wildlife Resources [UDWR])
unpublished data; Western Association of Fish and Wildlife Agencies 2015). The focal area covers approximately 103,600 ha² in the vicinity of the towns of Park Valley (lat. 41°49′16″N, long. 113°24′03″W) and Rosette, and former towns of Rosebud and Dove Creek in western Box Elder County, Utah. The area was a mix of private and public land, and predominantly used for domestic livestock and alfalfa (Medicago sativa) hay production. Utah School and Institutional Trust Lands Administration, BLM, and USFS administered lands are interspersed throughout creating a mosaic of jurisdictions and land uses.

The study area was composed primarily of sagebrush-steppe habitat characterized by big (A. tridentata spps.) and small sagebrush (A. nova and A. arbuscula). Dominant understory grasses included Sandberg’s bluegrass (Poa secunda), cheatgrass (Bromus tectorum), crested wheatgrass (Agropyron cristatum), and bluebunch wheatgrass (Pseudoregnaria spicata). Common forbs included milkvetch (Astragalus spp.), phlox (Phlox spp.), hawksbeard (Crepis spp.), lupine (Lupinus spp.), and western yarrow (Achillea millefolium). Encroaching (pinyon-juniper; PJ) woodlands were present throughout the study area. Spruce (Picea spp.), fir (Abies spp.), quaking aspen (Populus tremuloides), and curl-leaf mahogany (Cercocarpus ledifolius) communities were found at higher elevation areas throughout the study area. Elevation ranged from 1,350 m to 2,950 m. Mean annual precipitation was 304 mm primarily occurred during the winter and spring. Mean temperature ranged from -3.8 °C in January to 22.3 °C in July (National Oceanic and Atmospheric Administration 2010).

Conifer removal projects in the study area were first initiated ~30 years ago. However, because of little maintenance, conifers have recolonized and expanded beyond
the removal areas. In 2008, conifer removal projects in the study area increased both in size and frequency. Since 2008, nearly 8,100 ha of conifer canopy cover in the study area has been removed through active management (e.g. one and two-way chaining, lop-and-scatter, and mechanical mastication).

Sage-grouse Radio-marking

From 2012 – 2015, we captured, radio-marked, and monitored 96 female sage-grouse in our study area. To minimize possible handling effects on nest initiation, sage-grouse were captured near leks where they were found roosting in early spring prior to nesting season. Trapping occurred primarily on the periphery of known lekking and wintering areas to maximize trapping productivity, and minimize the risk of a bird leaving the study area due to recognized site fidelity (Reinhart et al. 2013; Robinson and Messmer 2013).

Sage-grouse trapping occurred at night in minimal light conditions, using All-Terrain-Vehicles, spotlights, and dip nets following protocols described by Wakkinen et al. (1992) and Connelly et al. (2003). We determined age of female sage-grouse and attached a numbered aluminum leg band and an 18-22g Very High Frequency (VHF) radio-necklace (Advanced Telemetry Systems, Isanti, MN, and Holohil Systems, Ltd., Ontario, Canada). All birds were processed and released as quickly as possible at the site of capture. Aging and sexing of birds was conducted based on feather characteristics and molt patterns (Crunden 1963; Eng 1955).

We predominantly used ground-based radio-telemetry coupled with visual confirmations to relocate radio-marked birds. Each radio-marked bird location was recorded using handheld global positioning systems (GPS) using UTM Zone 12 N in the NAD 1983
datum. Research protocols were approved by the Utah State University Institutional Animal Care and Use Committee permit #1547, and UDWR Certificate of Registration Number 2BAND8743.

Nest Monitoring

We monitored the radio-marked females (2-3 locations per week) during the lekking season, and from nest initiation and through nest incubation (Aldridge and Brigham 2001; Schroeder 1997). We recorded nest fate to be used in analysis of resource selection and fate. We determined nest fate by observing eggshell fragments for signs of successful hatch, including separated membranes, and cupping of shell halves (Rearden 1951). If a nest was abandoned prior to estimated hatch date, and the eggs were crushed, punctured, or absent, the nest was classified as unsuccessful (Patterson 1952), and the status of the female was immediately investigated. If we determined that a nest failed (due to predation or abandonment), we reduced tracking efforts of the female (1-2 locations per week), due to the extremely low likelihood of her re-nesting (Cook 2015). A GPS point was recorded at the exact site of every nest as soon as the nest fate was determined.

Brood Monitoring

When a female successfully hatched her clutch (i.e., at least one egg hatched), we tracked and recorded GPS locations of her and her brood 2-3 times per week. We determined brood success as a radio-marked female with chicks surviving ≥ 50 days. When a brooding hen female was observed or flushed ≤ 50 days post-hatch with ≥ 2 adult sage-grouse and/or no chicks on more than 2 consecutive sampling occasions we determined her brood to be unsuccessful. At 50 days, we located and flushed the female
and her chicks to determine brood success (Cook 2015; Dahlgren et al. 2010b; Schroeder 1997). To maximize detection probability, sampling occasions of females with chicks were conducted before 0800 a.m. to reduce the potential for chick dispersal but have sufficient light to detect, classify, and count adults and chicks. In the event the female flushed without chicks, we repeated flush procedures on the following day. If the second flush still provided inconclusive results, we located the female on the second night with a spotlight and attempted to observe chicks (Dahlgren et al. 2010b). If chicks were still not observed, we classified the female as having an unsuccessful brood. We did not account for brood mixing because individual chicks were not marked and thus our brood survival estimates may be underestimated (Dahlgren et al. 2010a).

**Landscape Classification**

We used a baseline surface disturbance map (Manier et al. 2014) of SGMAs (Dahlgren et al. 2016a) in Utah (Gifford et al. 2014) to determine sage-grouse distance (km) from disturbances (Roads > 72 kph, Roads 40-72 kph, Roads < 40kph, Urban and Non-Urban Development, Powerlines, and Agriculture). Urban development was defined as any building capable of being inhabited or used. Non-urban development was defined as mines (abandoned or used seasonally), pipelines, structures not capable of use (abandoned house trailers, etc.), and miscellaneous unclassified development. Agriculture included irrigated/non-irrigated alfalfa production/pasture, fallow, and pasture (see Gifford et al. 2014 for descriptions). The baseline disturbance map was considered static throughout the study period because there was little to no changes in any anthropogenic disturbance. We used a 10m resolution Digital Elevation Model (DEM; Utah Automated Geographic Reference Center 2013) to derive elevation values.
Because sage-grouse have previously been shown to select mesic sites (Connelly et al. 2011; Stiver et al. 2015), we derived a spatial distribution of mesic habitat by merging all mesic vegetation types as well as open water and springs within the LANDFIRE 2012 (LANDFIRE 2012) Vegetation Type map. To measure conifer canopy cover, we used Falkowski et al. (2014) remotely sensed conifer cover map. This dataset delineated conifer canopy cover into 5 classes: 1) 0-4%, 2) 4-10%, 3) 10-20%, 4) 20-50%, and 5) >50% conifer canopy cover per acre. We ground-truthed the conifer cover map and corrected values as necessary to reflect true canopy cover class values. To measure conifer removal treatments, we developed maps using WRI data (State of Utah WRI 2011) and private landowner data for all known conifer treatments for each year from 2012-2015 and corrected conifer cover values in the canopy cover data where necessary. Because conifer removal projects were implemented annually, we developed cover maps to reflect conifer distribution for each year’s nesting and brooding season. All landscape variables except canopy cover were evaluated as distance-to metrics and calculated in ArcGIS. Distance to landscape variables was zero both at the edge of and within the landscape variable area. Due to model convergence issues, canopy cover was evaluated as a continuous measure (1-5) of conifer distribution rather than categorical representations of conifer classes.

Variables were investigated for correlation to reduce multicollinearity using Pearson’s correlation test with an \( r > +/- 0.6 \) threshold for inclusion for both nest and brood locations (Hosmer and Lemeshow 2002). Within the nest site analysis, elevation and mesic habitat were correlated \( (r = -0.61) \), thus we removed elevation because nest selection could not occur in high elevations due to snowpack at higher elevations during
nesting season. Similarly, agriculture and urban areas were correlated \( r = 0.83 \). We removed urban development because most urban development in our study area occurs in association with agriculture, but not all agriculture was associated with urban development.

Within the resource selection analysis, agriculture and roads > 72 kph were correlated. \( r = -0.61 \). We removed roads > 72kph because the majority of roads in the study area > 72 kph are located in proximity to agriculture, but agriculture may be independent of roads > 72 kph. Agriculture and urban areas were correlated \( r = 0.89 \), thus, we removed urban areas for the same reason acknowledged in the nest models. Elevation and power lines were also correlated \( r = 0.62 \), thus, we removed powerlines since most power lines were associated with main roads (Gifford et al. 2014). See Table 2-1 for a summary of used landscape classification variables.

### Data Analysis

#### Nest Success

We used Generalized Linear Models (GLMs) to evaluate the influence of individual nest site location on nest success. We identified our best-fitting population-level model from 32 a priori models built using our aforementioned list of landscape variables (Table 2-1; Burnham and Anderson 2002). Models included varying combinations of the landscape variables, but distance to treatments was included in 31/32 models. The single non-distance to treatment model evaluated the univariate influence of conifer canopy cover on nest success. We evaluated model fit using Akaike Information Criterion scores adjusted for small sample sizes (AICc: Burnham and Anderson 2002). We selected the most parsimonious model within 2 \( \Delta \text{AICc} \) of the top model to reduce
All analyses were performed using the statistical package in Program R (R version 3.2.2, www.r-project.org, accessed 1 Oct 2015).

**Brood Habitat Selection**

We used a RSF framework to compare female sage-grouse brood habitat selection from 1 May to 1 August (Manly et al. 2002). We used aforementioned landscape variables as candidate predictors in our models. We used a generalized linear mixed effects model (GLMM) with a random intercept for each individual to allow for interpretation of selection among different individuals (Gillies et al. 2006). This further allowed us to account for spatial and temporal autocorrelation among individuals while accounting for varying numbers of locations among individuals (Gilles et al. 2006). Locations were pooled by brooding year (e.g., Female_1_2014, Female_1_2015) to provide a population estimate across the study period while accounting for changing availability as conifers were removed throughout the study period (Kohl et al. 2013).

We estimated brooding female sage-grouse RSFs at the third order scale (Johnson 1980) for any individual with >5 brood locations within a given year. A brood location is a point on the landscape where a radio-marked females with chicks was found. We defined an annual population-level brooding distribution by calculating a 95% Kernel Density Estimation (KDE) using the Geospatial Modelling Environment (GME; Beyer 2015). We then generated 1 000 random points per annual brooding area to quantify habitat availability. As such, availability was identical for all birds within a given year, but varied across years.

We constructed GLMMs using the landscape variables described above. To assist with convergence issues, all landscape variables were normalized ($m = 0, sd = 1$) across
the full dataset of used and available locations. We identified our best-fitting population-level model from 28 a priori candidate models (Table S2) using AICc (Burnham and Anderson 2002). Our candidate models included distance to treatments in every model. We selected the most parsimonious population-level model within 2 ΔAICc of the top model. This resulted in a two-level random-effect model (Gillies et al. 2006), in which $g(x)$ is estimated for location $i$ for female $j$:

$$g(x) = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \cdots + \beta_n x_{ni} + \gamma_{0j}$$

where $x_n$ are covariates with fixed regression coefficients $\beta_n$, $\beta_0$ is the mean intercept, and $\gamma_{0j}$ is the random intercept calculated as the difference between the mean intercept $\beta_0$ for all groups and the intercept for group $j$ (Gillies et al. 2006; Skrondal and Rabe-Heskett 2004). Employing the population-level model, we imposed a random slope-intercept model to evaluate the functional response of brooding female sage-grouse to annual-specific landscape variables. This allowed each landscape variable to sequentially interact with the random term for the individual resulting in a model in which separate intercepts and slopes were fit for each individual. This produced individual-level (conditional) coefficient estimates for each individual according to the specified landscape variable (Benson et al. 2015) and a fixed (marginal) effect for all other variables. For example, if the top model included elevation, distance to treatments, and canopy cover, the first model would consist of an interaction between elevation and the random intercept for individual. This model would produce a population-level response coefficient estimate for distance to treatments and canopy cover in addition to conditional coefficients (i.e., random slopes) for elevation by individual. In comparison, the second model would consist of an interaction between individual female and variable 2, in this
case distance to treatments. We employed the random-slope-intercept model across each landscape variable since habitat selection is a multi-dimensional process, and as such this allowed us to evaluate fitness according to conifer treatment while also accounting for individual variation in resource selection across all other landscape variables.

Because this random-slope RSF design requires a reference individual from which to calculate conditional coefficients, we selected an “average brooding female.” To identify the reference individual, we calculated the difference between the mean individual-level value of use and the population-level mean value of availability for each landscape variables by individual. The difference value was then averaged across landscape variables but within individuals to provide a single measure of landscape use relative to landscape availability. This value was sorted and individuals were ranked according to sample size and the mean and median difference value. This resulted in the selection of a 2015 female which was the 3rd individual from population mean and median and consisted of the second largest sample size. It is worth noting that this “average” females also raised at least one chick to maturity. The RSF analysis was performed using package lme4 (Bates et al. 2015) in Program R (R version 3.2.2, www.r-project.org, accessed 1 Oct 2015)

**Habitat Selection and Individual Fitness**

Individual-specific conditional responses were subtracted from the reference individual conditional response for each landscape variable. These values (maintained in the log-odds form) were extracted for each brooding female sage-grouse and used as predictors in a GLM that included individual brood success or failure. Because we had previously applied model selection to the population-level habitat selection model, no
model selection approach was used to evaluate the influence of habitat selection on brood success. This produced an odds ratio (i.e., probability) of brood success based on the individual-level selection coefficients (i.e., functional response) for a landscape variable of interest once we held the selection preference for all other landscape variables at their population-level mean selection coefficient.

RESULTS

Nesting

We monitored 95 individual sage-grouse nests, of which 61 hatched and brooding was initiated. Some of the individual sage-grouse we monitored nested in more than one year ($n = 16$). Our model selection process identified high model uncertainty with 8 models occurring within 2 $\Delta$AICc (Table 2-2). We selected the most parsimonious model ($\Delta$AICc = 0.83), which identified distance to treatment as the sole predictor of sage-grouse nest success. This suggests that for every 1 km a nest was located away from a conifer removal area, the probability of nest success were reduced by 9.1% ($\beta = -0.096$, $P < 0.05$, Fig. 2-2a). In comparison, a univariate canopy cover model was not a predictor of nest success ($\beta = -0.346$, $P = 0.11$, Fig. 2-2b), although the population-level response suggested the potential for a negative influence of conifer canopy cover on nest success.

Brooding

We documented 700 brood locations from 56 individual broods. Of these, 43 were successful, and fledged at least one chick at 50 days old. Multiple females initiated brooding in more than one year ($n=7$), however only one female successfully fledged a brood in multiple years. Our population-level model selection process identified 2
models with strong support as our best fitting model (Table 2-3). These included a model excluding distance to mesic areas (ΔAICc = 0), and the full model including all variables (ΔAICc = 1.97). The population-level top model indicated that female sage-grouse with broods selected for lower distances to conifer removal areas ($\beta = -0.524, P < 0.01$), and nonurban development ($\beta = -0.430, P < 0.01$). They selected for greater distances to roads < 40 kph ($\beta = 0.104, P < 0.01$), roads 40-72 kph ($\beta = 0.199, P < 0.01$), and agriculture ($\beta = 0.264, P < 0.01$). Female sage-grouse with broods also selected for areas of higher elevation ($\beta = 0.317, P < 0.01$), and lower conifer canopy cover ($\beta = -1.341, P < 0.01$). Because landscape variables were normalized, we were able to determine that conifer canopy cover and distance to treatments are the strongest drivers of female sage-grouse resource selection in our study area. This is of note because we observed that more ($n = 48$) successful brooding females selected areas closer to conifer removal areas compared to a few successful brooding females ($n = 7$) that selected areas farther from conifer removal areas (Table 2-4).

**Habitat Selection and Fitness**

Our brood success model suggested that the probability of brood success declined by 52.6% for every 1 unit change in the log-odds of selection for distance to treatment, however the result was only marginally significant ($P = 0.09$, Fig. 2-3a). Similarly, the probability of brood success declined at a stronger rate (77.2%) as the selection for conifer canopy cover increased ($P < 0.05$, Fig. 2-3b). In essence, sage-grouse females had a higher likelihood of brood success if they selected brooding locations closer to a conifer removal area and if the brooding area was located in habitat with minimal conifer canopy cover.
DISCUSSION

We documented a functional response to conifer canopy cover removal treatments for individual female sage-grouse that enhanced individual reproductive potential for both nesting and brooding efforts. To our knowledge this is the first research to link individual female sage-grouse selection of nest and brood sites in proximity of conifer removal treatments to increased success. This research is unique in that we used data commonly-recorded during ecological studies (i.e., GPS nest and brood locations and female nest and brood success; Connelly et al. 2003) to evaluate the effect of resource selection on nest and brood success. We also demonstrated a novel approach to using a RSF to investigate the potential effects of habitat manipulations on a population.

Distance to treatment was the sole predictor of sage grouse nest success in our GLMs. While most anthropogenic disturbance is considered detrimental to sage-grouse (Aldridge and Boyce 2007; Beck and Mitchell 2000; Blickley et al. 2012; Holloran et al. 2005; Johnson et al. 2011), we showed that strategic disturbances (conifer removal via mastication, chaining, and lop-and-scatter) may benefit sage-grouse that select these sites. We recorded multiple sage-grouse nesting attempts \((n = 8)\) with varying success in treatments < 5 years old. We believe these observations suggest that the local sage-grouse population we studied may be limited by habitat availability, in other words usable space (Dahlgren et al. 2016a). We particularly note the behavior of a female in 2015 that followed a conifer masticating tractor into a previously phase 2-3 conifer stand, found a remnant patch of sagebrush with acceptable cover, nested, and hatched a brood (Sandford et al. 2015). This behavior was bolder than previously observed in our study area, but demonstrated that sage-grouse immediately recognize newly re-opened habitat
with an intact sagebrush canopy as usable space. Our observations indicate support for Knick et al.’s (2014) suggestions that conifer removal for the benefit of sagebrush obligate species should occur at large scales adjacent to extensive sagebrush stands.

We evaluated brood fate as a function of the log-odds of habitat selection which highly complicates back-transforming the data from probability of brood success to a measurable distance from conifer removal. As a result, we simply state that for every 1 unit increase in our resource selection coefficient, such that a female sage-grouse selected areas further from a conifer removal area, the probability of that female successfully fledging at least one chick to 50 days decreased by 52.6%. Although a direct interpretation of distance is not possible, it is clear that without conifer removal, resource selection of these sites closer to removal areas could not occur, thus removing a source of increased fitness.

We hypothesize that the reduction in conifer cover may have contributed to increased fitness through a combination of factors which may include decreasing available avian nest and perch sites for potential sage-grouse nest and brood predators (Commons et al. 1999; Fedy et al. 2014), providing a release of forbs and grasses (Miller and Eddleman 2000; Schaefer et al. 2003), and reestablishing mesic areas (Deboot et al. 2008) critical to early brood success (Stiver et al. 2015). Frey et al. (2013) found that when conifers were removed, sage-grouse selected for mulched and seeded conifer removal sites over previously favored agricultural areas. Previous research in our study area suggested that sage grouse immediately recognized and used conifer removal areas depending on a suite of factors including proximity to treeless sagebrush cover occupied
by sage-grouse, intact sagebrush cover within treated areas post-conifer removal, and
distance to mesic sites (Cook 2015; Wing 2014).

Cook (2015), Sandford et al. (2015), and Wing (2014) noted that sage grouse in
our study area readily expanded when suitable habitat was reopened, suggesting that the
population may be space limited. Dahlgren et al. (2016a) observed that across Utah,
sage-grouse populations in with less habitat space made smaller brood movements from
nest sites while populations in large areas made larger movements. They suggested that
increasing usable space could increase habitat availability and movements. In view of
our results, we suggest that removing conifers at scales > 57 ha and adjacent to existing
sagebrush habitat may not only provide increased habitat availability, but also increased
fitness and population stability.

We suggest the methods and spatial scale of conifer removal may also affect sage-
grouse use of treatment sites, particularly as it relates to distance to open occupied
sagebrush habitat, remaining intact sagebrush canopy cover within conifer removal areas,
and distance to mesic areas. Improperly managed prescribed fire could have a negative
impact on the shrubs and herbaceous understory plants important for sage-grouse
(Connelly et al. 2011; Knick et al. 2014; Roundy et al. 2014), whereas mechanical conifer
removal can maintain sufficient understory to attract sage-grouse use depending on pre-
removal conditions (Frey et al. 2013; Sandford et al. 2015).

The prescribed fire treatments studied by Knick et al. (2014) exhibited 6-24%
residual conifer canopy cover and woodland canopy cover >4% has been implicated as
being associated with sage-grouse lek extirpation and avoidance (Baruch-Mordo et al.
2013; Fedy et al. 2014). Mechanical treatments may obtain higher conifer removal
percentages than prescribed fire because they involve more human control in the outcome (A. Clark, UDNR, personal communication; Frey et al. 2013). However, mechanical treatments may require more frequent re-treatment because they often miss seedlings, and do not directly alter the seed bank. Because sage-grouse are a landscape-species (Connelly et al. 2011), the scale of treatments may also affect the probability of sage-grouse use (Doherty et al. 2010; Frey et al. 2013). The conifer removal treatments we studied were completed in a SGMA that exhibited some of the highest sage-grouse densities reported in Utah (UWDR 2009).

Population-level investigations are often used to compare species (Kohl et al. 2013), or relate habitat manipulation or disturbance to population-level fitness (Benson et al. 2015; Cain et al. 2008; Harrington et al. 1999). Dahlgren et al. (2016b) provided evidence that telemetry-based studies can provide unbiased demographic information for analysis and monitoring, and male-based leks counts of sage-grouse can be an effective index to overall population change. Population-level variation in vital rates can be highly informative of landscape-scale demographic rates (DeCesare et al. 2014). The integration of these data in concert with our RSF approach to assessing sage-grouse fitness could provide new insight into population dynamics in response to management actions at greater temporal and spatial scales. Studies based on long-term demographic data are needed to enhance scientific rigor for prioritization of the most cost effective species conservation and management actions. These studies could provide the basis for using male-based lek counts to track the effect of conservation actions on long-term population stability (Utah Governor’s Office 2013).
MANAGEMENT IMPLICATIONS

We demonstrated that the removal of conifer canopy cover on large areas by mechanical methods adjacent to occupied sage-grouse habitat may have a positive effect on individual female nest and brood survival rates. In our study area, over 8100 ha of conifers have been removed using various mechanical methods at project scales of greater than 57 ha each, generally on the periphery of existing sagebrush habitat. However, more information is needed regarding female sage-grouse selection and fitness relative to methods and scale of conifer canopy removal projects and the effect of this management strategy on population stability. Lastly, we recommend the incorporation of animal-mounted GPS technology to increase sage-grouse site selection data sample size. The use of this technology could also better detect female sage-grouse behavioral responses to different conifer canopy removal methods at a finer temporal scale.

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Table 2-1. Candidate variables and their metrics included in greater sage-grouse (*Centrocercus urophasianus*) nest and brood site selection and success probability models for Park Valley, Utah from 2012 to 2015.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Distance to</th>
<th>Canopy Cover</th>
<th>Elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Units</td>
<td>Kilometers</td>
<td>Kilometers</td>
<td>Kilometers</td>
</tr>
<tr>
<td>Roads &gt;72kph</td>
<td>Kilometers</td>
<td>Kilometers</td>
<td>Kilometers</td>
</tr>
<tr>
<td>Roads 40-72kph</td>
<td>Kilometers</td>
<td>Kilometers</td>
<td>Kilometers</td>
</tr>
<tr>
<td>Roads &lt;40kph</td>
<td>Kilometers</td>
<td>Kilometers</td>
<td>Kilometers</td>
</tr>
<tr>
<td>Power lines</td>
<td>Kilometers</td>
<td>Kilometers</td>
<td>Kilometers</td>
</tr>
<tr>
<td>Agriculture</td>
<td>Kilometers</td>
<td>Kilometers</td>
<td>Kilometers</td>
</tr>
<tr>
<td>Urban Development</td>
<td>Kilometers</td>
<td>Kilometers</td>
<td>Kilometers</td>
</tr>
<tr>
<td>Nonurban Development</td>
<td>Continuous(1-5)</td>
<td>Kilometers</td>
<td>Kilometers</td>
</tr>
</tbody>
</table>

Note: Female presence in a category was denoted as a “0” in distance-to layers.
**Table 2-2.** AIC table of top ranking generalized linear candidate models using habitat variables to predict individual greater sage-grouse (*Centrocercus urophasianus*) nest success probability in Park Valley, Utah from 2012 to 2015.

<table>
<thead>
<tr>
<th>Predictor Variables</th>
<th>K</th>
<th>AICc</th>
<th>ΔAICc</th>
<th>AICcWt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treat, Ag</td>
<td>3</td>
<td>128.84</td>
<td>0.00</td>
<td>0.12</td>
</tr>
<tr>
<td>Treat, Ag, Roads&lt;40</td>
<td>4</td>
<td>129.56</td>
<td>0.72</td>
<td>0.09</td>
</tr>
<tr>
<td>Treat</td>
<td>2</td>
<td>129.67</td>
<td>0.83</td>
<td>0.08</td>
</tr>
<tr>
<td>Treat, Ag, Power</td>
<td>4</td>
<td>129.97</td>
<td>1.13</td>
<td>0.07</td>
</tr>
<tr>
<td>Treat, Roads&lt;40</td>
<td>3</td>
<td>130.31</td>
<td>1.47</td>
<td>0.06</td>
</tr>
<tr>
<td>Treat, Mesic</td>
<td>3</td>
<td>130.44</td>
<td>1.60</td>
<td>0.06</td>
</tr>
<tr>
<td>Treat, Ag, NonUrb</td>
<td>4</td>
<td>130.68</td>
<td>1.84</td>
<td>0.05</td>
</tr>
<tr>
<td>Treat, Canopy</td>
<td>5</td>
<td>130.85</td>
<td>2.00</td>
<td>0.05</td>
</tr>
<tr>
<td>Treat, Mesic, Canopy</td>
<td>6</td>
<td>131.10</td>
<td>2.26</td>
<td>0.04</td>
</tr>
</tbody>
</table>

*Notes:* Variables abbreviated to fit within table margins. ‘Treat’ is defined as distance (km) to conifer removal area, ‘Power’ is defined as distance (km) to powerlines, ‘Roads<40’ is defined as distance (km) to roads less than 40 kph, ‘Ag’ is defined as distance (km) to agricultural areas, ‘NonUrb’ is defined as distance (km) to non-urban development, ‘Canopy’ is defined as canopy cover class (1-5), and ‘Mesic’ is defined as distance (km) to mesic area. A ‘0’ in any distance-to category indicated that a nest was at or within the habitat variable.
Table 2-3. AIC table of top ranking generalized linear mixed effects candidate models using habitat variables to predict population level habitat selection of greater sage-grouse (*Centrocercus urophasianus*) females with broods in Park Valley, Utah from 2012 to 2015.

<table>
<thead>
<tr>
<th>Predictor Variables</th>
<th>K</th>
<th>AICc</th>
<th>ΔAICc</th>
<th>AICcWt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treat, Elev, Roads&gt;40, Roads&lt;40, Ag, NonUrb, Canopy</td>
<td>9</td>
<td>6759.73</td>
<td>0</td>
<td>0.73</td>
</tr>
<tr>
<td>Treat, Elev, Roads&gt;40, Roads&lt;40, Ag, NonUrb, Canopy, Mesic</td>
<td>10</td>
<td>6761.7</td>
<td>1.97</td>
<td>0.27</td>
</tr>
<tr>
<td>Treat, Elev, Roads&gt;40, Ag, NonUrb, Canopy, Mesic</td>
<td>9</td>
<td>6788.07</td>
<td>28.34</td>
<td>0.27</td>
</tr>
</tbody>
</table>

**Notes:** Variables abbreviated to fit table margins. ‘Treat’ is defined as distance (km) to conifer removal area, ‘Elev’ is defined as elevation (m), ‘Roads>40’ is defined as distance to roads 40-72 kph, ‘Roads<40’ is defined as distance (km) to roads less than 40 kph, ‘Ag’ is defined as distance (km) to agricultural areas, ‘NonUrb’ is defined as distance (km) to non-urban development, ‘Canopy’ is defined as canopy cover class (1-5), and ‘Mesic’ is defined as distance (km) to mesic area. A ‘0’ in any distance-to-category indicated that a nest was at or within the habitat variable.
Table 2-4. Summary of population level based best-model estimates showing the individual-level marginal response (selection coefficient) for 56 individual female sage-grouse (*Centrocercus urophasianus*) in Park Valley, Utah from 2012 to 2015.

<table>
<thead>
<tr>
<th>Sign</th>
<th>Treatment</th>
<th>Roads 40-72kph</th>
<th>Roads &lt;40kph</th>
<th>Agriculture</th>
<th>NonUrban</th>
<th>Conifer Canopy</th>
<th>Elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n b p</td>
<td>n b p</td>
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<td>20 13 20</td>
<td>32 22 6</td>
<td>36 29 12</td>
<td>22 15 22</td>
<td>55 40 16</td>
<td>37 29 2</td>
</tr>
<tr>
<td>-</td>
<td>48 34 37</td>
<td>36 28 23</td>
<td>24 18 13</td>
<td>20 12 9</td>
<td>34 26 6</td>
<td>1 1 1</td>
<td>19 12 14</td>
</tr>
</tbody>
</table>

Notes: *n* indicates the total number of female sage-grouse with a brood according to selection coefficient, *b* indicates the number of sage-grouse females that fledged a brood regardless of coefficient significance in each sign category, *p* is the number of females regardless of brood success that displayed a statistically significant selection coefficient (*p* ≤ 0.05). Negative coefficient signs for ‘distance to’ variables indicates a selection for a distance closer to the landscape variable. Negative coefficients for conifer canopy indicate an aversion to higher canopy class. Negative coefficients for elevation indicate a selection for lower elevation.
Figure 2-1. Utah’s greater sage-grouse (*Centrocercus urophasianus*) Management Area 1, located in northwest Box Elder County, Utah (Utah Governor’s Office 2013).
Figure 2-2a. Probability of female sage-grouse (*Centrocercus urophasianus*) nest success as a function of conifer canopy cover class in Park Valley, Utah from 2012 to 2015. Probability of nest success decreased by 30% for each unit increase in conifer canopy cover (*p*=0.11).

Notes: Conifer canopy cover percent divided into 5 classes: 1) 0-4%, 2) 4-10%, 3) 10-20%, 4) 20-50%, 5) 50+% per acre.

Figure 2-2b. Probability of female sage-grouse (*Centrocercus urophasianus*) nest success as a function of distance (km) to conifer removal area in Park Valley, Utah from 2012 to 2015. Probability of nest success declined by 9.1% for every 1km a nest was located away from a conifer removal area (*p*<0.05).
Figure 2-3a.
Probability of greater sage-grouse (Centrocercus urophasianus) brood success plotted against selection coefficient estimates of conifer canopy cover in Park Valley, Utah from 2012 to 2015. Avoidance indicates sage-grouse females choose sites with less conifer canopy cover. Selection indicates sage-grouse females choose sites with higher conifer canopy cover.

Figure 2-3b.
Probability of greater sage-grouse (Centrocercus urophasianus) brood success plotted against selection coefficient estimates of distance (km) to conifer removal areas in Park Valley, Utah from 2012-2015. Avoidance indicates sage-grouse females choose areas close to conifer removal areas. Selection indicates sage-grouse females choose areas away from conifer removal areas.
CHAPTER 3

USING PELLET SURVEYS TO ESTIMATE SAGE-GROUSE USE IN MANIPULATED SAGEBRUSH HABITATS IN NORTHWESTERN UTAH

ABSTRACT

The greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse) is heavily reliant on sagebrush (*Artemisia* spp.) communities across western North America. Despite being the most prevalent vegetation type in western North America, it is also considered one of the most threatened ecosystems because of changing land uses. In 2010, the sage-grouse was designated as a candidate species by the U.S. Fish and Wildlife Service (USFWS) for protection under the Endangered Species Act of 1973 due to range-wide population declines and long-term habitat loss. The USFWS has identified conifer encroachment into sagebrush communities as conservation threat to both sage-grouse and sagebrush ecosystems. As such, land managers have removed an unprecedented amount of conifer encroachment range wide to restore sage-grouse sagebrush habitats. Because conifer removal projects can be expensive and resource limited, managers require better information regarding the effect of these landscape level projects on sage-grouse habitat-use. I used line-transect pellet surveys to estimate sage-grouse use in contiguous sagebrush, conifer encroachment, and mechanical conifer removal treatments completed in the Box Elder Sage-grouse Management Area in northwestern Utah. Sage-grouse pellet densities were 4.6 / ha (95% CI = 1.2, 10.9) in conifer encroachment areas, 8.6 / ha (95% CI = 3.8, 15.2) in mechanical conifer removal areas, and 50.6 / ha (95% CI = 36.8, 69.9) in undisturbed sagebrush areas. Although the
pellet densities recorded between conifer encroachment and mechanical removal areas was not significant, this research demonstrates the potential for mechanical treatments to increase usable habitat space for sage-grouse in areas where conifers have encroached into sagebrush habitats.

INTRODUCTION

Greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse) are ground-dwelling sagebrush (*Artemisia* spp.) obligate birds that are found in much of western North America’s shrub-steppe rangelands (Patterson 1952). Due to their dependence on healthy sagebrush habitat, they are considered key indicators of sagebrush ecosystem health (Lyon and Anderson 2003, Knick et al. 2013). In 2015, following multiple petitions to protect the sage-grouse under the Endangered Species Acts of 1973 (ESA), the U.S. Fish and Wildlife Service (USWFS) determined that sage-grouse was not warranted for ESA protection (USFWS 2015).

As early as 2000, the West Box Elder Adaptive Resource Management Sage-grouse Local Working Group (BARM) began meeting to develop their own management plan for sage-grouse conservation in western Box Elder County, Utah (BARM 2007). The BARM plan identified pinyon (*Pinus* spp.) and juniper (*Juniperus* spp.; conifer) expansion into occupied sagebrush habitats as a threat to local sage-grouse conservation. As conifers expand into sagebrush habitats, they close the canopy, suppress sagebrush and herbs, and convert the micro-climate to a xeric condition that is unsuitable for sage-grouse (Miller and Eddlemann 2000, Miller 2005). Conifers may also offer perches and hiding cover for sage-grouse predators (Commons et al. 1999, Fedy et al. 2014).
Frey et al. (2013) reported that when encroaching conifers were mechanically masticated, sage-grouse selected for mastication sites over previously favored agricultural areas, which may have served as a surrogate sites for native mesic areas that had been converted to conifer cover (Klebenow, 1969, Connelly and Doughty 1989, Braun 1998, Connelly et al. 2000). Baruch-Mordo et al. (2013) observed that sage-grouse leks may be extirpated even when conifer cover is as low as 4% within 1 km of a lek. Sandford et al. (2015) documented sage-grouse nesting in conifer removal areas. Sandford et al. (2016) reported a positive effect on nest and brood success when sage-grouse selected areas closer to conifer removal areas. Previous research in western Box Elder County (Wing 2014, Cook 2015, Sandford et al. 2015) identified sage-grouse use of conifer removal areas, but did not investigate or compare to sage-grouse use of conifer encroachment areas.

Sage-grouse surveys are often performed to estimate sage-grouse use of small treatment plots in sagebrush, or large landscapes where detecting radio-marked individuals in specific habitat types is unlikely. Both ocular and auditory point transects (Knick et al., 2014) and pellet line transect methods (Dahlgren et al. 2006, Guttery 2011, Hanser et al. 2011, Graham 2013, Cook 2015) have been used to estimate sage-grouse use of manipulated habitat. Previous research in small sagebrush treatments used relatively short transect lengths to estimate fecal pellet densities: 500 m (Graham 2013); 3 stratified transects of 636 m by sample unit (Dahlgren et al. 2006); and for 1 m circular plots per site (Guttery 2011). However, recent research in the study area (Cook 2015) found that 2400 m square (600 x 600 m) transects increased detection rates and reduced travel time between transects.
STUDY AREA

My study was completed in western Box Elder County, Utah, in the southeast corner of the Snake River Plain/Sage-grouse Management Zone IV (Stiver et al. 2015). In the state of Utah, this region is described as the Box Elder Sage-grouse Management Area (SGMA) in Utah’s Conservation Plan for Greater Sage-grouse (Utah Governor’s Office 2013). The study area encompassed approximately 150,000$^2$ ha around the rural towns of Park Valley and Rosette. Land ownership was a mosaic of private, Bureau of Land Management, U.S. Forest Service, and Utah State and Institutional Trust Lands Administration. Geographically, the study was bounded to the north by the Raft River Mountains, to the west by the Dove Creek and Grouse Creek Mountains, and to the south and east by Utah Highway 30 (Fig. 3-1). The primary land uses of the study area are domestic livestock grazing ($Bos taurus$ and $Ovis aries$) and alfalfa ($Medicago sativa$) hay production.

The study area occurred at an overlap between the Great Basin sagebrush community and the sagebrush-steppe community, and displays characteristics of both ecological types (Miller and Eddleman 2000). Wyoming ($A. tridentata wyomingensis$), and black sagebrush ($A. nova$) dominated the study area, with conifer encroachment areas interspersed, along with small communities of mountain sagebrush ($A. t. vaseyana$), curl leaf mahogany ($Cercocarpus ledifolius$), spruce ($Picea$ spp.), fir ($Abies$ spp.) and aspen ($Populus tremuliodes$) in higher elevations. Elevation ranged from 1,600 to 2,600 m above sea level.

Mean annual precipitation between 1990 and 2015 was 29.3 cm in Rosette (1706 m elevation). Most precipitation occurred between December and June, averaging 2.8
cm per month. Mean temperature ranged from -9.4 °C in December to 30.3 °C in July (Western Regional Climate Center 2015). Higher elevations remained colder, received more precipitation, and could retain snow well into the summer. The 2014 field season was characterized a dry winter, warm spring, unusually wet summer, and average fall. The 2015 season was characterized by a dry winter, extremely early spring, unusually wet and early summer, and average fall.

I evaluated 3 different dominant habitat types in the study area; conifer removal areas, conifer encroachment areas, and contiguous, undisturbed sagebrush areas. More than 30 conifer removal projects of various sizes (10 – 600 ha) have been completed in the study area since 2007. Removal methods included one and two-way chaining (Cain 1971), mastication (Fecon Bull Hog, Lebanon, OH), pull-and-pile, and lop-and-scatter. Conifer encroachment areas in proximity to conifer removal sites were determined using Falkowski et al.’s (2014) remotely sensed imagery. Contiguous sagebrush habitat in proximity to conifer encroached areas and removal sites were also surveyed to provide reference data.

**METHODS**

Using data provided by private landowners, the U.S. Natural Resources Conservation Services, and Utah’s Watershed Restoration Initiative (WRI; State of Utah Watershed Restoration Initiative 2011), I mapped all conifer removal sites in the study area. I adapted Cook’s (2015) methods, and considered each 2400 m square to be composed of four individual 600 m transects. Two 600 m transects (two 400 m transects joined by two 200 m transects) were also utilized in areas where habitat configuration prevented the 4 transect design. Due to limited time and resources, I established 86
transects in 15 of the conifer removal areas. I also established 94 transects in conifer encroachment areas, and 68 transects in sagebrush habitat. Transects were stratified into the three habitat types across the study area. Because transects were required to fall in one specific habitat type, I examined Falkowski et al.’s (2014) map for areas large enough to contain the 4 transect design. When sufficient area was located, transects were placed without any other prior knowledge of the area. To confirm that pellet surveys occurred in available habitat, I built 95% home range isopleths of sage-grouse telemetry data collected concurrently in 2014 and 2015, and confirmed that all of our pellet survey transects occurred within the combined home ranges.

Transects were loaded onto handheld global positioning system (GPS) receivers to guide field observers. Each transect was validated for habitat consistency by a single observer, and walked at a slow pace (≤ 1.2 km / hr). Observers visually scanned for fecal pellets and cecal droppings within 2 m of either side of the transect line (Dahlgren et al. 2006, Cook 2015). Pellets detected beyond the 2 m threshold were also recorded as sage-grouse presence. Observers classified > 2 pellets within 30 cm of each other as a single occurrence, and measured distance to transect from the center of the cluster. Individual pellets were classified as a single occurrence, and distance from transect to pellet was recorded.

**Data Analysis**

All analysis were performed in program R (R version 3.2.2, www.r-project.org, accessed 1 Oct 2015). I used package RDistance (McDonald et al. 2015) to estimate detection functions, and estimate density. I inspected the data for normality and truncated detections to a maximum of 3 m due to observed outliers in each data set. I
also limited maximum detection likelihood to 1 to prevent spurious results, and limited
the number of expansions to either 0 or 1. I used Akaike’s Information Criterion adjusted
for small sample sizes (AICc: Burnham and Anderson 2002) to select the best detection
function for each habitat type. Once a detection function was selected, it was
incorporated into the density estimation function. Confidence intervals were determined
via bootstrapping, using the fitted density estimation model to simulate 3000 replications
of the original data sets (Dixon 1993, Hagen et al. 2007, Guttery 2011).

RESULTS

I conducted pellet surveys on 248 transects from 2014 to 2015. Of the 248
transects, 94 were located in conifer encroachment areas, 86 were located in conifer
removal areas, and 68 were located in undisturbed sagebrush areas. Because clusters and
individual pellets were recorded as 1 occurrence, “pellets” and “pellet density” refers to
density of occurrences.

The best fitting detection function for pellets in conifer encroachment areas was a
negative exponential likelihood with no expansions (AICc: 54.5, Table 3-1). This
provided an estimate of 4.6 pellets/ha (95% CI = 1.2, 10.9), with a 25.7% detection
probability. The best fitting detection function for pellets in conifer removal areas was a
negative exponential likelihood with no expansions (AICc: 82.2, Table 3-2). This
provided an estimate of 8.6 pellets/ha (95% CI = 3.8, 15.2), and a 24.3% detection
probability. The best fitting detection function for pellets in sagebrush areas was a
hazard rate likelihood with 1 cosine expansion (AICc: 1038.64, Table 3-3). This
provided an estimate of 50.6 pellets/ha (95% CI = 36.8, 69.6) and a 48% detection
probability (Fig. 3–2).
DISCUSSION

This study demonstrated that sage-grouse use as detected by pellet surveys of the dominant habitat types of the study area varied considerably. Sage-grouse pellet density was lowest in conifer encroachment areas, higher in conifer removal areas, and was significantly higher in undisturbed sagebrush reference areas. The increase in pellet count densities when conifer canopy was reduced suggests that sage-grouse are responding to the increase in usable space (Cook 2015, Dahlgren et al. 2016).

Guthery (1997) stated that increasing overall space that is usable to a species may provide better opportunity for population growth than improving existing habitat. Dahlgren et al. (2016) analyzed sage-grouse telemetry from across the state of Utah from 1998-2013, and concluded that sage-grouse in Utah may be limited in their movements by unsuitable habitat. My observations further suggest that the sage-grouse population in the study area may be limited by conifer encroachment.

My estimate of 50.6 pellets/ha (95% CI = 26.8, 69.6) in undisturbed sagebrush habitat is comparable to the 57.8 pellets/ha Dahlgren et al. (2006) observed in the Parker Mountain SGMA in south-central Utah. In a neighboring sage-grouse population, Graham (2013) estimated 163 pellets/ha in undisturbed sagebrush. However, their study used fewer and shorter transects, all within 3 km of a lek, preventing landscape level inferences. Cook (2015) was unable to report sage-grouse pellet densities in conifer encroachment and removal areas due to insufficient sample size. However, they did determine that factors such as proximity to mesic areas and habitat currently occupied by sage-grouse were strong predictors of sage-grouse use of conifer removal areas. Hanser et al. (2011) stratified pellet surveys across areas of differing disturbance types and
intensities, and concluded that pellet surveys used in ecological modeling correctly classified habitat as occupied at >75% of active leks in Wyoming.

Many of the sage-grouse pellet detections in conifer encroachment areas occurred in remnant sagebrush patches (~2 ha) surrounded by early phases of conifer encroachment. This suggests that the conifer encroachment may be in historical sage-grouse habitat, and sage-grouse are being extirpated from the area. Further, most of the sage-grouse pellet detections were roost piles, indicating that sage-grouse may only select these areas under the cover of night. Very few pellet detections occurred in areas where conifer domination was contiguous.

Pellet survey transects were stratified to mitigate overlap and obtain adequate sample sizes without double counting pellets. Dahlgren et al. (2006) found that in the Parker Mountain SGMA in south-central Utah, 70% of sage-grouse pellets decayed within 10 months of deposition, and the remaining pellets had lost color and structural integrity. As such, the 12 month interval between pellet surveys further reduced risk of double counting or sampling pellets > 1 year old.

Because sagebrush is a slow growing species, conifer removal areas may not see an immediate increase in sage-grouse use comparable to undisturbed sagebrush. However, merely having removed the conifers provides known benefits to sage-grouse. If these areas receive continued maintenance to prevent conifer return, they may return to their former sagebrush dominated landscape and likely see further increased sage-grouse use. Periodic maintenance treatment in removal areas could also reduce cost associated with large scale treatments thus making sustaining conifer free areas economically feasible. Continued monitoring of conifer encroachment and removal sites may reveal a
time lag between conifer removal and significant sage-grouse use. Continued monitoring could also increase sample size and detect conifer removal methods that provide the fastest and largest sage-grouse response.

MANAGEMENT IMPLICATIONS

My research suggests that the sage-grouse population in the study area has great potential for conservation. Despite challenges like altered fire regimes, habitat loss and degradation, invasive plants like cheatgrass (*Bromus tectorum*), and conifer encroachment, the population exhibits above average reproductive rates and relatively high survival rates compared to other population in the state of Utah. Removing conifer encroachment opens usable space, providing access to resources and allowing the sage-grouse to expand its habitat. Because conifer encroachment suppresses sagebrush communities and extirpates sage-grouse, managers should look for opportunities to create usable space and future sagebrush habitat. My research provides valuable information regarding sage-grouse use of conifer encroachment areas, conifer removal areas, and undisturbed sagebrush habitat in the Box Elder SGMA. This information should be used to guide further habitat management for the benefit of sage-grouse in the Box Elder SGMA.

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Table 3-1. Candidate models for estimating greater sage-grouse (*Centrocercus urophasianus*) pellet density per hectare in pinyon (*Pinus* spp.) and juniper (*Juniperus* spp.) removal habitat in northwestern Utah, 2014-2015. Note the selected model is in bold.

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Table 3-2. Candidate models for estimating greater sage-grouse (*Centrocercus urophasianus*) pellet density per hectare in pinyon (*Pinus* spp.) and juniper (*Juniperus* spp.) encroachment habitat in northwestern Utah, 2014-2015. Note the selected model is in bold.

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Table 3-3. Candidate models for estimating greater sage-grouse (*Centrocercus urophasianus*) pellet density per hectare in sagebrush (*Artemisia* spp.) habitat in northwestern Utah, 2014-2015. Note the selected model is in bold.

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Figure 3-1. Locations of greater sage-grouse (*Centrocercus urophasianus*) pellet density estimation transects conducted from 2014-2015 in Utah’s Box Elder Sage-grouse Management Area. Note the overlap of 2015 treatment transects and 2014 conifer transects. These were treated in the fall of 2014 after pellet surveys were completed. Due to most conifer removal projects occurring on private property, project perimeters have been excluded.
Figure 3-2. Estimated greater sage-grouse (*Centrocercus urophasianus*) pellet density in pinyon (*Pinus* spp.) and juniper (*Juniperus* spp.; conifer) encroachment habitat, conifer removal habitat, and undisturbed sagebrush (*Artemisia* spp.) habitat in northwestern Utah, 2014-2015.
ABSTRACT

As a sagebrush (*Artemisia* spp.) obligate, the greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) is considered an indicator species of sagebrush ecosystem health. Sage-grouse require sufficient sagebrush canopy cover during the winter to survive. However, sage-grouse also select micro-sites within sagebrush habitats that exhibit diverse vegetation composition and structure for nesting and brood-rearing. Although general vegetation composition and structure at sage-grouse nesting and brood-rearing micro-sites has been previously reported, these measurements may vary considerably across the species range. To provide better information regarding the role of vegetation structure and composition at habitat micro-sites used by sage-grouse to nest and raise broods in Utah, I compared shrub, grass, and forb percent cover and height, percent bare ground, litter, and rock composition, and visual obstruction [VOR] at used and random sites within the Box Elder Sage-grouse Management Area (SGMA) in northwestern Utah. I performed 2 sample 2 tailed t-tests to determine if nest and brood fate differed based on habitat micro-site vegetation characteristics. Sage-grouse nest success was not affected by the vegetation parameters measured. Successful broods selected sites that exhibited greater inward VOR, percent shrub cover, percent sagebrush cover and height, percent forb cover and height, and grass height than sites selected by unsuccessful broods. Further, sites used by successful broods exhibited greater inward VOR height, shrub cover and height, sagebrush cover and height, forb height, grass
height, and less bare ground and rock composition than random sites. To sustain and improve sage-grouse population levels in the Box Elder SGMA, managers should focus on maintaining existing sagebrush habitat and look for opportunities to expand the habitat base by conifers in areas where they have encroached into sagebrush habitats.

INTRODUCTION

The greater sage-grouse (Centrocercus urophasianus; sage-grouse) is considered a key indicator of the health of sagebrush steppe ecosystems (Knick et al. 2013). In 2010, the U.S. Fish and Wildlife Service (USFWS) determined the sage-grouse was a candidate for protection under the Endangered Species Act of 1973 (USWFS 2010). The USFWS cited habitat loss and degradation as major factors causing sage-grouse population declines.

Sage-grouse are landscape species that require expansive areas of sagebrush for nesting (Connelly et al. 2011a, 2011b). Their winter diet is composed almost entirely of sagebrush (Dalke et al. 1963; Patterson 1952). However, there are many other resources within sagebrush habitat that determine sage-grouse use and fitness. Sage-grouse chicks are dependent on a diet of insects and forbs during the first few weeks of development (Drut et al. 1994; Johnson and Boyce 1990; Klebenow and Gray 1968). Therefore, immediately after hatch a female may have to move her chicks to a more mesic area where habitat characteristics provide increased available forbs and insects (Connelly et al. 2011c). Adult sage-grouse may also consume forbs when available, and may even travel great distances to find areas that provide abundant forbs such as higher elevations, mesic areas, and agricultural fields (Patterson 1952; Reinhart et al. 2013).
In Utah, sage-grouse inhabit an estimated 29,208 km\(^2\), just 41% of their historic range (Beck et al. 2003). The State of Utah identified altered fire regimes, invasive plant species, and lack of vegetation management as major sage-grouse conservation threats in Utah (Utah Governor’s Office 2013). The Utah Plan identified 11 Sage-grouse Management Areas (SGMAs) as having the greatest potential for sage-grouse conservation in the state (Dahlgren et al. 2016). The West Box Elder Adaptive Resources Management Sage-grouse Local Working Group (BARM) developed the initial sage-grouse conservation plan for western Box Elder County (BARM 2007). The conservation threats identified by BARM were fully incorporated in the Utah Plan and the area was subsequently designated as the Box Elder SGMA (Utah Governor’s Office 2013).

In 2007, BARM partnered with the Bureau of Land Management (BLM), Natural Resources Conservation Service (NRCS), and Utah’s Watershed Restoration Initiative (WRI) to implement habitat management projects to benefit sage-grouse, and other local wildlife (BARM, 2007). Many of these projects focused on reducing pinyon (\textit{Pinus} spp.) and juniper (\textit{Juniperus} spp.; conifer) canopy cover in sagebrush habitats. Since 2007, > 30 conifer removal projects encompassing > 8000 hectares have been completed in Box Elder SGMA. Commons et al. (1999), Doherty et al. (2010), and Baruch-Mordo et al. (2013) previously reported sage-grouse avoidance areas where conifers have encroached on otherwise suitable sagebrush habitats. Other projects completed in the area sought to increase brood-rearing habitats by reducing dense sagebrush canopy cover (BARM 2007; Dahlgren et al. 2006).
Previous research in the Box Elder (Knerr 2007; Wing 2014) and Parker Mountain SGMA in south-central Utah (Dahlgren 2006; Dahlgren et al. 2006) demonstrated that sage-grouse populations can thrive in habitats that exhibit vegetation characteristics below threshold recommendations (Connelly et al. 2000; Stiver et al. 2015). Because of the management emphasis directed toward habitat protection, restoration, and improvement for sage-grouse in the Box Elder SGMA, it is important that land managers have information regarding sage-grouse responses to on-going efforts. Better information is needed regarding the vegetation characteristics of the nesting and brooding habitats sage-grouse are selecting and how these characteristics may affect nest and brood success for application of management. The objective of this research is to describe the breeding habitat micro-site vegetation characteristics in the Box Elder SGMA and their effect on sage-grouse recruitment.

**STUDY AREA**

The study was conducted in western Box Elder County, Utah, in the Raft River subunit of the Box Elder SGMA (Fig. 1-1; Utah Governor’s Office 2013), and the southeast corner of the Snake River Plain Management Zone (Stiver et al. 2006). The focal area covered approximately 150,000 ha² in the vicinity of the towns of Park Valley (lat. 41°49’16”N, long. 113°24’03’W) and Rosette, and former towns of Rosebud and Dove Creek. The area was a mosaic of private, state, and public lands administered by the BLM and U.S. Forest Service (USFS). The predominant land use was domestic livestock (*Bos taurus* and *Ovis aries*) grazing; alfalfa (*Medicago sativa*) hay production and rock quarrying were also common in the study area. Geographically, the study area was bounded by the Raft River Mountains to the north, the Grouse Creek Mountains to
the west, and the Great Salt Lake hardpan to the south and east. Elevation ranged from 1,350 m to 2,950 m above sea level.

Mean annual precipitation between 1990 and 2015 was 29.26 cm in Rosette (1706 m. elevation). Most precipitation occurred between December and Jun, averaging 2.8 cm per month. Mean temperature ranged from -9.4 °C in December to 30.3 °C in July (Western Regional Climate Center 2015). Higher elevations remain colder, receive more precipitation, and elevations >2438 m may retain snow well into the summer. The 2014 field season was characterized a dry winter, warm spring, unusually wet summer, and average fall. The 2015 season was characterized by a dry winter, extremely early spring, unusually wet and early summer, and average fall.

Vegetation in the study area is driven by soil type, precipitation, and elevation. The study area was composed primarily of sagebrush-steppe habitat characterized by big (A. tridentata spps.) and small sagebrush (A. nova and A. arbuscula) species. Other shrub and tree species included rabbitbrush (Chrysothamnus spp.), greasewood (Sarcobatus vermiculatus), antelope bitterbrush (Purshia tridentata), serviceberry (Amelanchier utahensis), snowberry (Symphoricarpos albigula), chockecherry (Prunus virginiana), juniper, pinyon pine, spruce (Picea spp.), fir (Abies spp.), quaking aspen (Populus tremuloides), and curl-leaf mahogany (Cercocarpus ledifolius). Common native and introduced grasses included Sandberg’s bluegrass (Poa secunda), cheatgrass (Bromus tectorum), crested wheatgrass (Agropyron cristatum), bluebunch wheatgrass (Pseudoregnaria spicata), and Great Basin wildrye (Leymus cinereus). Common forbs included milkvetch (Astragalus spp.), phlox (Phlox spp.), hawksbeard (Crepis spp.), lupine (Lupinus spp.), and western yarrow (Achillea millefolium).
The sage-grouse population in the study area has been monitored by the Utah Division of Wildlife Resources (UDWR) since the 1950’s. The Box Elder SGMA encompasses one of the largest and most stable sage-grouse populations in Utah; 577 male sage grouse were counted on 42 leks in 2013 (UDWR unpublished data; Western Association of Fish and Wildlife Agencies 2015). The BARM was formed in 2000 with the intent of conserving sage-grouse in the area. In 2012 it evolved into the West Box Elder Coordinated Resource Management Group, representing a diverse group of landowners, government personnel, and non-government conservation groups also focused on grazing improvement, economic development, and watershed restoration (BARM 2012).

METHODS

Sage-grouse Radio-marking

From 2014 to 2015, I captured, radio-marked, and monitored 71 female sage-grouse in the study area. To minimize possible handling effects on nest initiation, sage-grouse were captured on or near leks where they were found roosting in early spring prior to nesting season. Trapping occurred primarily on the periphery of known lekking and wintering areas to maximize trapping productivity, and minimize the risk of a bird leaving the study area due to recognized site fidelity (Reinhart et al. 2013; Robinson and Messmer 2013).

Sage-grouse were trapped at night in minimal light conditions, using All-Terrain-Vehicles, spotlights, and dip nets following protocols described by Giesen et al. (1982), Wakkinen et al. (1992), and Connelly et al. (2003). Sage-grouse ages were determined based on the appearance of primaries 9 and 10, and sex based on plumage characteristics
and size (Connelly et al. 2003; Crunden 1963; Eng 1955). Female sage-grouse received a size 14 numbered aluminum leg band (National Band Company, Newport, KY) and an 18-22g Very High Frequency (VHF) radio-necklace (Advanced Telemetry Systems, Isanti, MN, and Holohil Systems, Ltd., Ontario, Canada). Other data collected included sage-grouse weight, whether it was previously flushed by the trapping team, presence of a roost pile, behavior during handling, cloud cover, wind speed (Beaufort scale), temperature, time from capture to release, and Global Positioning System (GPS) coordinates (UTM, NAD 1983, Zone 12). All birds were processed and released as quickly as possible at the site of capture. Research protocols were approved by the Utah State University Institutional Animal Care and Use Committee permit #1547, and UDWR Certificate of Registration Number 2BAND8743.

Nest Monitoring

Radio-marked females were monitored 2-3 times per week during the lekking season, and from nest initiation and through incubation (Aldridge and Brigham 2001; Schroeder 1997). Because sage-grouse may abandon nests when flushed (Connelly et al. 2003), observers located nests by circling the telemetry signal in an inward spiraling pattern until the female was observed, or distance to the estimated nest site was ≤ 10 m. If a female was located at the same site during two subsequent visits, she was assumed to be incubating. When incubation was confirmed, observers recorded their observation point on a handheld GPS, recorded a distance and bearing to the hen, and made a small, natural marker to aid in re-sighting the nest on subsequent visits.

After confirming the initiation of nest incubation, observers returned 2-3 times per week to confirm nest status. We determined nest fate by observing eggshell fragments
for signs of successful hatch, including separated membranes, and cupping of shell halves (Rearden 1951). If a nest was abandoned prior to its estimated hatch date, and the eggs were crushed, punctured, or absent, the nest was classified as unsuccessful (Patterson 1952), searched the area for eggs fragments to estimate clutch size, and the status of the female was immediately investigated. If we determined that a nest failed (due to predation or abandonment), we reduced tracking efforts of the female (1-2 locations per week), due to the extremely low likelihood of her re-nesting (Cook 2015). In the event we suspected a female had re-nested, the above protocol was repeated. A GPS location was recorded at every nest site as soon as the nest fate was determined.

Vegetation surveys were performed at nest sites within a week after nest fate was determined. Nest shrub species, height, diameter, and visual obstruction to and from the nest were recorded, as well as other characteristics of the site. A Robel pole (Robel et al. 1970) was placed in the nest bowl, and observers recorded the lowest visible height class (cm) from 4 m away, and 1 m above ground level at 4 different transects. Robel measurements were also taken from the nest site looking out to 4 m at each transect. Four 15 m transects were examined, originating at the nest bowl and going in the four cardinal directions. Along each transect, the line-intercept method was used to evaluate the canopy cover and height of shrub species (Canfield 1941). Forb and grass canopy cover and height, as well as bare ground, rock, and litter cover was measured using the Daubenmire frame technique (Daubenmire 1959) at 3 m intervals along each transect.

**Brood Monitoring**

When a female successfully hatched her clutch (i.e., at least one egg hatched), we tracked and recorded GPS locations of her and her brood 2-3 times per week. When
tracking broods, we again performed inward spirals toward the telemetry signal until the female or a chick was observed, or estimated distance to the brood was ≤ 10 m. We classified brood success as a radio-marked female with chicks surviving ≥ 50 days. When a brooding female was observed or flushed ≤ 50 days post-hatch with ≥ 2 adult sage-grouse and/or no chicks on more than 2 consecutive sampling occasions we determined her brood to be unsuccessful, reduced tracking efforts and ceased performing vegetation surveys.

At 50 days, we located and flushed the female and her chicks to determine brood success (Cook 2015; Dahlgren et al. 2010a; Schroeder 1997). To maximize detection probability, sampling occasions of females with chicks were conducted before 0800 hrs. to reduce the potential for chick dispersal but have sufficient light to detect, classify, and count adults and chicks. Observers walked directly toward the telemetry signal until the hen flushed, and then performed an outward spiral with 5-10m spacing for 20 minutes (Dahlgren et al., 2010a). In the event the female flushed without chicks, we repeated flush procedures on the following day. If the second flush still provided inconclusive results, we located the female on the second night with a spotlight and attempted to observe chicks (Dahlgren et al. 2010a). If chicks were still not observed, we classified the female as having an unsuccessful brood. We did not account for brood mixing because individual chicks were not marked and thus our brood survival estimates may be underestimated (Dahlgren et al. 2010b).

Vegetation surveys were collected at sites used by radio-marked sage-grouse females with broods. Due to time and budget restraints, brood site surveys were conducted at approximately every other brood site recorded per brood; approximately 2
surveys were performed per bird per week. Observers returned to the site 2-7 days after observing the brood, and set the origin of transects where the chick or female was observed, or the estimated location. Measurements were collected in the same manner as for nests, with slight adjustments. Transect length was reduced to 10 m, and a total of 4 Daubenmire frames were placed at 2.5 m intervals. The same line-intercept procedure was used to evaluate shrub species cover and height. Robel measurements were taken only from 4 m along each transect looking toward the point where the female was located; no outward-looking Robel measurements were taken.

In addition to brood vegetation surveys, random surveys were conducted to compare used sites to available sites. Approximately one random site was generated for every 2 brood sites. Random survey sites were determined by drawing 2 poker chips from a bag while at a brood vegetation survey site. Eight marked poker chips were in a bag: 4 chips each with a cardinal direction, and 4 chips each with 100, 200, 300, or 400 m. The combination of direction and distance defined where the random vegetation survey would be performed from the brood site. Random vegetation surveys were performed using the same protocol as brood site vegetation surveys.

Data Analysis

I used Program R (R version 3.2.2, www.r-project.org, accessed 1 Oct 2015) to calculate descriptive statistics for all nests, failed nests, successful nests, all brood sites, sites used by successful broods, sites used by unsuccessful broods, and random sites. Two sample, two tailed t-tests were used to evaluate differences in reproductive success and use due to vegetation characteristics. Differences were considered significant at $P < 0.05$. 
RESULTS

I completed 646 vegetation surveys during my study. These surveys included 62 nest sites (41 successful, 21 unsuccessful), 402 brood sites, and 183 random sites. Surveys were completed from 9 May to 7 August in 2014, and 3 May to 1 August in 2015.

Nest Success

Nest success was not related to vegetation characteristics recorded at the nest sites (Table 4-1). The species of the dominant shrub at the nest site was not a determining factor ($t = -0.2033$, $P = 0.8401$); 10 of 42 (23.8%) of nests were not located under sagebrush. Successful nests were located under mountain sagebrush ($n = 11$), Wyoming sagebrush ($n = 19$), black sagebrush ($n = 2$), basin wildrye ($n = 1$), rubber rabbitbrush ($C. viscidiiflorus$; $n = 1$), Utah serviceberry ($n = 1$), snowberry ($n = 2$), antelope bitterbrush ($n = 1$), broom snakeweed ($Guteirizia sarothatae$; $n = 1$), live juniper ($n = 1$), and mechanically treated, dead juniper ($n = 2$). Unsuccessful nests were located under mountain sagebrush ($n = 6$), Wyoming sagebrush ($n = 8$), rubber rabbitbrush ($n = 2$), Utah serviceberry ($n = 1$), antelope bitterbrush ($n = 1$), and live juniper ($n = 1$).

There was no difference in the nest shrub height ($t = 0.30$, $P = 0.766$), diameter ($t = 0.02$, $P = 0.987$), toward nest visual obstruction ($t = 0.08$, $P = 0.939$), or from nest visual obstruction ($t = 0.44$, $P = 0.665$) at successful and unsuccessful nest sites (Table 4-2). Successful and unsuccessful nests did not differ in sagebrush cover ($t = -0.41$, $P = 0.684$), sagebrush height ($t = 0.85$, $P = 0.400$), forb cover ($t = -1.35$, $P = 0.188$), forb height ($t = 0.20$, $P = 0.843$), grass cover ($t = -1.23$, $P = 0.225$), or grass height ($t = 0.15$, $P = 0.882$). Further, successful and unsuccessful nests did not differ in bare ground ($t = 0.01$).
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0.71, \( P = 0.482 \), rock composition (\( t = -0.69, \ P = 0.493 \)), or litter cover (\( t = 1.34, \ P = 0.191 \)).

All nest sites averaged 31.4\% (± 1.86 SE) shrub cover, 36.9 cm (± 1.44 SE) shrub height, 19.5\% (± 2.10 SE) sagebrush cover, 38.6 cm (± 2.41 SE) sagebrush height, 79.0 cm (± 2.7 SE) inward VOR, 57.7 cm (± 3.5 SE) outward VOR, 3.8\% (± 0.55 SE) forb cover, 7.8 cm (± 0.58 SE) forb height, 6.0\% (± 0.64 SE) grass cover, and 21.7 cm (± 1.30 SE) grass height. Nest sites averaged 21.5\% (± 1.53 SE) bare ground, 13.0\% (± 1.14 SE) rock composition, and 42.3\% (± 2.48 SE) litter cover.

**Brood Success**

Three broods were not included in the brood fate analysis because their fate could not be determined due to radio-collar failure. Successful broods used sites with averages of 59.6 cm (± 2.04 SE) inward looking visual obstruction, 38.5\% (± 1.24 SE) shrub cover, 39.7 cm (± 1.92 SE) shrub height, 23.9\% (± 1.0 SE) sagebrush cover, 37.1 cm (± 1.1 SE) sagebrush height, 4.6\% (± 0.29 SE) forb cover, 13.6 cm (± 0.49 SE) forb height, 8.1\% (± 0.38 SE) grass cover, 32.5 cm (± 0.71 SE) grass height, 23.2\% (± 0.76 SE) bare ground, 15.4\% (± 0.83 SE) rock composition, and 48.8\% (± 1.16 SE) litter cover (Table 4-3).

Unsuccessful broods used sites with averages of 51.1 cm (± 2.83 SE) inward-looking visual obstruction, 27.8\% (± 1.79 SE) shrub cover, 49.0 cm (± 13.52 SE) shrub height, 19.8\% (± 1.4 SE) sagebrush cover, 32.9 cm (± 1.4 SE) sagebrush height, 2.6\% (± 0.24 SE) forb cover, 10.1 cm (± 0.65 SE) forb height, 7.3\% (± 0.45 SE) grass cover, 26.4 cm (± 0.93 SE) grass height, 25.3\% (± 1.25 SE) bare ground, 17.8\% (± 1.33 SE) rock composition, and 47.4\% (± 1.54 SE) litter cover (Table 4-3).
Random sites averaged 47.7 cm (± 2.09 SE) inward-looking visual obstruction, 29.9% (± 1.38 SE) shrub cover, 33.6 cm (± 1.65 SE) shrub height, 19.7% (± 1.2 SE) sagebrush cover, 33.0 cm (± 1.7 SE) sagebrush height, 4.4% (± 0.43 SE) forb cover, 11.5 cm (± 0.52 SE) forb height, 7.8% (± 0.48 SE) grass cover, 29.7 cm (± 0.89 SE) grass height, 26.1% (± 1.08 SE) bare ground, 19.0% (± 1.13 SE) rock composition, and 45.9% (± 1.36 SE) litter cover (Table 4-3).

Vegetation characteristics at micro-sites used by successful and unsuccessful broods were compared (Table 4-4). Successful brood site vegetation characteristics differed from unsuccessful brood sites with greater inward-looking visual obstruction \( (t = 2.43, P = 0.016) \), shrub cover \( (t = 4.91, P < 0.001) \), greater sagebrush cover \( (t = 2.46, P = 0.015) \), greater sagebrush height \( (t = 2.32, P = 0.021) \), greater forb cover \( (t = 5.17, P < 0.001) \), greater forb height \( (t = 4.31, P < 0.001) \), and greater grass height \( (t = 5.19, P < 0.001; \) Table 4-4). Successful and unsuccessful brood sites did not differ in shrub height \( (t = -0.68, P = 0.498) \), grass cover \( (t = 1.28, P = 0.201) \), bare ground \( (t = -1.42, P = 0.158) \), rock composition \( (t = -1.50, P = 0.136) \), and litter cover \( (t = 0.75, P = 0.456) \).

Successful brood site vegetation characteristics were also compared to random sites (Table 4-4). Successful brood sites showed greater inward-looking visual obstruction \( (t = 4.08, P < 0.001) \), greater shrub cover \( (t = 4.62, P < 0.001) \), greater shrub height \( (t = 2.40, P = 0.017) \), greater sagebrush height \( (t = 2.80, P = 0.005) \), greater sagebrush height \( (t = 2.07, P = 0.039) \), greater forb height \( (t = 2.94, P = 0.003) \), greater grass height \( (t = 2.43, P = 0.016) \), less bare ground \( (t = -2.13, P = 0.034) \), and less rock composition \( (t = -2.56, P = 0.011) \). Successful brood sites did not differ from random
sites in forb cover \((t = 0.35, P = 0.723)\), grass cover \((t = 0.52, P = 0.602)\), or litter cover \((t = 1.60, P = 0.109)\).

Sites used by broods that failed were also compared to random sites. Sites used by broods that failed showed less forb cover \((t = -3.59, P < 0.001)\) and shorter grass \((t = -2.56, P = 0.011)\). Sites used by broods that failed did not differ in inward-looking visual obstruction \((t = 0.97, P = 0.333)\), shrub cover \((t = -0.94, P = 0.348)\), shrub height \((t = 1.13, P = 0.262)\), sagebrush cover \((t = 0.05, P = 0.964)\), sagebrush height \((t = -0.04, P = 0.970)\), forb height \((t = -1.68, P = 0.093)\), grass cover \((t = -0.65, P = 0.514)\), bare ground \((t = -0.45, P = 0.656)\), rock composition \((t = -0.71, P = 0.479)\), or litter cover \((t = 0.70, P = 0.486)\).

**DISCUSSION**

Vegetation characteristics selected by sage-grouse females for nesting in the study area were within range-wide estimates for other sage-grouse populations (Connelly et al. 2011a). From 2014-2015, 75.4% of observed sage-grouse nests were under some species of sagebrush. This is lower than many other study areas, where 90% or more of nests (Connelly et al. 2011a) are located under sagebrush. However, my observations corroborate previous data in our study area (Wing 2014), and exceed results reported for an adjacent population (Knerr 2007). There were a few instances of sage-grouse females selecting areas of conifer cover for nest sites. In the study area, 15 of 61 (24.6%) of nest sites were located in association with conifer cover. This is greater than previously reported in the same area (Wing 2014), similar to a neighboring population (Knerr 2007), and less than reported in another area in Utah by Duvuvuei (2013). Of the 15 nests in conifer encroachment areas, 60% \((n=9)\) hatched. The fact that so many hens nested in
conifer areas (not necessarily under conifer) may suggest that conifer encroachment has advanced well into historic nesting areas.

From 2014-2015, I observed 6 hens nesting in conifer removal areas ranging from 7 years old to in progress (Sandford et al. 2015). Of the hens that nested in conifer removal areas, 4 of 6 (67%) successfully hatched their nest. Though none of the hens stayed exclusively in conifer removal areas to raise their brood, 3 of 4 (75%) remained in the conifer removal area for at least a week post-hatch. By performing a Resource Selection Function (RSF; Chapter 2), I determined that sage-grouse females experienced higher nest success when they selected areas closer to conifer removal areas. The RSF suggested that there was no observed effect on nest success when females selected areas closer to existing conifer cover.

Mean total shrub canopy at nest sites was 31.4%, and similar to previous research in the study area (Wing 2014). This is greater than other areas in Utah that ranged from 13.2 – 23.8% (Dahlgren 2006; Duvuvuei 2013; Knerr 2007). At 4.2%, forb cover at nest sites was lower than the 7.4-9.4% range previously observed in the study area (Wing 2014), lower than the 18.5% at Grouse Creek, Utah (Knerr 2007), and lower than the 14.5% reported at Anthro Mountain, Utah (Duvuvuei 2013). However, forb cover was higher than the 1% cover reported for Parker Mountain, Utah (Dahlgren 2006). The observed 6% grass cover was also lower than the 18% previously reported in the study area (Wing 2014), lower than the 21.5% reported in the Grouse Creek area (Knerr 2007), lower than the 17.57% reported on Anthro Mountain, but similar to the 8.24% reported on Parker Mountain (Dahlgren 2006).
There are some large temporal factors to consider when analyzing nest and brood sites. At nest sites, vegetation characteristics are measured after the nest is vacated. For a successful nest, this means observers are measuring site characteristics over a month after the female sage-grouse selected it. If a nest fails, that means the vegetation characteristics measured are likely greater than at initiation, but lower than at the expected hatch date. The same can be said for successful and unsuccessful broods. Broods that fail prior to 50 days have not been exposed to the full vegetation growth potential of their habitat, and thus their cumulative vegetation measurements may be lower than successful broods by default. These variations may illicit spurious conclusions about vegetation influence, and caution must be taken when comparing sites. Random vegetation measurements of nearby habitat at nest initiation, as well as measuring failed nests at the expected hatch date may help to standardize nest comparisons. Because a female’s behavior changes after having lost her brood, continuing to monitor vegetation may not be a viable alternative. However, breaking the 50 day brooding period in to 10 day bins may allow for comparisons of phases of brood rearing while allowing for broods that fail to be excluded from later season comparisons.

Because I was able to collect location data on all broods, including those that failed early, I had an adequate sample size to compare vegetation site selection of successful and unsuccessful broods. Similar to nest sites, forb cover at brood sites was low at 4.2% compared to the 10.1% reported by Wing (2014), the 21.4% reported by Knerr (2007) and the 18.4% reported by Duvuvuei (2013). Further, sites used by successful broods exhibited 4.6% forb cover, while those used by broods that failed exhibited just 2.6%, and random sites exhibited 4.4% forb cover. Visual obstruction at
sites used by successful broods averaged 59.6 cm, this was greater than 47.0 at Grouse Creek (Knerr 2007). Visual obstruction was higher at sites used by successful broods than unsuccessful broods (51.1 cm), and random sites (47.7 cm). Because shrub cover, forb height, and grass height were also greater in sites used by successful broods, it appears that hiding cover may have been more important than actual quantity or quality of forage. The RSF (Chapter 2) showed that sage-grouse females that selected sites nearer to conifer canopy experienced lower probability of successfully raising chicks. This may indicate that successful broods selected areas exhibiting higher cover for predator avoidance.

When comparing our data to current sage-grouse habitat recommendations for the BLM, (Stiver et al. 2015) we see some noteworthy differences. Recommended sagebrush cover at nest and early brood sites is 15-25%; nest sites in the study area averaged 20.5% total sagebrush cover, and 31.4% total shrub cover. Mean sagebrush height was 36.2 cm, within the recommended range of 30-80 cm; mean total shrub height was 37.0 cm. Total grass cover at nest sites in the study area averaged 6%; 4% lower than the lowest perennial grass cover recommendation. Forb cover at 3.8% was also below the 5% lowest recommendation. However, average combined grass and forb height at 29.5 cm was above the recommended minimum of 18 cm.

Successful brood sites also displayed variable agreement with Stiver et al. (2015) late brood-rearing habitat recommendations. Successful brood sites averaged 23.9% sagebrush cover; the high end of the 10-25% recommended. However, mean sagebrush height at 37.1 cm was below the recommended 40-80 cm range. Combined grass and forb cover at successful broods sites averaged 12.6%; below the recommended minimum
of 15%. Despite these differences this population is considered one of the most stable and productive in the state (UDWR 2002).

Many sagebrush areas in the study area are large, contiguous stands, exhibiting minimal to no conifer expansion (Cook 2015). In areas affected by conifer expansion, positive sage-grouse response to conifer removal has been immediate (Cook 2015, Sandford et al. 2015). Although forb and grass cover was lower than reported for other studies in Utah, sagebrush canopy cover was higher than many management areas in Utah. Sage-grouse populations in the study area also exhibited greater survival and reproductive rates than other populations in Utah. Because the population in the study area is quite stable, it does not appear that forb and grass abundance is a limiting factor.

My research documented that habitat vegetation micro-site characteristics were not a major defining factor of nest success. However, because broods have different needs than adult sage-grouse, it is important that a large, diverse, healthy landscape is available to sage-grouse. If wildlife managers seek to maintain and increase the Box Elder SGMA sage-grouse populations, actions should be directed towards protecting and expanding the current habitat. Attempting to improve existing habitat would likely not garner as great a benefit as protecting what remains, and creating more.

Because of their effect on both understory vegetation and sage-grouse breeding behavior, conifer encroachment sites represent a major threat to sage-grouse habitat in northwestern Utah. Conifer encroachment in the study area was readily apparent in breeding, nesting, and brood-rearing habitats. Sage-grouse leks in the study area were observed at the immediate fringe of conifer cover, but use of conifer cover was rare, suggesting that the sage-grouse in the study area were so limited by habitat availability
that they were forced to use fringe habitat. Conifer removal within sage-grouse habitat, and in areas with sufficient remaining sagebrush understory may be the most effective habitat restoration opportunity for this population.

**MANAGEMENT IMPLICATIONS**

My research suggests that there is great potential for conservation of this population of sage-grouse. Despite altered fire regimes, habitat loss and degradation, conifer encroachment, and invasive plants like cheatgrass, this population still exhibits above-average reproductive rates and relatively high survival rates compared to other populations in the state of Utah. Micro-site vegetation characteristics are not a determining factor in nest success, but do differ between successful and unsuccessful broods, and random sites. Because conifer encroachment suppresses herbaceous growth and extirpates sage-grouse, managers should use conifer removal as a tool to expand habitat for sage-grouse, and increase available forage and cover. My research provides valuable information regarding some of the microhabitat characteristics that are selected by sage-grouse in western Box Elder County. This information should be used to guide further management of sage-grouse habitat in northwestern Utah.

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Table 4-1. Vegetation structure and ground cover at greater sage-grouse (*Centrocercus urophasianus*) nest sites in northwestern Utah, 2014-2015.

<table>
<thead>
<tr>
<th></th>
<th>Successful (SE)</th>
<th>Range</th>
<th>Unsuccessful (SE)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nest Shrub</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height&lt;sup&gt;a&lt;/sup&gt; (cm)</td>
<td>78.0(3.7)</td>
<td>44.0-153.0</td>
<td>75.8(5.1)</td>
<td>44.0-160.0</td>
</tr>
<tr>
<td>Diameter&lt;sup&gt;a&lt;/sup&gt; (cm)</td>
<td>149.5(10.3)</td>
<td>62.0-458.0</td>
<td>149.3(7.7)</td>
<td>103.0-226.0</td>
</tr>
<tr>
<td>VOR&lt;sup&gt;b&lt;/sup&gt; in (cm)</td>
<td>79.1(3.2)</td>
<td>48.0-128.0</td>
<td>78.6(5.1)</td>
<td>48.0-150.0</td>
</tr>
<tr>
<td>VOR&lt;sup&gt;b&lt;/sup&gt; out (cm)</td>
<td>58.8(3.9)</td>
<td>23.0-155.0</td>
<td>55.3(7.1)</td>
<td>15.0-150.0</td>
</tr>
<tr>
<td>Total shrub cover&lt;sup&gt;a&lt;/sup&gt; (%)</td>
<td>30.4(2.4)</td>
<td>1.0-70.7</td>
<td>33.7(2.6)</td>
<td>9.0-54.5</td>
</tr>
<tr>
<td>Total shrub height&lt;sup&gt;a&lt;/sup&gt; (cm)</td>
<td>37.6(1.6)</td>
<td>17.4-61.2</td>
<td>35.5(2.9)</td>
<td>14.4-65.4</td>
</tr>
<tr>
<td>Sagebrush cover&lt;sup&gt;a&lt;/sup&gt; (%)</td>
<td>20.0(1.8)</td>
<td>0.0-47.9</td>
<td>21.4(2.7)</td>
<td>3.9-45.3</td>
</tr>
<tr>
<td>Sagebrush height&lt;sup&gt;a&lt;/sup&gt; (cm)</td>
<td>37.1(2.0)</td>
<td>0.0-60.7</td>
<td>34.1(2.9)</td>
<td>11.9-54.8</td>
</tr>
<tr>
<td>Forb cover&lt;sup&gt;a&lt;/sup&gt; (%)</td>
<td>3.2(0.6)</td>
<td>0.0-16.1</td>
<td>5.0(1.1)</td>
<td>0.0-15.9</td>
</tr>
<tr>
<td>Forb height&lt;sup&gt;a&lt;/sup&gt; (cm)</td>
<td>7.9(0.7)</td>
<td>0.0-22.2</td>
<td>7.6(1.0)</td>
<td>0.0-18.8</td>
</tr>
<tr>
<td>Grass cover (%)</td>
<td>5.5(0.8)</td>
<td>0.4-22.3</td>
<td>7.1(1.0)</td>
<td>1.9-14.1</td>
</tr>
<tr>
<td>Grass height (cm)</td>
<td>21.9(1.6)</td>
<td>7.3-53.4</td>
<td>21.4(2.4)</td>
<td>6.0-50.3</td>
</tr>
<tr>
<td>Bare ground (%)</td>
<td>22.2(1.9)</td>
<td>5.8-62.4</td>
<td>19.9(2.6)</td>
<td>9.4-47.5</td>
</tr>
<tr>
<td>Rock composition (%)</td>
<td>12.4(1.3)</td>
<td>2.0-31.8</td>
<td>14.3(2.3)</td>
<td>3.3-44.6</td>
</tr>
<tr>
<td>Litter cover (%)</td>
<td>44.6(2.9)</td>
<td>12.9-80.2</td>
<td>37.3(4.7)</td>
<td>7.6-72.1</td>
</tr>
</tbody>
</table>

<sup>a</sup>Includes measurements of trees, and zero shrub, sagebrush, forb, and grass cover

<sup>b</sup>VOR refers to Visual Obstruction Reading measured with a Robel pole
Table 4-2. Statistical comparison of vegetative characteristics and ground cover at successful and unsuccessful greater sage-grouse (*Centrocercus urophasianus*) nest sites in northwestern Utah, 2014-2015.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sample 1</th>
<th>Sample 2</th>
<th>$t$</th>
<th>$P$</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>VOR In</td>
<td>Successful</td>
<td>Unsuccessful</td>
<td>0.08</td>
<td>0.939</td>
<td>-11.73-12.66</td>
</tr>
<tr>
<td>VOR Out</td>
<td>Successful</td>
<td>Unsuccessful</td>
<td>0.44</td>
<td>0.665</td>
<td>-13.06-20.17</td>
</tr>
<tr>
<td>Nest Shrub Height</td>
<td>Successful</td>
<td>Unsuccessful</td>
<td>0.30</td>
<td>0.766</td>
<td>-12.37-16.64</td>
</tr>
<tr>
<td>Nest Shrub Diameter</td>
<td>Successful</td>
<td>Unsuccessful</td>
<td>0.02</td>
<td>0.987</td>
<td>-25.00-25.96</td>
</tr>
<tr>
<td>Shrub Cover</td>
<td>Successful</td>
<td>Unsuccessful</td>
<td>-0.95</td>
<td>0.347</td>
<td>-10.51-3.76</td>
</tr>
<tr>
<td>Shrub Height</td>
<td>Successful</td>
<td>Unsuccessful</td>
<td>0.64</td>
<td>0.529</td>
<td>-4.73-9.02</td>
</tr>
<tr>
<td>Sagebrush Cover</td>
<td>Successful</td>
<td>Unsuccessful</td>
<td>-0.41</td>
<td>0.684</td>
<td>-8.01-5.31</td>
</tr>
<tr>
<td>Sagebrush Height</td>
<td>Successful</td>
<td>Unsuccessful</td>
<td>0.85</td>
<td>0.400</td>
<td>-4.17-10.20</td>
</tr>
<tr>
<td>Forb Cover</td>
<td>Successful</td>
<td>Unsuccessful</td>
<td>-1.35</td>
<td>0.188</td>
<td>-4.31-0.88</td>
</tr>
<tr>
<td>Forb Height</td>
<td>Successful</td>
<td>Unsuccessful</td>
<td>0.20</td>
<td>0.843</td>
<td>-2.26-2.75</td>
</tr>
<tr>
<td>Grass Cover</td>
<td>Successful</td>
<td>Unsuccessful</td>
<td>-1.23</td>
<td>0.225</td>
<td>-4.23-1.02</td>
</tr>
<tr>
<td>Grass Height</td>
<td>Successful</td>
<td>Unsuccessful</td>
<td>0.15</td>
<td>0.882</td>
<td>-5.34-6.19</td>
</tr>
<tr>
<td>Rock Composition</td>
<td>Successful</td>
<td>Unsuccessful</td>
<td>0.71</td>
<td>0.482</td>
<td>-4.20-8.73</td>
</tr>
<tr>
<td>Litter Cover</td>
<td>Successful</td>
<td>Unsuccessful</td>
<td>-0.69</td>
<td>0.493</td>
<td>-7.29-3.60</td>
</tr>
</tbody>
</table>

*Significant $P$-value at < 0.05
Table 4-3. Vegetation structure and ground cover at sites used by successful and unsuccessful greater sage-grouse (*Centrocercus urophasianus*) broods, and random sites in northwestern Utah, 2014-2015.

<table>
<thead>
<tr>
<th></th>
<th>Successful</th>
<th>Unsuccessful</th>
<th>Random</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>□ (SE) Range</td>
<td>□ (SE) Range</td>
<td>□ (SE) Range</td>
</tr>
<tr>
<td>VOR(^a) in (cm)</td>
<td>59.6(2.0) 10.0-207.5</td>
<td>51.1(2.8) 10.0-142.0</td>
<td>47.7(2.1) 6.3-172.5</td>
</tr>
<tr>
<td>Total shrub cover(^b) (%)</td>
<td>38.5(1.2) 0.0-93.5</td>
<td>27.8(1.8) 0.0-84.6</td>
<td>29.9(1.4) 0.0-94.0</td>
</tr>
<tr>
<td>Total shrub height(^b) (cm)</td>
<td>39.7(1.9) 0.0-402.6</td>
<td>49.0(13.5) 7.0-1440.0</td>
<td>33.6(1.7) 0.0-194.4</td>
</tr>
<tr>
<td>Total sagebrush cover(^b) (%)</td>
<td>23.9(1.0) 0.0-85.1</td>
<td>19.8(1.4) 0.0-59.7</td>
<td>19.7(1.2) 0.0-83.7</td>
</tr>
<tr>
<td>Total sagebrush height(^b) (cm)</td>
<td>37.1(1.1) 0.082.9</td>
<td>32.9(1.4) 0.0-72.2</td>
<td>33.0(1.7) 0.0-220.1</td>
</tr>
<tr>
<td>Forb cover(^b) (%)</td>
<td>4.6(0.3) 0.0-42.7</td>
<td>2.6(0.2) 0.0-14.1</td>
<td>4.4(0.4) 0.0-47.8</td>
</tr>
<tr>
<td>Forb height(^b) (cm)</td>
<td>13.6(0.5) 1.0-55.3</td>
<td>10.1(0.6) 1.0-35.7</td>
<td>11.5(0.5) 0.0-41.4</td>
</tr>
<tr>
<td>Grass cover (%)</td>
<td>8.1(0.4) 0.5-36.9</td>
<td>7.3(0.4) 0.1-25.8</td>
<td>7.8(0.5) 0.8-33.6</td>
</tr>
<tr>
<td>Grass height (cm)</td>
<td>32.5(0.7) 8.8-60.5</td>
<td>26.4(0.9) 7.1-53.2</td>
<td>29.7(0.9) 7.3-85.3</td>
</tr>
<tr>
<td>Bare ground (%)</td>
<td>23.2(0.8) 1.0-67.0</td>
<td>25.3(1.3) 3.3-62.3</td>
<td>26.1(1.1) 2.5-64.4</td>
</tr>
<tr>
<td>Rock composition (%)</td>
<td>15.4(0.8) 0.6-73.2</td>
<td>17.8(1.3) 1.3-69.4</td>
<td>19.0(1.1) 0.1-81.1</td>
</tr>
<tr>
<td>Litter cover (%)</td>
<td>48.8(1.2) 12.2-89.7</td>
<td>47.4(1.5) 14.8-82.3</td>
<td>45.9(1.4) 10.9(89.1)</td>
</tr>
</tbody>
</table>

\(^a\)VOR refers to Visual Obstruction Reading measured with a Robel pole

\(^b\)Includes measurements of trees, and zero shrub, sagebrush, forb, and grass cover
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sample 1</th>
<th>Sample 2</th>
<th>$t$</th>
<th>$P$</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>VOR in</td>
<td>Successful</td>
<td>Unsuccessful</td>
<td>2.43</td>
<td>0.016*</td>
<td>1.61-15.33</td>
</tr>
<tr>
<td>VOR in</td>
<td>Successful</td>
<td>Random</td>
<td>4.09</td>
<td>&lt;0.001*</td>
<td>6.17-17.60</td>
</tr>
<tr>
<td>VOR in</td>
<td>Unsuccessful</td>
<td>Random</td>
<td>0.97</td>
<td>0.333</td>
<td>-3.52-10.35</td>
</tr>
<tr>
<td>Shrub cover</td>
<td>Successful</td>
<td>Unsuccessful</td>
<td>4.92</td>
<td>&lt;0.001*</td>
<td>6.41-14.98</td>
</tr>
<tr>
<td>Shrub cover</td>
<td>Successful</td>
<td>Random</td>
<td>4.63</td>
<td>&lt;0.001*</td>
<td>4.93-12.21</td>
</tr>
<tr>
<td>Shrub cover</td>
<td>Unsuccessful</td>
<td>Random</td>
<td>-0.94</td>
<td>0.348</td>
<td>-6.58-2.33</td>
</tr>
<tr>
<td>Shrub height</td>
<td>Successful</td>
<td>Unsuccessful</td>
<td>-0.68</td>
<td>0.498</td>
<td>-36.69-17.78</td>
</tr>
<tr>
<td>Shrub height</td>
<td>Successful</td>
<td>Random</td>
<td>2.41</td>
<td>0.017*</td>
<td>1.11-11.06</td>
</tr>
<tr>
<td>Shrub height</td>
<td>Unsuccessful</td>
<td>Random</td>
<td>1.13</td>
<td>0.262</td>
<td>-11.63-42.38</td>
</tr>
<tr>
<td>Sagebrush cover</td>
<td>Successful</td>
<td>Unsuccessful</td>
<td>2.46</td>
<td>0.015*</td>
<td>0.82-7.49</td>
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<td>Sagebrush cover</td>
<td>Successful</td>
<td>Random</td>
<td>2.80</td>
<td>0.005*</td>
<td>1.26-7.21</td>
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<tr>
<td>Sagebrush cover</td>
<td>Unsuccessful</td>
<td>Random</td>
<td>0.05</td>
<td>0.964</td>
<td>-3.48-3.65</td>
</tr>
<tr>
<td>Sagebrush height</td>
<td>Successful</td>
<td>Unsuccessful</td>
<td>2.32</td>
<td>0.021*</td>
<td>0.62-7.70</td>
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<tr>
<td>Sagebrush height</td>
<td>Successful</td>
<td>Random</td>
<td>2.07</td>
<td>0.039*</td>
<td>0.20-7.96</td>
</tr>
<tr>
<td>Sagebrush height</td>
<td>Unsuccessful</td>
<td>Random</td>
<td>-0.04</td>
<td>0.970</td>
<td>-4.42-4.26</td>
</tr>
<tr>
<td>Forb cover</td>
<td>Successful</td>
<td>Unsuccessful</td>
<td>5.18</td>
<td>&lt;0.001*</td>
<td>1.21-2.68</td>
</tr>
<tr>
<td>Forb cover</td>
<td>Successful</td>
<td>Random</td>
<td>0.36</td>
<td>0.723</td>
<td>-0.84-1.21</td>
</tr>
<tr>
<td>Forb cover</td>
<td>Unsuccessful</td>
<td>Random</td>
<td>-3.59</td>
<td>&lt;0.001*</td>
<td>-2.73--0.79</td>
</tr>
<tr>
<td>Forb height</td>
<td>Successful</td>
<td>Unsuccessful</td>
<td>4.31</td>
<td>&lt;0.001*</td>
<td>1.91-5.11</td>
</tr>
<tr>
<td>Forb height</td>
<td>Successful</td>
<td>Random</td>
<td>2.94</td>
<td>0.003*</td>
<td>0.70-3.52</td>
</tr>
<tr>
<td>Forb height</td>
<td>Unsuccessful</td>
<td>Random</td>
<td>-1.68</td>
<td>0.093</td>
<td>-3.03-0.24</td>
</tr>
<tr>
<td>Grass cover</td>
<td>Successful</td>
<td>Unsuccessful</td>
<td>1.29</td>
<td>0.200</td>
<td>-0.40-1.90</td>
</tr>
<tr>
<td>Grass cover</td>
<td>Successful</td>
<td>Random</td>
<td>0.52</td>
<td>0.601</td>
<td>-0.88-1.52</td>
</tr>
<tr>
<td>Grass cover</td>
<td>Unsuccessful</td>
<td>Random</td>
<td>-0.65</td>
<td>0.514</td>
<td>-1.73-0.87</td>
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<tr>
<td>Grass height</td>
<td>Successful</td>
<td>Unsuccessful</td>
<td>5.19</td>
<td>&lt;0.001*</td>
<td>3.77-8.37</td>
</tr>
<tr>
<td>Grass height</td>
<td>Successful</td>
<td>Random</td>
<td>2.43</td>
<td>0.016*</td>
<td>0.53-5.02</td>
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<tr>
<td>Grass height</td>
<td>Unsuccessful</td>
<td>Random</td>
<td>-2.56</td>
<td>0.011*</td>
<td>-5.82-0.76</td>
</tr>
<tr>
<td>Bare ground</td>
<td>Successful</td>
<td>Unsuccessful</td>
<td>-1.42</td>
<td>0.158</td>
<td>-4.97-0.81</td>
</tr>
<tr>
<td>Bare ground</td>
<td>Successful</td>
<td>Random</td>
<td>-2.13</td>
<td>0.034*</td>
<td>-5.42-0.21</td>
</tr>
<tr>
<td>Bare ground</td>
<td>Unsuccessful</td>
<td>Random</td>
<td>-0.45</td>
<td>0.656</td>
<td>-4.00-2.52</td>
</tr>
<tr>
<td>Rock composition</td>
<td>Successful</td>
<td>Unsuccessful</td>
<td>-1.50</td>
<td>0.136</td>
<td>-5.43-0.75</td>
</tr>
<tr>
<td>Rock composition</td>
<td>Successful</td>
<td>Random</td>
<td>-2.56</td>
<td>0.011*</td>
<td>-6.34-0.83</td>
</tr>
<tr>
<td>Rock composition</td>
<td>Unsuccessful</td>
<td>Random</td>
<td>-0.71</td>
<td>0.479</td>
<td>-4.67-2.20</td>
</tr>
<tr>
<td>Litter cover</td>
<td>Successful</td>
<td>Unsuccessful</td>
<td>0.75</td>
<td>0.456</td>
<td>-2.36-5.24</td>
</tr>
<tr>
<td>Litter cover</td>
<td>Successful</td>
<td>Random</td>
<td>1.60</td>
<td>0.109</td>
<td>-0.65-6.39</td>
</tr>
<tr>
<td>Litter cover</td>
<td>Unsuccessful</td>
<td>Random</td>
<td>0.70</td>
<td>0.486</td>
<td>-2.61-5.48</td>
</tr>
</tbody>
</table>

*Significant $P$-value at < 0.05
CHAPTER 5

CONCLUSIONS

Despite being found unwarranted for protection under the Endangered Species Act of 1973 (ESA), the greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) remains a species of conservation concern across its range. The state of Utah has completed an unprecedented amount of habitat projects designed to benefit sage-grouse (Utah Department of Natural Resources 2014). These projects have largely been based on research that was completed over the past two decades describing the ecology of sage-grouse in Utah (Messmer 2015). Because resources are often limited, wildlife managers require a better understanding of sage-grouse ecology and responses to management actions and disturbances to plan, prioritize, and implement projects to optimize costs and species benefits.

Dahlgren et al. (2016) concluded that seasonal movements for most sage-grouse populations in Utah are limited by usable habitat space. The state of Utah has identified conifer expansion as a major conservation threat to the species in most of the state’s the sage-grouse management areas (SGMAs). To evaluate sage-grouse responses and how overall individual fitness may be affected by habitat selection in SGMAs where mechanical conifer removal projects have been completed, I captured, radio-marked, and monitored the vital rates and habitat-use patterns of 45 female sage-grouse between February 2014 and December 2015 in the Box Elder SGMA. I also incorporated radio-telemetry locations and vital rates for female sage-grouse obtained from previous research completed in the SGMA (Wing 2014, Cook 2015). I used these data to model nest and brood success relative to mechanical conifer removal areas and conifer
encroachment (Chapter 2). I also completed sage-grouse pellet surveys in undisturbed sagebrush, conifer encroachment, and mechanical conifer removal areas to compare sage-grouse habitat-use patterns (Chapter 3). Additionally, I compared breeding habitat micro-site vegetation characteristics at successful and unsuccessful nests and brood sites monitored from 2014-2015 to determine what habitat factors may affect these vital rates (Chapter 4). Lastly, I report on an observation of novel sage-grouse nesting behavior in response to an on-going conifer mastication treatment in the Appendix.

Using telemetry locations and vital rates for female sage-grouse from 2012-2015, I modeled distances to disturbances, conifer removal areas, conifer encroachment, and important habitat features to determine if distance from mechanical conifer removal and encroachment affected individual sage-grouse reproductive fitness. Models predicted indicated that the probability of nest success declined significantly as sage-grouse females selected nest sites farther from conifer removal areas. Models also indicated that probability of brood success declined significantly as females selected brood sites farther from conifer removal areas. Probability of brood success also declined significantly as females selected brood sites closer to existing conifer cover.

I conducted pellet surveys in undisturbed sagebrush habitat, conifer encroachment, and conifer removal areas. Conifer encroached areas exhibited the lowest mean pellet densities. Areas where conifers had been removed by mechanical methods displayed higher mean pellet densities. Although the differences in pellet densities were not statistically significant, they may be biologically important. These observations further validated reports of sage-grouse use of areas where conifers were removed using mechanical methods (Frey et al. 2013, Wing 2014, Cook 2015, Sandford et al. 2015), and
the fitness benefits for individual birds that select areas to nest and raise broods near these treatments (Chapter 2). Sage-grouse use of sagebrush habitat was significantly greater than either conifer encroachment or removal areas.

To investigate whether micro-site vegetation had an influence on nest and brood success, I collected vegetation descriptions of 61 nest sites, 402 brood sites, and 183 random sites from 9 May to 7 August in 2014 and 3 May to 1 August in 2015. The breeding habitat micro-site vegetation characteristics at successful and unsuccessful nest sites did not differ. However, successful broods selected micro-sites exhibiting greater inward-looking visual obstruction, shrub cover, sagebrush cover, sagebrush height, forb cover, forb height, and grass height than unsuccessful broods. Further, successful broods selected areas with greater inward-looking visual obstruction, shrub cover, shrub height, sagebrush cover, sagebrush height, forb height, grass height, and less bare ground and rock composition than random sites. To sustain and improve sage-grouse population levels in the Box Elder SGMA, managers should focus on maintaining existing sagebrush habitat and look for opportunities to expand the habitat base by removing conifers in areas where they have encroached into sagebrush habitats.

**LITERATURE CITED**


APPENDIX
GREATER SAGE-GROUSE YEARLING FEMALE SELECTS NEST SITE IN AN
ACTIVE CONIFER MASTICATION TREATMENT

Greater sage-grouse (Centrocercus urophasianus; sage-grouse) have experienced long-term range-wide population declines and now may occupy less than 50% of their historic range (Schroeder et al. 2004). Conifer encroachment into sagebrush (Artemisia spp.) habitat has been identified as a major conservation threat by the U.S. Fish and Wildlife Service (USFWS) as the agency reviews the listing status of the species for possible protection under the Endangered Species Act of 1973 (USFWS 2013).

Conifer encroachment into sagebrush habitats negatively impacts sage-grouse at landscape scales (Doherty et al. 2008, Casazza et al. 2011, Baruch-Mordo et al. 2013). Sage-grouse will utilize areas following conifer removal (Frey et al. 2013, Cook 2015). However, to date no one has documented sage-grouse nesting behavior as an immediate response to recently completed conifer removal projects (Knick et al. 2014).

On March 12, 2015 we captured and radio-collared a yearling female sage-grouse (hereafter 0422) with a very high frequency (VHF) radio-collar (Advanced Telemetry Systems, Inc., Isanti, MN, USA 55040-7123). We used ground-based telemetry to re-locate 0422 every 3-4 days pre-incubation and then every 2 days during incubation until nest fate was determined.

On March 16, 2015 a conifer mastication project of ~233 ha was initiated on Bureau of Land Management (BLM) administered lands in our study area in northwestern Utah. The areas surrounding the conifer treatment were either open sagebrush communities or previous conifer removal areas (Figure A-1). Treatment

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activities occurred from mid-March to mid-May 2015 and proceeded through the area from west to east generally along a north to south line. In the current and previous years, radio-collared females nested in the sagebrush areas adjacent the mastication treatments (Wing 2014, Cook 2015).

From March 19 – April 3, 2015 0422 localized locations within ~200 m of operating mastication equipment. On April 7 we observed 0422 on a nest site, ~400 m west of operating equipment. On April 6, 0422 had begun incubation and was observed on or very near the nest every other day until May 3 when all 5 eggs hatched. The area around the nest site was previously a mix of sagebrush canopy and conifer cover in phase II; where conifer is codominant with sagebrush and herbs (Miller et al. 2005). Following treatment, undisturbed live shrub canopy cover was 16.6%. Following hatch, 0422 moved northwest out of the treatment area into sagebrush dominated habitat.

Past research has documented sage-grouse avoidance of conifers (Doherty et al. 2008), negative effects on lek counts (Baruch-Mordo et al. 2013), and sage-grouse habitat-use following conifer removal (Frey et al. 2013). However, to our knowledge, we present the first documentation of a sage-grouse immediately using a conifer masticated area during an active treatment for breeding habitat, specifically nesting. Our observation provides support for Cook’s (2015) recommendations that if conifer treated areas are located adjacent to occupied sage-grouse habitat these restored sagebrush communities may become readily occupied.

Research was conducted under permit # 2322 with Utah State University’s Institutional Animal Care and Use Committee. Financial support for this project was provided by Utah’s Watershed Restoration Initiative. We thank A. Clark, Utah
Department of Natural Resources, for his support of this work. We thank J. Bryan and B. Jessop of the BLM, Salt Lake City, Utah for their efforts in implementing the conifer mastication project. We thank the West Box Elder Coordinated Resource Management group and the many Box Elder County landowners who provide access to their private lands to conduct our research.

LITERATURE CITED


Wing, B. 2014. The role of vegetation structure, composition, and nutrition in greater sage-grouse ecology in northwestern Utah. Master’s Thesis, Utah State University, Logan, UT.
Figure A-1. Locations and nest site of a female greater sage-grouse (*Centrocercus urophasianus*) in a recently masticated conifer site (~233 ha), March-May 2015, Park Valley, Utah. Imagery and conifer canopy cover data were pre-2015. Bottom photo shows post-mastication on the site.
14 March 2016

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