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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

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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

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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% (β = -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.

(145 pages)

PUBLIC ABSTRACT

Greater Sage-grouse Vital Rate and Habitat Use Response to Landscape Scale Habitat

Manipulations and Vegetation Micro-Sites in Northwestern Utah

Charles P. Sandford

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.

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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.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW: BIOLOGY, SPECIES

CONSERVATION THREATS, AND MANAGEMENT

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 km^2 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.

2014). 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.

Literature Cited

Baruch-Mordo, S., J. S. Evans, S. P. Severson, D. E. Naugle, J. D. Maestas, J. M. Kiesecker, M. J. Falkowski, C. A. Hagen, and K. P. Reese. 2013. Saving sage-grouse from the trees: A proactive solution to reducing a key threat to a candidate species. Biological Conservation 167:233-241.

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

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

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

Benson, J. F., P. J. Mahoney, and B. R. Patterson. 2015. Spatiotemporal variation in selection of roads influences mortality risk for canids in an unprotected landscape. Oikos 124:1664-1673.

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

Beyer, H. L., D. T. Haydon, J. M. Morales, J. L. Frair, M. Hebblewhite, M. Mitchell, and J. Matthiopoulos. 2010. The interpretation of habitat preference metrics under use-availability designs. Philosophical Transactions of the Royal Society B: Biological Science 365:2245-2254.

Box Elder Adaptive Resource Management Local Working Group [BARM]. 2007. West Box Elder greater sage-grouse (*Centrocercus urophasianus*) local conservation plan. Utah State University Extension and Jack H. Berryman Institute and Utah Division of Wildlife Resources, Salt Lake City, USA.

Box Elder Adaptive Resource Management Local Working Group [BARM]. 2012. 2012 West Box Elder CRM sage-grouse accomplishment report. Utah State University Extension, Logan, USA.

Bradley, B., and E. Fleishman. 2008. Relationships between expanding pinyon-juniper cover and topography in the central Great Basin, Nevada. Journal of Biogeography 35:951-964.

Braun, C. E., T. Britt, and R. O. Wallestad. 1977. Guidelines for maintenance of sage-grouse habitats. Wildlife Society Bulletin 5:99-106.

Cain, J.W. III, P. R. Krausman, J. R. Morgart, B. D. Jansen, and M. P. Pepper. 2008. Responses of desert bighorn sheep to removal of water sources. Wildlife Monographs 171:1-30.

Cirrus Ecological Solutions, and Logan Simpson Design. 2013. West Box Elder County coordinated resource management plan. Logan, Utah, USA.

Commons, M. L., R. K. Baydack, and C. E. Braun. 1999. Sage grouse response to
pinyon-juniper management. Pages 238-239 *in* USDA Forest Service Proceedings
RMRS-P-9. Ogden, Utah, USA.

Connelly, J. W., C. A. Hagen, and M. A. Schroeder. 2011a. Characteristics and Dynamics
of Greater Sage-Grouse Populations. Pages 53-67 *in* S. Knick and J. W. Connelly,
editors. Greater sage-grouse: Ecology and conservation of a landscape species
and its habitats. Volume 38. Studies in Avian Biology. University of California
Press, Berkeley, USA.

Connelly, J. W., E. T. Rinkes, and C. E. Braun. 2011b. Characteristics of Greater Sage-
Grouse Habitats: A Landscape Species at Micro- and Macroscales. Pages 69-83 *in*
S. Knick and J. W. Connelly, editors. Greater sage-grouse: Ecology and
conservation of a landscape species and its habitats. Volume 38. Studies in Avian
Biology. University of California Press, Berkeley, USA.

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

Connelly, J. W., and L. A. Doughty. 1989. Sage grouse use of wildlife water
developments in southeastern Idaho. Pages 167-172 *in* G. K. Tsukamoto and S. J.
Stiver, editors. Wildlife water developments: proceedings of the wildlife water
development system. Nevada Department of Fish and Game, Reno, USA.

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

Connelly, J. W., S. T. Knick, M. J. Schroeder, and S. J. Stiver. 2004. Conservation

    assessment framework of greater sage-grouse and sagebrush habitats. Western

    Association of Fish and Wildlife Agencies, Cheyenne, Wyoming, USA.

Cook, A. 2015. Greater sage-grouse seasonal habitat models, response to juniper

    reduction, and effects of capture behavior on vital rates in northwest Utah. Thesis,

    Utah State University, Logan, USA.

Crawford, J. A., R. A. Olson, N. E. West, J. C. Mosley, M. A. Schroeder, T. D. Whitson,

    R. F. Miller, M. A. Gregg, and C. S. Boyd. 2004. Ecology and management of

    sage-grouse and sage-grouse habitat. Journal of Range Management 57:2-19.

Dahlgren, D. K. 2006. Greater sage-grouse reproductive ecology and response to

    experimental management of mountain big sagebrush on Parker Mountain, Utah.

    Dissertation, Utah State University, Logan, USA.

Dahlgren, D. K., T. A. Messmer, B. A. Crabb, R. T. Larsen, T. A. Black, S. N. Frey, E. T.

    Thacker, R. J. Baxter, and J. D. Robinson. 2016. Seasonal movements of greater

    sage-grouse populations in Utah: implications for species conservation. Wildlife

    Society Bulletin.

DeCesare, N. J., M. Hebblewhite, F. Schmiegelow, D. Hervieux, G. J. McDermid, L.

    Neufeld, M. Bradley, J. Whittington, K. G. Smith, L. E. Morgantini, M.

    Wheatley, and M. Musiani. 2012. Transcending scale dependence in identifying

    habitat with resource selection functions. Ecological Applications 22:1068-1083.

DeCesare, N. J., M. Hebblewhite, M. Bradley, D. Hervieux, L. Neufeld, and M. Musiani.

    2014. Linking habitat selection and predation risk to spatial variation in survival.

    Journal of Animal Ecology 83:343-352.

Doherty, K. E., D. E. Naugle, and B. L. Walker. 2010. Greater sage-grouse nesting habitat: The importance of managing at multiple scales. Journal of Wildlife Management 74:1544-1553.

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

Duvuvuei, O. V. 2013. Vital rates, population trends, and habitat-use patterns of a translocated greater sage-grouse population: Implications for future translocations. Thesis, Utah State University, Logan, USA.

Eng, R.L. 1963. Observations on the breeding biology of male sage grouse. The Journal of Wildlife Management 841–846.

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

Fischer, R. A., A. D. Apa, W. L. Wakkinen, K. P. Reese, and J. W. Connelly. 1993. Nesting-area fidelity of sage-grouse in southeastern Idaho. Condor 95:1038-1041.

Frey, S. N., R. Curtis, K. Heaton. 2013. Response of a small population of greater sage-grouse to tree removal: Implications of limiting factors. Human-Wildlife Interactions 7:260-272.

Graham, S. E. 2013. Greater sage-grouse habitat selection and use patterns in response to vegetation management practices in northwestern Utah. Thesis, Utah State University, Logan, USA.

Gregg, M. A., M. R. Dunbar, and J. A. Crawford. 2007. Use of implanted radiotransmitters to estimate survival of greater sage-grouse chicks. Journal of Wildlife Management 71:646-651.

Guthery, F. S. 1997. A philosophy of habitat management for northern bobwhites. Journal of Wildlife Management 61:291–301.

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

Harrington, R., N. Owen-Smith, P. C. Viljoen, H. C. Biggs, D. R. Mason, and P. Funston. 1999. Establishing the causes of the roan antelope decline in the Kruger National Park, South Africa. Biological Conservation 90:69-78.

Hausleitner, D. 2003. Population dynamics, habitat use and movements of greater sage-grouse in Moffat County, Colorado. Thesis. University of Idaho. Moscow, USA.

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

Holloran, M. J., B. J. Heath, A. G. Lyon, S. J. Slater, J. L. Kuipers, and S. H. Anderson. 2005. Greater sage-grouse nesting habitat selection and success in Wyoming. Journal of Wildlife Management 69:638-649.

Hornaday, W.T. 1916. Save the sage grouse from extinction: a demand from civilization
to the western states. New York Zoological Park Bulletin 5:179-219.

Idaho Sage-grouse Advisory Committee. 2006. Conservation plan for greater sage-grouse
in Idaho. Idaho Department of Fish and Game. Boise, USA.

Jenni, D. A., and J. E. Hartzler. 1978. Attendance at a sage grouse lek: implications for
spring censuses. Journal of Wildlife Management 42:46–52.

Johnson, D. H. 1980. The comparison of usage and availability measurements for
evaluating resource preference. Ecology 61:65-71.

Johnson, G. D., and M. S. Boyce. 1990. Feeding trials with insects in the diet of sage-
grouse chicks. Journal of Wildlife Management 54:89-91.

Klebenow, D. A., and G. M. Gray. 1968. Food habits of juvenile sage-grouse. Journal of
Range Management 21:80-83.

Knapp, P. A., P. T. Soule, and H. D. Grissino-Mayer. 2001. Detecting potential regional
effects of increased atmospheric CO_2 on growth rates of western juniper. Global
Change Biology 7:903-917.

Knerr, J. S. 2007. Greater sage-grouse ecology in western Box Elder County, Utah.
Thesis, Utah State University, Logan, USA.

Knick, S. T., S. E. Hanser, and K. L. Preston. 2013. Modeling ecological minimum
requirements for distribution of greater sage-grouse leks: Implications for
population connectivity across their western range, U.S.A. Ecology and Evolution
3:1539-1551.

Knick, S. T., S. E. Hanser, and M. Leu. 2014. Ecological scale of bird community response to pinon-juniper removal. Rangeland Ecology and Management 67:553-562.

Leclerc, M., E. VanderWal, A. Zoedrosser, J. E. Swenson, J. Kindberg, and F. Pelletier. 2015. Quantifying consistent individual differences in habitat selection. Oecologia 1-9.

Manly, B. J., L. L. McDonald, D. L. Thomas, T. L. McDonald, and W. P. Erickson. 2002. Resource selection by animals: Statistical design and analysis for field studies. Second Edition. Kluwer Academic Publishers, Dordrecht, Netherlands.

Messmer, T.A. 2013. Lessons learned from the greater sage-grouse: Challenges and emerging opportunities for agriculture and rural communities. National Agricultural and Rural Development Policy Center Policy Brief. Penn State University. State College, Pennsylvania USA.

Miller, R. F. 2005. Biology, ecology, and management of western juniper (*Juniperus occidentalis*). Agricultural Experiment Station, Oregon State University, Corvallis, USA.

Miller, R. F., and L. Eddleman. 2000. Spatial and temporal changes of sage grouse habitat in the sagebrush biome. Oregon State University, Agricultural Experiment Station, Corvallis, USA.

Miller, R. F., T. J. Svejcar, and J. A. Rose. 2000. Impacts of western juniper on plant community composition and structure. Journal of Range Management 53:574-585.

Montana Sage Grouse Work Group. 2005. Management plan and conservation strategies for sage-grouse in Montana – final. Montana Fish, Wildlife, and Parks. Helena, USA.

Morris, L. R. 2011. Land-use legacies of cultivation in shrubland: Ghosts in the ecosystem. Pages 11-16. *In* Threats to Shrubland Ecosystem Integrity. Volume 17. S. J. and Jessie E. Quinney Natural Resources Research Library, Logan, Utah, USA.

Morris, L. R., T. A. Monaco, and R. L. Shelley. 2011. Land-use legacies and vegetation recovery 90 years after cultivation in Great Basin sagebrush ecosystems. Rangeland Ecology and Management 64:488-497.

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

Mysterud. A., and R.A. Ims. 1998. Functional responses in habitat use: Availability influences relative use in trade-off situations. Ecology 79:1435-1441.

Patterson, R.L. 1952. The sage grouse in Wyoming. Sage Books Incorporated, Denver, Colorado, USA.

Ralphs, M. H., and F. E. Busby. 1978. A project that made a second spring for Park Valley. Rangeman's Journal 5:86-88.

Ralphs, M. H., and F. E. Busby. 1979. Prescribed burning: Vegetative change, forage production, cost, and returns on six demonstration burns in Utah. Journal of Range Management 32:267-270.

Rogers, G.E. 1964. Sage grouse investigations in Colorado. Technical Publication 16.
Colorado Game, Fish, and Parks Department, Denver, USA.

Sandford, C. P., D. K. Dahlgren, and T. A. Messmer. 2015. Sage-grouse nests in an
active conifer mastication site. Prairie Naturalist 47:105-106.

Schroeder, M. A. 1997. Unusually high reproductive effort by sage-grouse in a
fragmented habitat in north-central Washington. Condor 90:933-941.

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

Schroeder, M. A., J. R. Young, and C. E. Braun. 1999. Greater sage-grouse
(*Centrocercus urophasianus*). *In* A. Poole, editor. The birds of North America.
Cornell Lab of Ornithology, Ithaca, New York, USA.

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

Scott, J. W. 1942. Mating behavior of sage grouse. Auk 59: 477-498.

State of Nevada Sagebrush Ecosystem Council. 2014. 2014 Nevada greater sage-grouse
conservation plan. Carson City, USA.

State of Wyoming Game and Fish Commission. 2003. Wyoming greater sage-grouse
conservation plan. Cheyenne, USA.

Stiver, S. J. 2011. The legal status of greater sage-grouse: organizational structure of
planning efforts. Pages 33-49 *in* S. Knick and J. W. Connelly, editors. Greater
Sage-Grouse: ecology and conservation of a landscape species and its habitats.

Volume 38. Studies in Avian Biology. University of California Press, Berkeley, USA.

Stiver, S. J., A. D. Apa, J. Bohne, S. D. Bunnell, P. Diebert, S. Gardner, M. Hillard, C. McCarthy, M. A. Schroeder. 2006. Greater Sage-grouse Comprehensive Conservation Strategy. Western Association of Fish and Wildlife Agencies. Unpublished report. Cheyenne, Wyoming.

Stiver, S. J., E. T. Rinkes, D. E. Naugle, P. D. Makela, D. A. Nanace, J. W. Karl. 2015. Sage-grouse habitat assessment framework. U.S. Bureau of Land Management. Technical Reference 6710-1. U.S. Bureau of Land Management and Western Association of Fish and Wildlife Agencies, Denver, CO, USA.

Thacker, E. T. 2010. Greater sage-grouse seasonal ecology and responses to habitat manipulations in northern Utah. Dissertation, Utah State University, Logan, USA.

United States Fish and Wildlife Service [USFWS]. 2001. Endangered and threatened wildlife and plants; 12-month finding for a petition to list the Washington population of western sage grouse (*Centrocercus urophasianus* phaios) as threatened or endangered. Federal Register 66:22984-22986.

United States Fish and Wildlife Service [USFWS]. 2005. Endangered and threatened wildlife and plants; 12-month findings for petitions to list the greater sage-grouse (*Centrocercus urophasianus*) as threatened or endangered. Federal Register 70:2243-2282.

United States Fish and Wildlife Service [USFWS]. 2010. Endangered and threatened wildlife and plants; 12-month findings for petitions to list the greater sage-grouse

(*Centrocercus urophasianus*) as threatened or endangered. Federal Register 75:13910-14014.

United States Fish and Wildlife Service [USFWS]. 2015. Endangered and threatened wildlife and plants; 12-month findings for petitions to list the greater sage-grouse (*Centrocercus urophasianus*) as threatened or endangered. Federal Register 80:59857-59942.

Utah Department of Wildlife Resources [UDWR]. 2002. Strategic management plan for sage-grouse. Publication 09-17. Utah Department of Natural Resources, Division of Wildlife Resources, Salt Lake City, USA.

Utah Governor's Office. 2013. Conservation Plan for Greater Sage-grouse in Utah. Utah's Public Lands Policy Coordination Office, Salt Lake City, USA.

Western Association of Fish and Wildlife Agencies [WAFWA]. 2015. Greater sage-grouse population trends: An analysis of lek count databases 1965-2015. Western Association of Fish and Wildlife Agencies, Cheyenne, Wyoming, U.S.A.

Western Regional Climate Center. 2015. Historical climate information. Western U.S. historical summaries (individual stations), Rosette, Utah. <http://www.wrcc.dri.edu> Accessed 7 Jan 2016.

Wik, P.A. 2002. Ecology of greater sage-grouse in south-central Owyhee County, Idaho. Thesis. University of Idaho. Moscow, USA.

Williams, C. K., F. S. Guthery, R. D. Applegate, and M. J. Peterson. 2004. The northern bobwhite decline: Scaling our management for the twenty-first century. Wildlife Society Bulletin 32:861-869.

Wing, B. R. 2014. The role of vegetation structure, composition and nutrition in greater

sage-grouse ecology in northwestern Utah. Thesis, Utah State University, Logan,

USA.
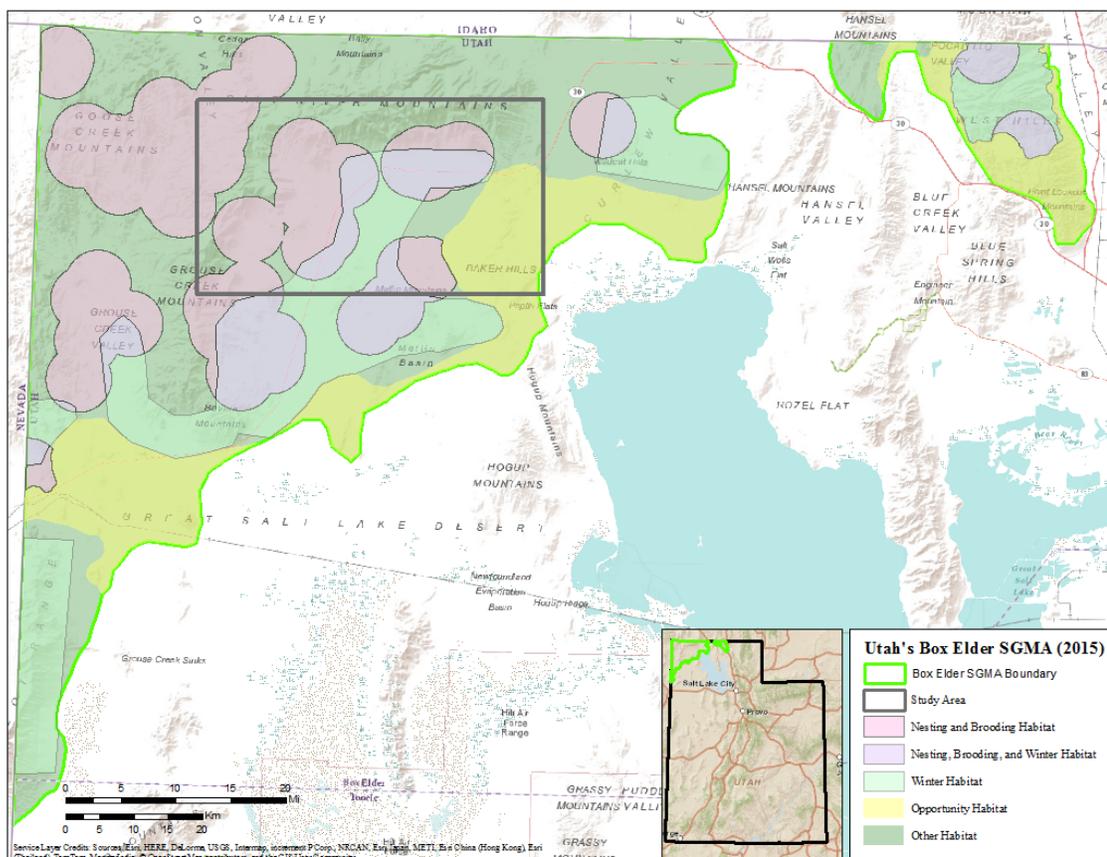
Figure 1-1. Western Box Elder County study area within the Box Elder Sage Grouse (*Centrocercus urophasianus*) Management Area (SGMA) as defined by the Conservation Plan for Greater Sage-grouse in Utah (Utah Governor's Office 2013). Though the SGMA boundaries remain unchanged, this map represents the 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[1]

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 ha^2 in the vicinity of the towns of Park Valley (lat.

41º49'16"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 ΔAICc of the top model to reduce

variation of added variables. 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:

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

where x_n are covariates with fixed regression coefficients β_n, β_0 is the mean intercept, and γ_{0j} is the random intercept calculated as the difference between the mean intercept β_0 for all groups and the intercept for group j (Gillies et al. 2006; Skrondal and Rabe–Hesket 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 ΔAICc (Table 2-2). We selected the most parsimonious model

(ΔAICc = 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 (β = -0.524, P < 0.01), and

nonurban development (β = -0.430, P < 0.01). They selected for greater distances to

roads < 40 kph (β = 0.104, P < 0.01), roads 40-72 kph (β = 0.199, P <

0.01), and agriculture (β = 0.264, P < 0.01). Female sage-grouse with broods also

selected for areas of higher elevation (β = 0.317, P < 0.01), and lower conifer canopy

cover (β = -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 8 100 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.

LITERATURE CITED

ALDRIDGE, C. L. AND R. M. BRIGHAM. 2001. Nesting and reproductive activities of greater sage-grouse in a declining northern fringe population. *Condor*. 103:537-543.

ALDRIDGE, C. L. AND M. S. BOYCE. 2007. Linking occurrence and fitness to persistence: Habitat based approach for endangered greater sage-grouse. *Ecological Applications* 17(2):508-526.

BARUCH-MORDO, S., J. S. EVANS, S. P. SEVERSON, D. E. NAUGLE, J. D. MAESTAS, J. M. KIESECKER, M. J. FALKOWSKI, C. A. HAGEN, AND K. P. REESE. 2013. Saving sage-grouse from the trees: A proactive solution to reducing a key threat to a candidate species. *Biological Conservation* 167:233-241.

BATES, D., M. MAECHLER, B. BOLKER, AND S. WALKER. 2015. Fitting linear mixed-effects models using lme4. *Journal of Statistical Software* 67(1):1-48. doi:10.18637/jss.v067.i01.

BECK, J. L., AND D. L. MITCHELL. 2000. Influences of livestock grazing on sage grouse habitat. *Wildlife Society Bulletin* 28(4):993-1002.

BENSON, J. F., P. J. MAHONEY, AND B. R. PATTERSON. 2015. Spatiotemporal variation in selection of roads influences mortality risk for canids in an unprotected landscape. *Oikos* 124:1664-1673.

BEYER, H. L., D. T. HAYDON, J. M. MORALES, J. L. FRAIR, M. HEBBLEWHITE, M. MITCHELL, AND J. MATTHIOPOULOS. 2010. The interpretation of habitat preference metrics under use-availability designs. Philosophical Transactions of the Royal Society B: Biological Science 365:2245-2254.

BEYER, H. L. 2015. Geospatial modelling environment. Version 0.7.4.0. Available at: http://www.spatialecology.com/gme. Accessed 1 October 2015.

BLICKLEY, J. L., D. BLACKWOOD, AND G. L. PATRICELLI. 2012. Experimental evidence for the effects of chronic anthropogenic noise on abundance of greater sage-grouse at leks. *Conservation Biology* 26:461-471.

BURNHAM, K. P. AND D. R. ANDERSON. 2002. Model selection and multi-model inference: A practical information-theoretic approach, second ed. Springer-Verlag, New York. 454 p.

CAIN, D. 1972. The Ely chain. Bureau of Land Management. Ely, Nevada, U.S.A.

CAIN, J. W. III, P. R. KRAUSMAN, J. R. MORGART, B. D. JANSEN, AND M. P. PEPPER. 2008. *Wildlife Monographs* 171:1-30.

COMMONS, M. L., R. K. BAYBACK, AND C. E. BRAUN. 1999. Sage-grouse response to pinyon-juniper management. USDA Forest Service Proceedings RMRS-P-9. p. 238-239.

CONNELLY, J. W., C. A. HAGEN, AND M. A. SCHROEDER. 2011. Characteristics and dynamics of greater sage-grouse populations, *In*: S. T. Knick and J. W. Connelly (EDS), Greater sage-grouse: Ecology and conservation of a landscape species and its habitats. Berkeley, CA, USA: University of California Press. Studies in Avian Biology 38. p. 53-67.

CONNELLY, J. W., K. P. REESE, AND M. A. SCHROEDER. 2003. Monitoring of greater sage-grouse habitats and populations. Station Bulletin 80. College of Natural Resources Experiment Station. University of Idaho, Moscow.

CONNELLY, J. W. AND L. A. DOUGHTY. 1989. Sage grouse use of wildlife water developments in southeastern Idaho. *In*: G. K. Tsukamoto and S. J. Stiver (EDS), Wildlife water developments: proceedings of the wildlife water development symposium. Nevada Department of Fish and Game, Reno, p. 167-173.

COOK, A. 2015. Greater sage-grouse seasonal habitat models, response to juniper reduction and effects of capture behavior on vital rates, in northwest Utah [thesis]. Utah State University, Logan.

CRUNDEN, C. W. 1963. Age and sex of sage grouse from wings. *Journal of Wildlife Management* 27:846-849.

DAHLGREN, D. K., T. A. MESSMER, B. A. CRABB, R. T. LARSEN, T. A. BLACK, S. N. FREY, E. T. THACKER, R. J. BAXTER, AND J. D. ROBINSON. 2016a. Seasonal Movements

of Greater Sage-grouse Populations in Utah: Implications for Species Conservation. *Wildlife Society Bulletin*.

DAHLGREN, D. K., M. R. GUTTERY, T. A. MESSMER, D. CAUDILL, R. D. ELMORE, R. CHI, AND D. N. KOONS. 2016b. Evaluating vital rate contributions to greater sage-grouse population dynamics to inform conservation. *Ecosphere*.

DAHLGREN, D. K. T. A. MESSMER, AND D. N. KOONS. 2010a. Achieving better estimates of greater sage-grouse chick survival in Utah. *Journal of Wildlife Management* 74:1286-1294.

DAHLGREN, D. K., T. A. MESSMER, E. T. THACKER, AND M. R. GUTTERY. 2010b. Evaluation of brood detection techniques: Recommendations for estimating greater sage-grouse productivity. *Western North American Naturalist* 70(2):233-237.

DAHLGREN, D. K., R. CHI, AND T. A. MESSMER. 2006. Greater sage-grouse response to sagebrush management in Utah. *Wildlife Society Bulletin* 34:975-985.

DEBOODT, T. L., M. P. FISHER, J. C. BUCKHOUSE, AND J. SWANSON. 2008. Monitoring hydrological changes related to western juniper removal: A paired watershed approach. Proceedings of the Third Interagency Conference on Research in the Watersheds. p. 227-232.

DECESARE, N. J., M. HEBBLEWHITE, F. SCHMIEGELOW, D. HERVIEUX, G. J. MCDERMID, L. NEUFELD, M. BRADLEY, J. WHITTINGTON, K. G. SMITH, L. E. MORGANTINI, M. WHEATLEY, AND M. MUSIANI. 2012. Transcending scale dependence in identifying habitat with resource selection functions. *Ecological Applications* 22(4):1068-1083.

DECESARE, N. J., M. HEBBLEWHITE, M. BRADLEY, D. HERVIEUX, L. NEUFELD, AND M. MUSIANI. 2014. Linking habitat selection and predation risk to spatial variation in survival. *Journal of Animal Ecology* 83:343-352.

DOHERTY, K. E., D. E. NAUGLE, AND B. L. WALKER. 2010. Greater sage-grouse nesting habitat: The importance of managing at multiple scales. *Journal of Wildlife Management* 74(7):1544-1553.

DOHERTY, K. E., D. E. NAUGLE, B. L. WALKER, AND J. M. GRAHAM. 2008. Greater sage-grouse winter habitat selection and energy development. *Journal of Wildlife Management* 72:187-195.

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

FALKOWSKI, M. J., K. NILAM, A. J. POZNANOVIC. 2014. Utah conifer mapping. University of Minnesota. <http://160.94.138.23>. Accessed 4 Jun 2014.

FEDY, B. C., K. E. DOHERTY, C. L. ALDRIDGE, M. O'DONNELL, J. L. BECK, B. BEDROSIAN, D. GUMMER, M. J. HOLLORAN, G. D. JOHNSON, N. W. KACZOR, C. P. KIROL, C. A. MANDICH, D. MARSHALL, G. MCKEE, C. OLSON, A. C. PRATT, C. C. SWANSON, AND B. L. WALKER. 2014. Habitat prioritization across large landscapes, multiple seasons, and novel areas: An example using greater sage-grouse in Wyoming. *Wildlife Monographs* 190:1-39.

FREY, S. N., R. CURTIS, AND K. HEATON. 2013. Response of a small population of greater sage-grouse to tree removal: implications of limiting factors. *Human-Wildlife Interactions* 7(2):260-272.

GIFFORD, S., E. LEYDSMAN-MCGINTY, C. MCGINTY, R. D. RAMSEY, AND L. LANGS-STONER. 2014. Baseline disturbance mapping of greater sage-grouse management areas in Utah. Utah State University Remote Sensing/GIS Laboratory, Logan.

GILLIES, C. S., M. HEBBLEWHITE, S. E. NIELSEN, M. A. KRAWCHUK, C. L. ALDRIDGE, J. L. FRAIR, D. J. SAHER, C. S. STEVENS, AND C. L. JERDE. 2006. Application of random effects to the study of resource selection by animals. *Journal of Animal Ecology* 75:887-898.

GUTHERY, F. S. 1997. A philosophy of habitat management for northern bobwhites. *Journal of Wildlife Management* 61:291–301.

HANSER, S. E. AND S. T. KNICK. 2011. Greater sage-grouse as an umbrella species for shrubland passerine birds: A multiscale assessment, in: S. T. Knick and J. W. Connelly (EDS), Greater sage-grouse: Ecology and conservation of a landscape species and its habitats. Berkeley, CA, USA: University of California Press. Studies in Avian Biology 38. p. 475-488.

HARRINGTON, R., N. OWEN-SMITH, P. C. VILJOEN, H. C. BIGGS, D. R. MASON, AND P. FUNSTON. 1999. Establishing the causes of the roan antelope decline in the Kruger National Park, South Africa. *Biological Conservation* 90:69-78.

HEBBLEWHITE, M. AND E. MERRILL. 2008. Modelling wildlife-human relationships for social species with mixed-effects resource selection models. *Journal of Applied Ecology* 45:834-844.

HOLLORAN, M. J., B. J. HEATH, A. G. LYON, S. J. SLATER, J. L. KUIPERS, AND S. H. ANDERSON. 2005. Greater sage-grouse nesting habitat selection and success in Wyoming. *Journal of Wildlife Management* 69:638–649.

HOSMER, D. W., S. LEMESHOW. 2000. Applied logistic regression, second ed. John Wiley & Sons, New York. 383 p.

HOLLORAN, M. J., B. J. HEATH, A. G. LYON, S. J. SLATER, J. L. KUIPERS, AND S. H. ANDERSON. 2005. Greater sage-grouse nesting habitat selection and success in Wyoming. *Journal of Wildlife Management* 69:638-649.

IDAHO SAGE-GROUSE ADVISORY COMMITTEE. 2006. Conservation plan for greater sage-grouse in Idaho. Idaho Department of Fish and Game, Boise.

JOHNSON, D. H. 1980. The comparison of usage and availability measurements for evaluating resource preference. *Ecology* 61(1):65-71.

JOHNSON, D. H., M. J. HOLLORAN, J. W. CONNELLY, S. E. HANSER, C. L. AMUNDSON, AND S. T. KNICK. 2011. Influences of environmental and anthropogenic features on greater sage-grouse populations, 1997-2007. *In*: S. T. Knick and J. W. Connelly (EDS), Greater sage-grouse: Ecology of a landscape species and its habitats. Berkeley, CA, USA: University of California Press. Studies in Avian Biology 38. p. 407-450.

KNICK, S. T., S. E. HANSER, AND K. L. PRESTON. 2013. Modeling ecological minimum requirements for distribution of greater sage-grouse leks: implications for population connectivity across their western range, U.S.A. *Ecological Evolution* 3:1539-1551.

KNICK, S. T., S. E. HANSER, AND M. LEU. 2014. Ecological scale of bird community response to pinon-juniper removal. *Rangeland Ecology & Management* 67:553-562.

KOHL, M. T., P. R. KRAUSMAN, K. KUNKEL, AND D. M. WILLIAMS. 2013. Bison versus cattle: are they ecologically synonymous? *Rangeland Ecology & Management* 66(6):721-731.

LANDFIRE. 2012. Existing vegetation type layer. LANDFIRE 1.1.0, U.S. Department of the Interior, Geological Survey. <http://landfire.cr.usgs.gov/viewer/>. Accessed 1 Oct 2015.

LECLERC, M., E. VANDERWAL, A. ZOEDROSSER, J. E. SWENSON, J. KINDBERG, AND F. PELLETIER. 2015. Quantifying consistent individual differences in habitat selection. *Oecologia*. p. 1-9.

MANIER, D. J., Z. H. BOWEN, M. L. BROOKS, M. L. CASAZZA, P. S. COATES, P. A. DIEBERT, S. E. HANSER, AND D. H. JOHNSON. 2014. Conservation buffer distance estimates for sage-grouse - A review. U.S. Geological Survey Open-File Report p. 2014-1239.

MANLY, B. F., L. L. MCDONALD, D. L. THOMAS, T. L. MCDONALD, AND W. P. ERICKSON. 2002. Resource selection by animals: statistical design and analysis for field studies, second ed. Kluwer Norwell, Massachusetts. 209 p.

MILLER, R. F. AND L. EDDLEMAN. 2000. Spatial and temporal changes of sage grouse habitat in the sagebrush biome. Oregon State University, Agricultural Experiment Station, Corvallis.

MILLER, R. F., S. T. KNICK, D. A. PYKE, C. W. MEINKE, S. E. HANSER, M. J. WISDOM, AND A. L. HILD. 2011. Characteristics of sagebrush habitat and limitations to long-term conservation. *In*: S. T. Knick and J. W. Connelly (EDS), Greater sage-grouse:

Ecology and conservation of a landscape species and its habitat. Berkeley, CA, USA: University of California Press. Studies in Avian Biology 38. p. 145-184.

MONTANA SAGE-GROUSE WORK GROUP. 2005. Management plan for and conservation strategies for sage-grouse in Montana – final. Montana Fish, Wildlife, and Parks. Helena.

MYSTERUD. A. AND R. A. IMS. 1998. Functional responses in habitat use: Availability influences relative use in trade-off situations. *Ecology* 79(4):1435-1441.

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION [NOAA]. 2010. National Climatic Data Center. 1981-2010 Monthly Normals. <http://www.ncdc.noaa.gov /cdoweb/datatools /normals>. Accessed 14 Sept 2014.

PATTERSON, R. L. 1952. The sage grouse of Wyoming. Sage Books Inc. Denver, CO, USA.

REARDEN, J. D. 1951. Identification of waterfowl nest predators. *Journal of Wildlife Management* 15:386-395.

REINHART, J. S., T. A. MESSMER, AND T. BLACK. 2013. Inter-seasonal movements in tri-state greater sage-grouse: implications for state-centric conservation plans. *Human-Wildlife Interactions* 7(2):172–181.

ROBINSON, J. D. AND T. A. MESSMER. 2013. Vital rates and seasonal movements of two isolated greater sage-grouse populations in Utah's West Desert. *Human-Wildlife Interactions* 7(2):182-194.

ROUNDY, B. A., R. F. MILLER, R. J. TAUSCH, K. YOUNG, A. HULET, B. RAU, B. JESSOP, J. C. CHAMBERS, AND D. EGGET. 2014. Understory cover responses to pinon-juniper

treatments across tree dominance gradients in the Great Basin. *Rangeland Ecology & Management* 67:482-494.

SANDFORD, C. P., D. K. DAHLGREN, AND T. A. MESSMER. 2015. Sage-grouse nests in an active conifer mastication site. *Prairie Naturalist* 47(2):105-106.

SCHAEFER, R. J., D. J. THAYER, AND T. S. BURTON. 2003. Forty-one years of vegetation change on permanent transects in northeastern California: Implications for wildlife. California Fish and Game 89(2):55-71.

SCHROEDER, M. A. 1997. Unusually high reproductive effort by sage grouse in a fragmented habitat in north-central Washington. *Condor*. 90:933-941.

SKRONDAL, A. AND S. RABE-HESKETH. 2004. Generalized latent variable modeling: Multilevel, longitudinal, and structural equation models. Chapman & Hall, New York. 508 p.

STATE OF NEVADA SAGEBRUSH ECOSYSTEM COUNCIL. 2014. 2014 Nevada greater sage-grouse conservation plan. Carson City.

STATE OF UTAH WATERSHED RESTORATION INITIATIVE [WRI]. 2011. <http://wildlife.utah.gov/watersheds/>. Accessed 1 March 2014.

STATE OF WYOMING GAME AND FISH COMMISSION. 2003. Wyoming greater sage-grouse conservation plan. Cheyenne.

STIVER, S. J., A. D. APA, J. BOHNE, S. D. BUNNELL, P. DIEBERT, S. GARDNER, M. HILLARD, C. MCCARTHY, AND M. A. SCHROEDER. 2006. Greater sage-grouse comprehensive conservation strategy. Western Association of Fish and Wildlife Agencies. Unpublished report. Cheyenne, Wyoming.

STIVER, S. J., E. T. RINKES, D. E. NAUGLE, P. D. MAKELA, D. A. NANACE, AND J. W. KARL. 2015. Sage-grouse habitat assessment framework. U.S. Bureau of Land Management. Technical Reference 6710-1. U.S. Bureau of Land Management and Western Association of Fish and Wildlife Agencies, Denver, Colorado.

THACKER. E. T. 2010. Greater sage-grouse seasonal ecology and responses to habitat manipulations in northern Utah [dissertation]. Utah State University, Logan.

U.S. FISH AND WILDLIFE SERVICE [USFWS]. 2010. Endangered and threatened wildlife and plants; 12-month findings for petitions to list the greater sage-grouse (*Centrocercus urophasianus*) as threatened or endangered. Federal Register 75:13910-14014.

U.S. FISH AND WILDLIFE SERVICE [USFWS]. 2013. Greater Sage-grouse (*Centrocercus urophasianus*) Conservation Objectives: Final Report. U.S. Fish and Wildlife Service, Denver, Colorado.

UTAH AUTOMATED GEOGRAPHIC REFERENCE CENTER [AGRC]. 2013. 10, 30, and 90m Elevation Models (DEMs). <http://gis.utah.gov/data/elevation-terrain-data/10-30-90-meter-elevation-models-usgs-dems/>. Accessed 1 Oct 2015.

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

UTAH DEPARTMENT OF NATURAL RESOURCES [UDNR]. 2014. Implementing Utah's Greater Sage-grouse Conservation Plan Annual Report. < http://wildlife.utah.gov/uplandgame/sage-grouse/pdf/2014_Greater_Sage-grouse_Annual_Report.pdf >. Accessed 1 December 2015.

UTAH GOVERNOR'S OFFICE. 2013. Conservation Plan for Greater Sage-grouse in Utah.

    Utah's Public Lands Policy Coordination Office, Salt Lake City.

WAKKINEN, W. L., K. P. REESE, J. W. CONNELLY, AND R. A. FISCHER. 1992. An improved

    spotlighting technique for capturing sage grouse. *Wildlife Society Bulletin*

    20:425–426.

WESTERN ASSOCIATION OF FISH AND WILDLIFE AGENCIES [WAFWA]. 2015. Greater

    sage-grouse population trends: An analysis of lek count databases 1965-2015.

    Western Association of Fish and Wildlife Agencies, Cheyenne, Wyoming.

WILLIAMS, C. K., F. S. GUTHERY, R. D. APPLEGATE, AND M. J. PETERSON. 2004. The

    northern bobwhite decline: Scaling our management for the twenty-first century.

    Wildlife Society Bulletin 32(3):861-869

WING, B. R. 2014. Role of vegetation structure, composition, and nutrition in greater

    sage-grouse ecology in northwestern Utah [thesis]. Utah State University, Logan.

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.

		Distance to								
	Treatment	Roads >72kph	Roads 40-72kph	Roads <40kph	Power lines	Agriculture	Urban Development	Nonurban Development	Canopy Cover Class	Elevation
Units	Kilometers	Kilometers	Kilometers	Kilometers	Kilometers	Kilometers	Kilometers	Kilometers	Continuous(1-5)	Meters

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* u*rophasianus*) nest success probability in Park Valley, Utah from 2012 to 2015.

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

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.

Predictor Variables	K	AICc	ΔAICc	AICcWt
Treat, Elev, Roads>40 , Roads<40, Ag, NonUrb, Canopy	9	6759.73	0	0.73
Treat, Elev, Roads>40, Roads<40, Ag, NonUrb, Canopy, Mesic	10	6761.7	1.97	0.27
Treat, Elev, Roads>40, Ag, NonUrb, Canopy, Mesic	9	6788.07	28.34	0

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.

																Distance to						Conifer				
Sign	Treatment			Roads 40-72kph			Roads <40kph			Agriculture			NonUrban			Canopy			Elevation		
	n	b	p	n	b	p	n	b	p	n	b	p	n	b	p	n	b	p	n	b	p
+	8	7	0	20	13	20	32	22	6	36	29	12	22	15	22	55	40	16	37	29	2
-	48	34	37	36	28	23	24	18	13	20	12	9	34	26	6	1	1	1	19	12	14

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 ($p \leq 0.05$). 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.
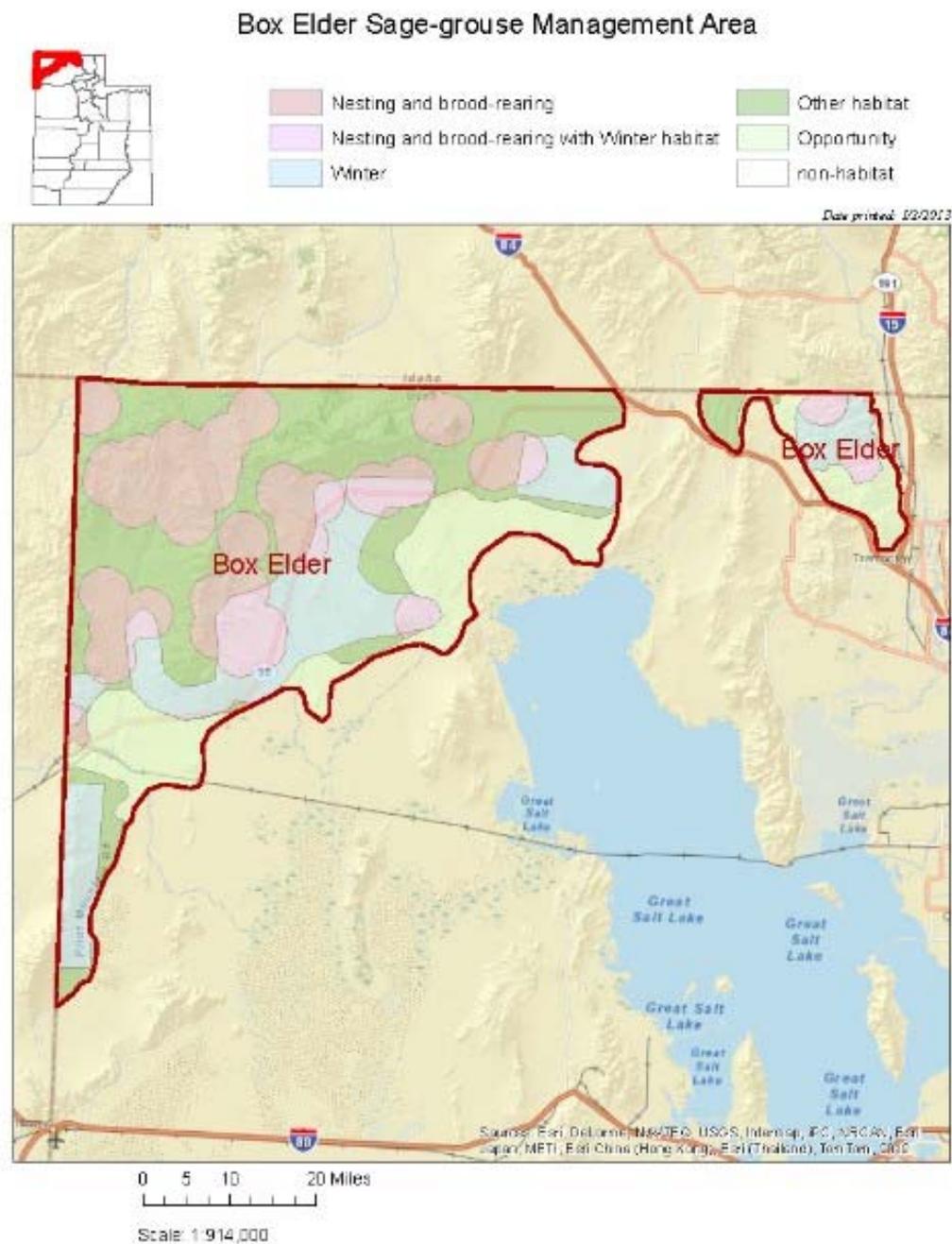
Figure 2-1. Utah's greater sage-grouse (*Centrocercus urophasianus*) Management Area 1, located in northwest Box Elder County, Utah (Utah Governor's Office 2013).
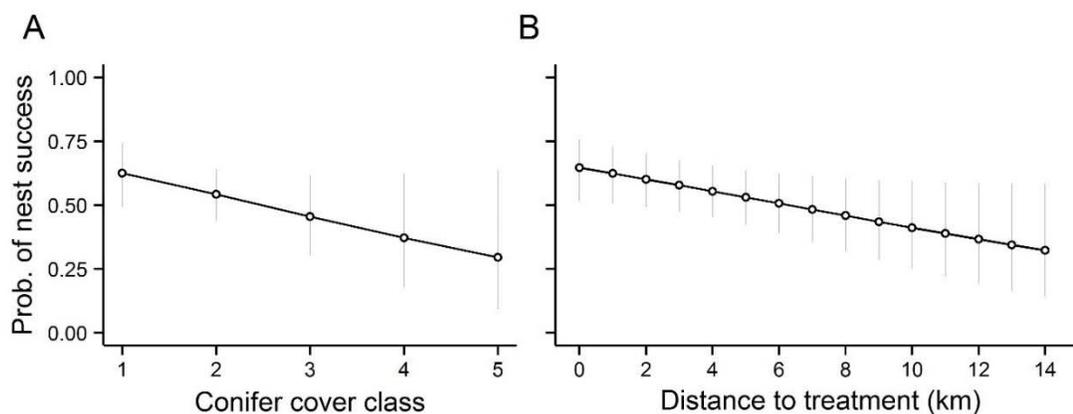
Figure 2-2a.
Probability of female sage-grouse
(*Centrocercus urophasianus*) nest
success as a function of conifer canopy
cover class in Park Valley, Utah from
2012 to 2015. Probability of nest
success decreased by 30% for each unit
increase in conifer canopy cover
(*p=0.11*).

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*)

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.
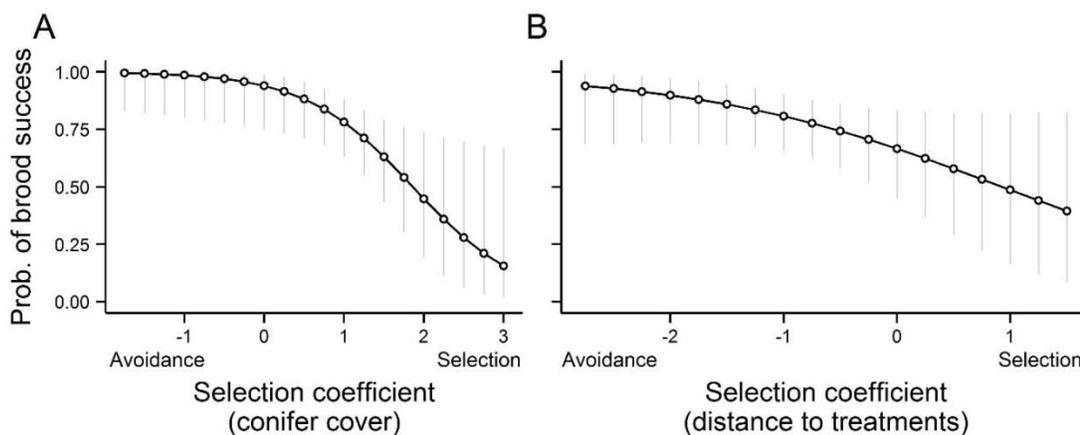
Figure 2-3a.
Probability of greater sage-grouse
(*Centrocercus urophasianus*) brood
success plotted against selection
coefficient estimates of conifer canopy
cover in Park Valley, Utah from 2012 to
2015. Avoidance indicates sage-grouse
females choose sites with less conifer
canopy cover. Selection indicates 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.

LITERATURE CITED

Baruch-Mordo, S., J. S. Evans, S. P. Severson, D. E. Naugle, J. D. Maestas, J. M. Kiesecker, M. J. Falkowski, C. A. Hagen, and K. P. Reese. 2013. Saving sage-grouse from the trees: A proactive solution to reducing a key threat to a candidate species. Biological Conservation 167:233-241.

Box Elder Adaptive Resource Management Local Working Group [BARM]. 2007. West

    Box Elder greater sage-grouse (*Centrocercus urophasianus*) local conservation

    plan. Utah State University Extension and Jack H. Berryman Institute and Utah

    Division of Wildlife Resources, Salt Lake City, USA.

Braun, C. E. 1998. Sage grouse declines in western North America: what are the

    problems? Proceedings of the Western Association of Fish and Wildlife Agencies

    78:139-156.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multi-model inference:

    A practical information-theoretic approach, second ed. Springer-Verlag, New

    York, USA.

Cain, D. 1971. The Ely chain. Bureau of Land Management. Ely, Nevada, USA.

Commons, M. L., R. K. Bayback, and C. E. Braun. 1999. Sage-grouse response to

    pinyon-juniper management. USDA Forest Service Proceedings RMRS-P-9. p.

    238-239. Provo, Utah, USA.

Connelly, J. W., M. A. Schroeder, A. R. Sands, and C. E. Braun. 2000. Guidelines to

    manage sage-grouse populations and their habitats. Wildlife Society Bulletin

    28:967-985.

Connelly, J. W., and L. A. Doughty. 1989. Sage grouse use of wildlife water

    developments in southeastern Idaho. Pages 167-173 *in* S. Stiver and G.

    Tsukomoto, editors. Symposium on wildlife water developments. Nevada

    Department of Fish and Game, Reno, USA.

Cook, A. 2015. Greater sage-grouse seasonal habitat models, response to juniper

reduction and effects of capture behavior on vital rates, in northwest Utah. Thesis,

Utah State University, Logan, USA.

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

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

Dahlgren, D. K., T. A. Messmer, B. A. Crabb, R. T. Larsen, T. A. Black, S. N. Frey, E. T.

Thacker, R. J. Baxter, and J. D. Robinson. 2016. Seasonal movements of greater

sage-grouse populations in Utah: Implications for species conservation. Wildlife

Society Bulletin.

Dixon, P. M. 1993. The bootstrap and the jackknife: describing the precision of

ecological indicies. Pages 290-318 *in* S.M. Scheiner and J. Gurevitch, editors.

Design and analysis of ecological experiments. Chapman and Hall, New York,

USA.

Falkowski, M. J., K. Nilam, and A. J. Poznanovic. 2014. Utah conifer mapping.

University of Minnesota. <http://160.94.138.23>. Accessed 4 Jun 2014.

Fedy, B. C., K. E. Doherty, C. L. Aldridge, M. O'Donnell, J. L. Beck, B. Bedrosian, D.

Gummer, M. J. Holloran, G. D. Johnson, N. W. Kaczor, C. P. Kirol, C. A.

Mandich, D. Marshall, G. McKee, C. Olson, A. C. Pratt, C. C. Swanson, and B. L.

Walker. 2014. Habitat prioritization across large landscapes, multiple seasons,

and novel areas: An example using greater sage-grouse in Wyoming. Wildlife

Monographs 190:1-39.

Frey, S. N., R. Curtis, and K. Heaton. 2013. Response of a small population of greater sage-grouse to tree removal: Implications of limiting factors. Human-Wildlife Interactions 7:260-272.

Graham, S. E. 2013. Greater sage-grouse habitat selection and use patterns in response to vegetation management practices in northwestern Utah. Thesis, Utah State University, Logan, USA.

Guthery, F. S. 1997. A philosophy of habitat management for northern bobwhites. Journal of Wildlife Management 61:291-301.

Guttery, M. R. 2011. Ecology and management of a high elevation southern range greater sage-grouse population: vegetation manipulation, early chick survival, and hunter motivations. Dissertation, Utah State University, Logan, USA.

Hanser, S. E., C. L. Aldridge, M. Leu, M. M. Rowland, S. E. Nielsen, and S. T. Knick. 2011. Greater sage-grouse: general use and roost site occurrence with pellet counts as a measure of relative abundance. Pages 112-140 *in* Sagebrush ecosystem conservation and management: ecoregional assessment tools and models for the Wyoming Basins. Allen Press, Lawrence, Kansas, USA.

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

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

Knick, S. T., S. E. Hanser, and K. L. Preston. 2013. Modeling ecological minimum requirements for distribution of greater sage-grouse leks: Implications for

population connectivity across their western range, U.S.A. Ecological Evolution
3:1539-1551.

Knick, S.T., S.E. Hanser, M. Leu. 2014. Ecological scale of bird community response to
pinon-juniper removal. Rangel. Ecol. Manag. 67, 553-562.

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

McDonald, T. L., R. M. Nielson, and J. D. Carlisle. 2015. Rdistance: Distance Sampling
Analyses. R package version 1.3.2. <https://CRAN.Rproject.org/
package=Rdistance>. Accessed 10 Jan 2016.

Miller, R. F. 2005. Biology, ecology, and management of western juniper (*Juniperus
occidentalis*). Agricultural Experiment Station, Oregon State University,
Corvallis, USA.

Miller, R. F., and L. Eddleman. 2000. Spatial and temporal changes of sage grouse
habitat in the sagebrush biome. Agricultural Experiment Station, Oregon State
University, Corvallis, USA.

Patterson, R. L. 1952. The sage grouse in Wyoming. Sage Books Incorporated, Denver,
Colorado, USA.

Sandford, C. P., D. K. Dahlgren, and T. A. Messmer. 2015. Sage-grouse nests in an
active conifer mastication site. The Prairie Naturalist 47:105-106.

Sandford, C. P., M. T. Kohl, T. A. Messmer, D. K. Dahlgren, A. Cook, and B. R. Wing.
2016. Greater sage-grouse resource selection drive reproductive fitness in conifer
removal system. Journal of Rangeland Ecology and Management.

State of Utah Watershed Restoration Initiative [WRI]. 2011. <http://wildlife.utah.gov/ watersheds/>. Accessed 1 March 2014.

Stiver, S. J., E. T. Rinkes, D. E. Naugle, P. D. Makela, D. A. Nance, and J. W. Karl. 2015. Sage-grouse habitat assessment framework. U.S. Bureau of Land Management. Technical Reference 6710-1. U.S. Bureau of Land Management and Western Association of Fish and Wildlife Agencies, Denver, Colorado, USA.

U.S. Fish and Wildlife Service. 2015. Endangered and threatened wildlife and plants; 12-month findings for petitions to list greater sage-grouse (*Centrocercus urophasianus*) as an endangered or threatened species. Federal Register 80, 59857-59942.

Utah Governor's Office. 2013. Conservation Plan for Greater Sage-grouse in Utah. Utah's Public Lands Policy Coordination Office, Salt Lake City, USA.

Western Regional Climate Center. 2015. Historical climate information. Western U.S. historical summaries (individual stations), Rosette, Utah. <http://www.wrcc.dri.edu> Accessed 7 Jan 2016.

Wing, B. R. 2014. The role of vegetation structure, composition and nutrition in greater sage-grouse ecology in northwestern Utah. Thesis, Utah State University, Logan, USA.

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.

Likelihood	Series	Expansions	Converged?	Scale?	AICc
Half Normal	cosine	0	Yes	ok	87.3969
Half Normal	cosine	1	Yes	ok	83.3052
Half Normal	hermite	1	Yes	ok	84.0147
Half Normal	simple	1	Yes	ok	87.4274
Hazard Rate	cosine	0	Bad	-	-
Hazard Rate	cosine	1	Yes	ok	85.4876
Hazard Rate	hermite	1	Bad	-	-
Hazard Rate	simple	1	Bad	-	-
Uniform	cosine	0	Bad	-	-
Uniform	cosine	1	Yes	ok	85.5066
Uniform	hermite	1	Yes	ok	85.7821
Uniform	simple	1	Yes	ok	85.7943
Negative Exponential	**cosine**	**0**	**Yes**	**ok**	**54.4733**
Negative Exponential	cosine	1	Yes	ok	55.5868
Negative Exponential	hermite	1	Yes	ok	84.3419
Negative Exponential	simple	1	Yes	ok	84.2783
Gamma	-	0	Yes	ok	110.176

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.

Likelihood	Series	Expansions	Converged?	Scale?	AICc
Half Normal	cosine	0	Yes	ok	55.3969
Half Normal	cosine	1	Yes	ok	57.4093
Half Normal	hermite	1	Yes	ok	57.4687
Half Normal	simple	1	No	-	-
Hazard Rate	cosine	0	Bad	-	-
Hazard Rate	cosine	1	Bad	-	-
Hazard Rate	hermite	1	Bad	-	-
Hazard Rate	simple	1	Bad	-	-
Uniform	cosine	0	Bad	-	-
Uniform	cosine	1	Bad	-	-
Uniform	hermite	1	No	-	-
Uniform	simple	1	Bad	-	-
Negative Exponential	**cosine**	**0**	**Yes**	**ok**	**54.4733**
Negative Exponential	cosine	1	Yes	ok	55.5868
Negative Exponential	hermite	1	Bad	-	-
Negative Exponential	simple	1	Bad	-	-
Gamma	-	0	Bad	-	-

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.

Likelihood	Series	Expansions	Converged?	Scale?	AICc
Half Normal	cosine	0	Yes	ok	1040.058
Half Normal	cosine	1	Yes	ok	1040.029
Half Normal	hermite	1	Yes	ok	1040.042
Half Normal	simple	1	Yes	ok	1039.863
Hazard Rate	cosine	0	Yes	ok	1040.994
Hazard Rate	**cosine**	**1**	**Yes**	**ok**	**1038.638**
Hazard Rate	hermite	1	Yes	ok	1041.752
Hazard Rate	simple	1	Yes	ok	1039.606
Uniform	cosine	0	Yes	ok	1040.953
Uniform	cosine	1	Yes	ok	1042.389
Uniform	hermite	1	Yes	ok	1042.031
Uniform	simple	1	Yes	ok	1042.11
Negative Exponential	cosine	0	Yes	ok	1052.037
Negative Exponential	cosine	1	Yes	ok	1045.329
Negative Exponential	hermite	1	Yes	ok	1043.31
Negative Exponential	simple	1	Yes	ok	1046.014
Gamma	-	0	Yes	ok	1271.273
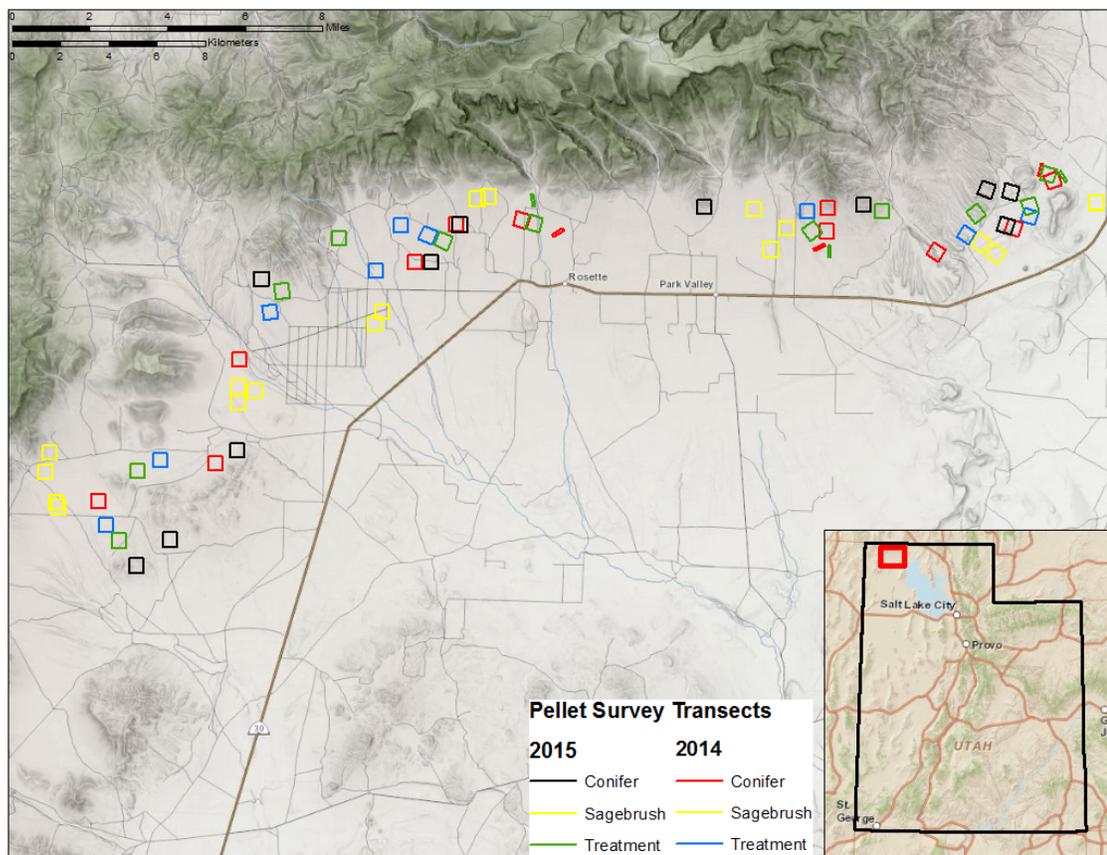
Figure 3-1. Locations of greater sage-grouse (*Centrocercus urophasianus*) pellet density estimation transects conducted from 2014-2015 in Utah's Box Elder Sage-grouse Management Area. Note the overlap of 2015 treatment transects and 2014 conifer transects. These were treated in the fall of 2014 after pellet surveys were completed. Due to most conifer removal projects occurring on private property, project perimeters have been excluded.
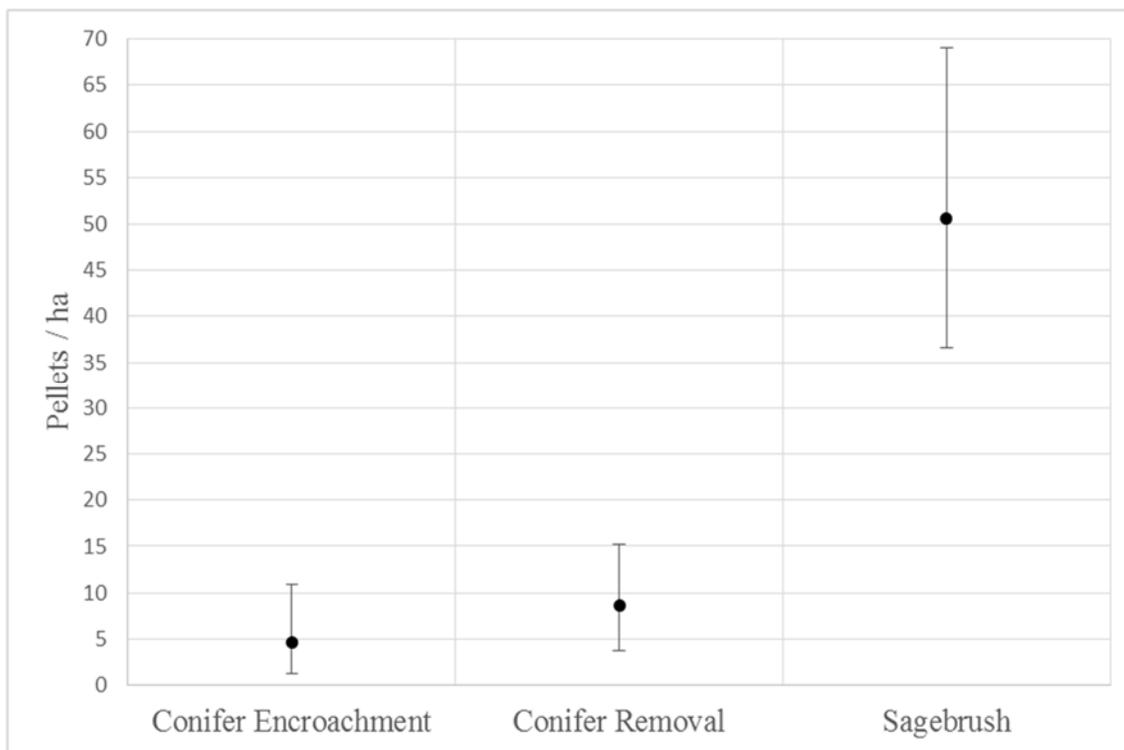
Figure 3-2. Estimated greater sage-grouse (*Centrocercus urophasianus*) pellet density in pinyon (*Pinus* spp.) and juniper (*Juniperus* spp.; conifer) encroachment habitat, conifer removal habitat, and undisturbed sagebrush (*Artemisia* spp.) habitat in northwestern Utah, 2014-2015.

CHAPTER 4

BREEDING HABITAT MICRO-SITE VEGETATION STRUCTURE AND GREATER

SAGE-GROUSE NEST AND BROOD SUCCESS IN NORTHWESTERN UTAH

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 (*Pinus* spp.) and juniper (*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 increased 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 ha^2 in the vicinity of the towns of Park Valley

(lat. 41º49'16"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 (*Symphoriocarpos 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. 2010*a*; 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., 2010*a*). 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. 2010*a*). 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. 2010*b*).

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 400m. 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. viscidiflorus*; n = 1), Utah serviceberry (n = 1), snowberry (n = 2), antelope bitterbrush (n = 1), broom snakeweed (*Guteirrizia 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 = $

0.71, *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. 2011*a*). 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. 2011*a*) 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.

LITERATURE CITED

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

BARUCH-MORDO, S., J. S. EVANS, S. P. SEVERSON, D. E. NAUGLE, J. D. MAESTAS, J. M. KIESECKER, M. J. FALKOWSKI, C. A. HAGEN, AND K. P. REESE. 2013. Saving sage-grouse from the trees: A proactive solution to reducing a key threat to a candidate species. *Biological Conservation* 167:233-241.

BECK, J. L., D. L. MITCHELL, B. D. MAXFIELD. 2003. Changes in the distribution and status of sage-grouse in Utah. *Western North American Naturalist* 63:203-214.

BOX ELDER ADAPTIVE RESOURCE MANAGEMENT LOCAL WORKING GROUP [BARM]. 2007. West Box Elder greater sage-grouse (*Centrocercus urophasianus*) local conservation plan. Utah State University Extension and Jack H. Berryman Institute and Utah Division of Wildlife Resources, Salt Lake City.

BOX ELDER ADAPTIVE RESOURCE MANAGEMENT LOCAL WORKING GROUP [BARM]. 2012. 2012 West Box Elder CRM sage-grouse accomplishment report. Utah State University Extension, Logan.

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

COMMONS, M. L., R. K. BAYDACK, C. E. BRAUN. 1999. Sage grouse response to pinyon-juniper management. Pages 238-239 *in* USDA Forest Service Proceedings RMRS-P-9. Ogden, Utah.

CONNELLY, J. W., C. A. HAGEN, AND M. A. SCHROEDER. 2011*b*. Characteristics and dynamics of greater sage-grouse populations. *In*: S.T. Knick and J.W. Connelly, [EDS]. Greater sage-grouse: Ecology and conservation of a landscape species and its habitats. Berkeley, CA, USA: University of California Press. Studies in Avian Biology 38. p. 53-67.

CONNELLY, J. W., E. T. RINKES, AND C. E. BRAUN. 2011*a*. Characteristics of greater sage-grouse habitats: A landscape species at micro- and macroscales. *In*: S.T. Knick and J.W. Connelly, [EDS]. Greater sage-grouse: Ecology and conservation of a

landscape species and its habitats. Berkeley, CA, USA: University of California Press. Studies in Avian Biology 38. p. 69-83.

CONNELLY, J. W., K. P. REESE, AND M. SCHROEDER. 2003. Monitoring of greater sage-grouse habitats and populations. College of Natural Resources Experiment Station, University of Idaho, Moscow.

CONNELLY, J. W., M. A. SCHROEDER, A. R. SANDS, AND C. E. BRAUN. 2000. Guidelines to manage sage-grouse populations and their habitats. *Wildlife Society Bulletin* 28:967-985.

CONNELLY, J. W., S. T. KNICK, C. E. BRAUN, W. L. BAKER, E. A. BEEVER, T. CHRISTIANSEN, K. E. DOHERTY, E. O. GARTON, C. A. HAGEN, S. E. HANSER, D. H. JOHNSON, M. LEU, R. F. MILLER, D. E. NAUGLE, S. J. OYLER-MCCANCE, D. A. PYKE, K. P. REESE, M. A. SCHROEDER, S. J. STIVER, B. L. WALKER, AND M. J. WISDOM. 2011*c*. Conservation of greater sage-grouse: A synthesis of current trends and future management. *In*: S.T. Knick and J.W. Connelly [EDS]. Greater sage-grouse: Ecology and conservation of a landscape species and its habitats. Berkeley, CA, USA: University of California Press. Studies in Avian Biology 38. p. 549-563.

COOK, A. 2015. Greater sage-grouse seasonal habitat models, response to juniper reduction, and effects of capture behavior on vital rates in northwest Utah. Thesis, Utah State University, Logan.

CRUNDEN, C. W. 1963. Age and sex of sage grouse from wings. *Journal of Wildlife Management* 27:846-850.

DAHLGREN, D. K. 2006. Greater sage-grouse reproductive ecology and response to experimental management of mountain big sagebrush on Parker Mountain, Utah. Dissertation, Utah State University, Logan.

DAHLGREN, D. K., R. CHI, AND T. A. MESSMER. 2006. Greater sage-grouse response to sagebrush management in Utah. *Wildlife Society Bulletin* 34:975-985.

DAHLGREN, D. K., T. A. MESSMER, AND D. N. KOONS. 2010*b*. Achieving better estimates of greater sage-grouse chick survival in Utah. *Journal of Wildlife Management* 74:1286-1294.

DAHLGREN, D. K., T. A. MESSMER, E. T. THACKER, AND M. R. GUTTERY. 2010*a*. Evaluation of brood detection techniques: Recommendations for estimating greater sage-grouse productivity. *Western North American Naturalist* 70:233:237.

DAHLGREN, D. K., T. A. MESSMER, B. A. CRABB, R. T. LARSEN, T. A. BLACK, S. N. FREY, E. T. THACKER, R. J. BAXTER, AND J. D. ROBINSON. 2016. Seasonal movements of greater sage-grouse populations in Utah: Implications for species conservation. *Wildlife Society Bulletin.*

DALKE, P. D., B. D. PYRAH, D. C. STANTON, J. E. CRAWFORD, AND E. F. SCHLATTERER. 1963. Ecology, productivity, and management of sage-grouse in Idaho. *Journal of Wildlife Management* 27:810-841.

DAUBENMIRE, R. F. 1959. A canopy-coverage method of vegetation analysis. *Northwest Science* 33:43-64.

DOHERTY, K. E., D. E. NAUGLE, AND B. L. WALKER. 2010. Greater sage-grouse nesting habitat: The importance of managing at multiple scales. *Journal of Wildlife Management* 74:1544-1553.

DRUT, M. S., W. H. PYLE, AND J. A. CRAWFORD. 1994. Diets and food selection of sage-grouse chicks in Oregon. *Journal of Range Management* 47:90-93.

DUVUVUEI, O. V. 2013. Vital rates, population trends, and habitat-use patterns of a translocated greater sage-grouse population: Implications for future translocations. Thesis, Utah State University, Logan.

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

GIESEN, K. M., T. J. SCHOENBERG, AND C. E. BRAUN. 1982. Methods for trapping sage-grouse in Colorado. *Wildlife Society Bulletin* 10:224-231.

JOHNSON, G. D. AND M. S. BOYCE. 1990. Feeding trials with insects in the diet of sage-grouse chicks. *Journal of Wildlife Management* 54:89-91.

KLEBENOW, D. A. AND G. M. GRAY. 1968. Food habits of juvenile sage-grouse. *Journal of Range Management* 21:80-83.

KNERR, J. S. 2007. Greater sage-grouse ecology in western Box Elder County, Utah. Thesis, Utah State University, Logan.

KNICK, S. T., S. E. HANSER, AND K. L. PRESTON. 2013. Modeling ecological minimum requirements for distribution of greater sage-grouse leks: Implications for population connectivity across their western range, U.S.A. *Ecology and Evolution* 3:1539-1551.

PATTERSON, R. L. 1952. The sage grouse in Wyoming. Sage Books Incorporated, Denver, Colorado. 341 p.

REARDEN, J. D. 1951. Identification of waterfowl nest predators. *Journal of Wildlife Management* 15:386-395.

REINHART, J. S., T. A. MESSMER, AND T. BLACK. 2013. Interseasonal movements in tri-state greater sage-grouse: Implications for state-centric conservation plans. *Human-Wildlife Interactions* 7(2):172-181.

ROBEL, R. J., J. N. BRIGGS, A. D. DAYTON, AND L. C. HULBERT. 1970. Relationships between visual obstruction measurements and weight of grassland vegetation. *Journal of Range Management* 23:295-297.

ROBINSON, J. S. AND T. A. MESSMER. 2013. Vital rates and seasonal movements of two isolated greater sage-grouse in Utah's West Desert. *Human-Wildlife Interactions* 7(2):182-94.

SANDFORD, C. P., D. K. DAHLGREN, AND T. A. MESSMER. 2015. Sage-grouse nests in an active conifer mastication site. *Prairie Naturalist* 47:105-106.

SCHROEDER, M. A. 1997. Unusually high reproductive effort by sage-grouse in a fragmented habitat in north-central Washington. *Condor* 90:933-941.

STIVER, S. J., A. D. APA, J. BOHNE, S. D. BUNNELL, P. DIEBERT, S. GARDNER, M. HILLARD, C. MCCARTHY, AND M. A. SCHROEDER. 2006. Greater sage-grouse comprehensive conservation strategy. Western Association of Fish and Wildlife Agencies. Unpublished report. Cheyenne, Wyoming.

STIVER, S. J., E. T. RINKES, D. E. NAUGLE, P. D. MAKELA, D. A. NANCE, AND J. W. KARL. 2015. Sage-grouse habitat assessment framework. U.S. Bureau of Land Management. Technical Reference 6710-1. U.S. Bureau of Land Management and Western Association of Fish and Wildlife Agencies, Denver, Colorado.

UNITED STATES FISH AND WILDLIFE SERVICE [USFWS]. 2010. Endangered and threatened wildlife and plants; 12-month findings for petitions to list the greater

sage-grouse (*Centrocercus urophasianus*) as threatened or endangered. Federal Register 75:13910-14014.

UTAH DEPARTMENT OF WILDLIFE RESOURCES [UDWR]. 2002. Strategic management plan for sage-grouse. Utah Department of Natural Resources, Division of Wildlife Resources, Publication 09-17, Salt Lake City, Utah.

UTAH GOVERNOR'S OFFICE. 2013. Conservation plan for greater sage-grouse in Utah. Utah's Public Lands Policy Coordination Office, Salt Lake City.

WAKKINEN, W. L., K. P. REESE, J. W. CONNELLY, AND R. A. FISCHER. 1992. An improved spotlighting technique for capturing sage-grouse. *Wildlife Society Bulletin* 20:425-426.

WESTERN REGIONAL CLIMATE CENTER. 2015. Historical climate information. Western U.S. historical summaries (individual stations), Rosette, Utah. <http://www.wrcc.dri.edu> Accessed 7 Jan 2016.

WING, B. R. 2014. The role of vegetation structure, composition and nutrition in greater sage-grouse ecology in northwestern Utah. Thesis, Utah State University, Logan.

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

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

[a]Includes measurements of trees, and zero shrub, sagebrush, forb, and grass cover
[b]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.

Parameter	Sample 1	Sample 2	*t*	*P*	95% CI
VOR In	Successful	Unsuccessful	0.08	0.939	-11.73-12.66
VOR Out	Successful	Unsuccessful	0.44	0.665	-13.06-20.17
Nest Shrub Height	Successful	Unsuccessful	0.30	0.766	-12.37-16.64
Nest Shrub Diameter	Successful	Unsuccessful	0.02	0.987	-25.00-25.96
Shrub Cover	Successful	Unsuccessful	-0.95	0.347	-10.51-3.76
Shrub Height	Successful	Unsuccessful	0.64	0.529	-4.73-9.02
Sagebrush Cover	Successful	Unsuccessful	-0.41	0.684	-8.01-5.31
Sagebrush Height	Successful	Unsuccessful	0.85	0.400	-4.17-10.20
Forb Cover	Successful	Unsuccessful	-1.35	0.188	-4.31-0.88
Forb Height	Successful	Unsuccessful	0.20	0.843	-2.26-2.75
Grass Cover	Successful	Unsuccessful	-1.23	0.225	-4.23-1.02
Grass Height	Successful	Unsuccessful	0.15	0.882	-5.34-6.19
Bare Ground	Successful	Unsuccessful	0.71	0.482	-4.20-8.73
Rock Composition	Successful	Unsuccessful	-0.69	0.493	-7.29-3.60
Litter Cover	Successful	Unsuccessful	1.34	0.191	-3.85-18.51

*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.

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

[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 4-4. Statistical comparison of vegetation characteristics and ground cover at sites used by successful and unsuccessful greater sage-grouse (*Centrocercus urophasianus*) broods, and random sites in northwestern Utah, 2014-2015.

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

*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, fob 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

Cook, A. 2015. Greater sage-grouse seasonal habitat models, response to juniper
   reduction and effects of capture behavior on vital rates, in northwest Utah. Thesis,
   Utah State University. Logan, USA.

Dahlgren, D. K., T. A. Messmer, B. A. Crabb, R. T. Larsen, T. A. Black, S. N. Frey, E. T.

Thacker, R. J. Baxter, and J. D. Robinson. 2016. Seasonal movements of greater sage-grouse populations in Utah: Implications for species conservation. Wildlife Society Bulletin.

Frey, S. N., R. Curtis, and K. Heaton. 2013. Response of a small population of greater sage-grouse to tree removal: Implications of limiting factors. Human-Wildlife Interactions 7:260-272.

Messmer, T. A. 2015. Sage-grouse conservation and management through science: The Utah experience - A summary of greater sage-grouse research in Utah 1996-2015. Jack H. Berryman Institute for Wildlife Damage Management. Utah State University, Logan, USA.

Sandford, C. P., D. K. Dahlgren, and T. A. Messmer. 2015. Sage-grouse nests in an active conifer mastication site. The Prairie Naturalist 47:105-106.

Utah Department of Natural Resources [UDNR]. 2014. Implementing Utah's Greater Sage-grouse Conservation Plan Annual Report. < http://wildlife.utah.gov/ uplandgame/sage-grouse/pdf/2014_Greater_Sage-grouse_Annual_Report.pdf >. Accessed 1 December 2015.

Wing, B. R. 2014. The role of vegetation structure, composition and nutrition in greater sage-grouse ecology in northwestern Utah. Thesis, Utah State University, Logan, USA.

APPENDIX

GREATER SAGE-GROUSE YEARLING FEMALE SELECTS NEST SITE IN AN

ACTIVE CONIFER MASTICATION TREATMENT[1]

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

[1] Coauthors: David K. Dahlgren, Terry A. Messmer

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.

LITERATURE CITED

Baruch-Mordo, S., J. W. Evans, J. P. Severson, D. E. Naugle, J. D. Maestas, J. M. Kiesecker, M. J. Falkowski, C. A. Hagen, and K. P. Reese. 2013. Saving sage-grouse from the trees: a proactive solution to reducing a key threat to a candidate species. Biological Conservation 167:233-241.

Casazza, M. L., P. S. Coates, and C. T. Overton. 2011. Linking habitat selection and brood success in Greater Sage-Grouse. *in* B. K. Sandercock, K. Martin, G. Segelbacher [EDS], Ecology, Conservation, and Management of Grouse. Berkeley, CA, USA: University of California Press. Studies in Avian Biology 39. p. 151–167.

Cook, A. 2015. Greater sage-grouse seasonal habitat models, response to juniper reduction and effects of capture behavior on vital rates, in northwest Utah. Master's Thesis, Utah State University, Logan, UT.

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

Frey, S. N., R. Curtis, and K. Heaton. 2013. Response of a small population of greater sage-grouse to tree removal: implications of limiting factors. Human-Wildlife Interactions 7:260-272.

Knick, S.T., S.E. Hanser, and M. Leu. 2014. Ecological scale of bird community response to piñon-juniper removal. Rangeland Ecology and Management 67:553-562.

Miller R. F., J. D. Bates, T. J. Svejcar, F. B. Pierson, and L. E. Eddleman. 2005. Biology, ecology and management of western juniper. Corvallis, OR, USA: Oregon State University, Agricultural Experiment Station. Technical Bulletin 152. 82 p.

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

U.S. Fish and Wildlife Service. 2013. Greater sage-grouse (Centrocercus urophasianus) conservation objectives: final report. U.S. Fish and Wildlife Service, Denver, CO.

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.
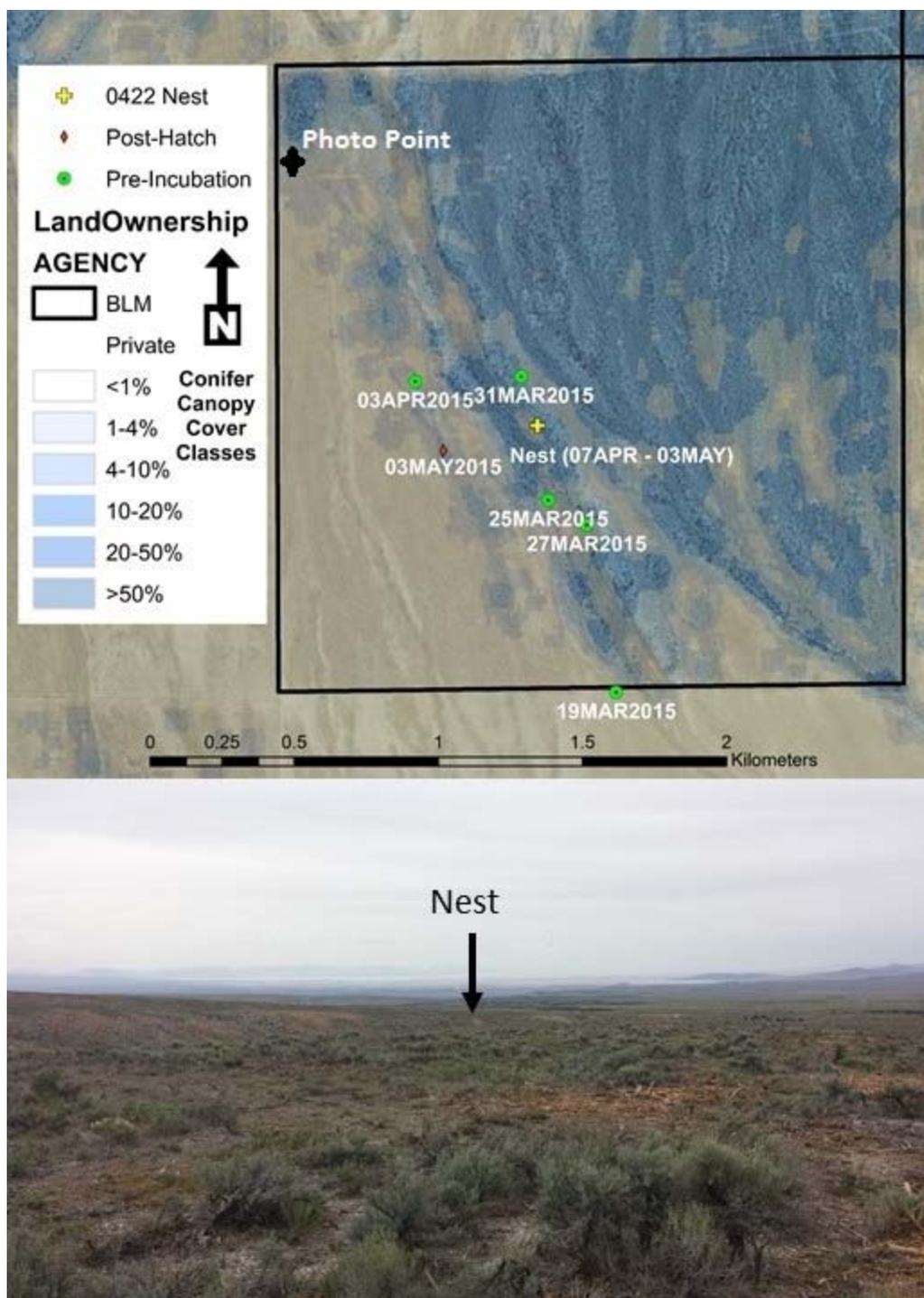
Figure A-1. Locations and nest site of a female greater sage-grouse (*Centrocercus urophasianus*) in a recently masticated conifer site (~233 ha), March-May 2015, Park Valley, Utah. Imagery and conifer canopy cover data were pre-2015. Bottom photo shows post-mastication on the site.

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Dear ~~Coauthor~~ David Dahlgren:

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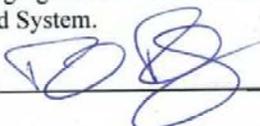
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Sandford, C. P., M. T. Kohl, T. A. Messmer, D. K. Dahlgren, A. Cook, B. R. Wing. 2016. Sage-grouse Resource Selection Drives Reproductive Fitness in a Conifer Managed System.

Signed: _____

14 March 2016

Charles Sandford
Dept. of Wildland Resources, Utah State University
5230 Old Main Hill
Logan, UT 84322

Dear Brian Wing:

I am in the process of preparing my thesis in the WILD department at Utah State University. I hope to complete my degree program in May, 2016.

I am requesting your permission to include the chapter you coauthored for submission to the Journal of Rangeland Ecology and Management, titled "Greater Sage-grouse Resource Selection Drives Reproductive Fitness in a Conifer Managed System". I will include acknowledgments and/or appropriate citations and copyright and reprint rights information in a special appendix. The bibliographic citation will appear at the end of the manuscript. Please advise me of any changes you require.

Please indicate your approval of this request by signing in the space provided, attaching any other form or instruction necessary to confirm permission. If you have any questions, please call me at the number below.

I hope you will be able to reply immediately.

Thank you for you cooperation,

Charles Sandford
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