1-1-2013

Greater sage-grouse habitat selection and use patterns in response to vegetation management practices in northwestern Utah

Stephanie E. Graham
Utah State University

GREATER SAGE-GROUSE HABITAT SELECTION AND USE PATTERNS IN RESPONSE TO VEGETATION MANAGEMENT PRACTICES IN NORTHWESTERN UTAH

by

Stephanie E. Graham

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

of

MASTER OF SCIENCE

in

Wildlife Biology

Approved:

Terry A. Messmer Major Professor	Christopher Call Committee Member
Frank Howe Committee Member	Mark McLellan Vice President for Research and Dean of the School of Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

2013

ABSTRACT

Greater Sage-Grouse Habitat Selection and Use Patterns

in Response to Vegetation Management Practices

in Northwestern Utah

by

Stephanie E. Graham, Master of Science

Utah State University, 2013

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

Greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) currently occupy an estimated 56% of the potential range-wide pre-European settlement habitat. Population declines have been largely attributed to direct habitat loss and fragmentation related to anthropogenic activities that promote wildfires and the subsequent spread of invasive plants. Vegetation manipulations, including the seeding of plant species, such as forage kochia (*Bassia prostrata*), have been identified as potential strategies to mitigate the risk of wildfire and enhance sage-grouse habitat in areas at risk to wildfires. I evaluated the composition changes that occurred in a lower elevation sagebrush (*Artemisia* spp.) plant community within the Grouse Creek Watershed in western Box Elder County, Utah, USA, in response to prescribed vegetation manipulations (green-stripping through chain harrowing, juniper mastication, seeding forage kochia, applying Plateau® herbicide) and studied the effect of these changes on sage-grouse habitat-use patterns and vital rates. I monitored 53 radio-collared sage-grouse throughout the Grouse Creek watershed from 2010-2012. Seasonal movements suggested local individual bird adaptations to annual variations in weather and habitat fragmentation. Sage-grouse selected for untreated areas; however, treated areas were used to expand the size of the lek. Untreated areas exhibited a higher percent composition of shrubs compared to areas that were chain harrowed to prepare a seedbed. Sage-grouse nest success and adult male survival rates during this study were relatively low compared to range-wide population estimates. Nest predation was higher for nests located closer to roads. The forage kochia seeded in the firebreaks emerged the season after seeding (2011). Using microhistological techniques, I detected small quantities of forage kochia in sage-grouse fecal pellets. Nutrient analysis confirmed that forage kochia samples collected from the sites exhibited a high protein content and low secondary metabolite content, similar to black sagebrush (*Artemisia nova*). Although greenstripping with forage kochia in lower elevation sagebrush communities may prove to be a beneficial technique for protecting rangelands from wildfire and provide a dietary source for wildlife, site preparation should be conducted to minimize the impact on existing sagebrush canopy cover habitats. Long-term monitoring should be implemented to determine extended effects of greenstripping treatments on sagebrush habitat and sage-grouse vital rates. Although individual sage-grouse demonstrated local adaptations to fragmentation and seasonal variations in weather, increased fragmentation and climate change in this part of the Great Basin may increase meta-population extirpation risks inhabiting lower elevation sagebrush areas in the Grouse Creek Watershed.

(176 pages)

PUBLIC ABSTRACT

Greater Sage-Grouse Habitat Selection and Use Patterns

in Response to Vegetation Management Practices

in Northwestern Utah

by

Stephanie E. Graham, Master of Science

Utah State University, 2013

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

Greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) are a sagebrush obligate species and an indicator of sagebrush (*Artemisia* spp.) habitat quality. Sage-grouse populations have declined across western North America. Fragmentation of landscapes and habitat loss have been identified as factors that negatively impact sage-grouse populations. Wildfires can increase the distribution of invasive plants and contribute to fragmentation and habitat loss across sagebrush ecosystems. Greenstripping has been identified as a technique to reduce the threat of wildfire and subsequent spread of invasive species. Forage kochia (*Bassia prostrata*) is a semi-shrub that contains a high moisture content year-round, high protein content, and has the ability to reduce wildfire spread across rangelands; however, greenstrip site preparation may also be a disturbance to the landscape.

I evaluated the impact of greenstripping on lower elevation sagebrush habitats and sage-grouse habitat use from 2010-2012 in the Grouse Creek Watershed, western Box Elder County, USA. I monitored 53 radio-collared sage-grouse to determine habitat use patterns, nest and brood success, and survival in response to the greenstripping. I recorded vegetation measurements at sage-grouse use locations and random locations to determine preferred habitat metrics. I used distance sampling to evaluate sage-grouse use of greenstripped areas compared to untreated sites. I used microhistological lab techniques to identify forage kochia in sage-grouse fecal pellets that were collected in the spring 2012.

My results suggest that sage-grouse preferred untreated areas. However, sage-grouse used the greenstrips to expand the size of a traditional lek. Based on my analysis of fecal pellets collected in the spring, I confirmed that forage kochia was consumed by sage-grouse at a low density, but sagebrush constituted the primary diet source. Long-term monitoring should be continued to evaluate if the greenstripping actually reduced fires risks and if sage-grouse use of the treated sites increased over time. The nest success and male survival estimates for this population were lower than range-wide averages. Although individual sage-grouse demonstrated local adaptations to fragmentation and seasonal variations in weather, increased fragmentation and climate change in the Great Basin may increase extirpation risks for the meta-population inhabiting lower elevation sagebrush areas in the Grouse Creek Watershed.

ACKNOWLEDGMENTS

First, I would like to thank my advisor, Dr. Terry A. Messmer, for his continued guidance and support throughout this project. Terry, your passion for good science and sage-grouse research is admirable. I also want to thank my committee, Dr. Frank Howe and Dr. Chris Call, for their assistance with the project. I appreciate all of your professional direction and motivation to help me expand my scope of research.

There are many individuals who were instrumental in the completion of this research. I'd like to say thank you to Dr. Michael Guttery, whom I like to call a good friend, lab mate, and mentor. His technical analytic assistance and everyday advice were indispensible. I would also like to thank Todd Black, Brian Maxfield, and Casey Cardinal for logistic support. Erin Duvuvuei, Seth Dettenmaier, Avery Cook, Kerry Shea, Mindi Lundberg, Chris Perkins, James Taylor, and Bryan Watt provided invaluable field assistance. These folks spent tireless hours helping trap sage-grouse in the middle of the night, complete vegetation plots, and map transmission poles. I also want to thank Dr. Joe Wheaton, Dr. Dale Gardner, Dr. Michael Piep, Beth Burritt, and Dr. Adam Brewerton for their analytic support.

This project would not have been possible without my funding sources, including the U.S. Bureau of Land Management, Utah State University, Jack H. Berryman Institute for Wildlife Damage Management, Utah Chapter of The Wildlife Society, Donald M. Rusch, and Quinney Professorship for Wildlife Conflict Management.

I wouldn't be in the natural resource field today without my family, who introduced me to variety of wildlife activities, and always urged me to be passionate and strive for success in my career. I would particularly like to thank my parents, Dr. Robert Graham, Dr. Theresa Vicroy, and Sara Squyres, who introduced me to hunting and outdoor adventures. Our trips as children to explore new cultures and ecosystems molded my desire to pursue a career involving wildlife. I would like to thank my siblings, Erin Graham, David Stroupe, Mary Catherine Graham, Kelly Graham, and William Graham. You all are an enthusiastic bunch that support me with endless advice and love, for which I am thankful. I would also like to say thank you to my husband, Leighton Schnell, who spent countless days in Grouse Creek, completing vegetation plots, tracking sage-grouse, and even feeding 300 people at the July 4th rodeo. It is an experience we will never forget. Thank you for all of your love and support.

Stephanie E. Graham

CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

The direct conversion, fragmentation, and degradation of sagebrush (*Artemisia* spp.) ecosystems has been implicated as a major factor contributing to the decline of greater sage-grouse (*Centrocercus urophasianus*;sage-grouse) populations range-wide (U.S. Department of the Interior 2010). Fragmentation of sagebrush dominated landscapes and the pattern of agricultural conversion among soil types have had detrimental effects on numerous sagebrush obligate species (Vander Haegan et al. 2000). Sage-grouse are an indicator of the potential effects of the loss and fragmentation of sagebrush ecosystems on other sagebrush obligate species (Stiver et al. 2006). Conservation of sage-grouse and other sagebrush obligate species will require identification and protection of resilient sagebrush habitats and the restoration of degraded sites to repair landscape structure and function (Connelly et al. 2011, Pyke 2011).

Sagebrush ecosystems that are not resilient to disturbances and subsequent spread of invasive species may cross into alternate stable states dominated by woodlands and annual grasslands. Reestablishment of the original plant community structure may not be attainable without human intervention (Briske et al. 2008, Pyke 2011). Restoration is often hampered by high costs, perceived low benefits, and frequent misapplication of management practices (Schupp 2000).

SAGE-GROUSE POPULATION STATUS AND TRENDS

Sage-grouse are a popular upland game, sagebrush obligate species that occupy sagebrush habitats throughout western North America. Currently, sage-grouse occupy <56% of their historical range across western North America (Schroeder et al. 2004). Historically, sage-grouse occupied approximately 33% of the land in Utah; however, sage-grouse currently occupy an estimated 13% of the state (Beck et al. 2003). These declines are a concern to land and wildlife managers throughout the species' range because of implications regarding the ecological condition and status of sagebrush ecosystems upon which sage-grouse and other sagebrush-obligate species depend (Schroeder et al. 1999).

In 2005, the U.S. Fish and Wildlife Service (USFWS) completed a range-wide status review of sage-grouse to address several petitions to list the species for protection under the Endangered Species Act of 1973 (ESA). In 2005, the USFWS determined that listing sage-grouse for ESA protection was not warranted. The USFWS was sued regarding this decision on the basis of process errors, and subsequently ordered by a federal judge to review their determination. In early 2010, the USFWS published a warranted but precluded decision, making sage-grouse an ESA candidate species (U.S. Department of the Interior 2010). Although the USFWS recognized the progress made by state and local sage-grouse working groups (LWGs), new concerns regarding habitat loss and fragmentation as a result of energy development and the lack of regulatory mechanisms to protect the species weighed heavily in their decision. Given the species candidate status, the USFWS must complete an annual species status review (U.S. Department of the Interior 2010).

Prior to any petitions being filed to list the species under the ESA, western state and provincial governments and their partners were conducting research to describe sage-grouse population ecology, identify potential threats, and develop and implement conservation strategies to protect the species (Stiver et al. 2006). For example, Utah implemented its first LWG in 1996 (Utah State University Cooperative Extension 1997). In 2004, the sage-grouse range-wide conservation assessment had been completed (Connelly et al. 2004), and by 2006, the range-wide conservation assessment strategy had been completed to prioritize and guide range-wide conservation actions (Stiver et al. 2006). Connelly et al. (2004) and Stiver et al. (2006) acknowledged that much of the research needed to define sage-grouse biology had been completed, but that more research was needed to describe localized species ecology and population responses to management actions.

Variation in Sage-grouse Vital Rates

Vital rates in sage-grouse populations (i.e., nest and brood success, productivity, survival) vary temporally and across different geographical regions in response to several factors, such as predation, weather, disease, and habitat fragmentation (Connelly et al. 2011). Reported annual hen survival rates range from 0.25 to 0.96, and may reflect differences in winter weather and West Nile virus (Moynahan et al. 2006). Local population declines have also been attributed to low recruitment rates and poor quality brood-rearing habitat (Crawford and Lutz 1985, Connelly and Braun 1997).

Dahlgren (2009) and Guttery (2011) reported that population growth was most influenced by survival of adult hens and chicks. Taylor et al. (2012) also identified nest success as an important parameter affecting sage-grouse production. Brood amalgamation has been suggested as a possible strategy used by sage-grouse to increase chick survival and enhance recruitment. Dahlgren et al. (2010) reported brood amalgamation occurred in up to 43% of the broods they studied in Utah and involved over 21% of the chicks monitored.

Chick survival rates have been positively correlated with grass height and insect presence (Gregg and Crawford 2009, Guttery 2011). Dahlgren et al. (2006) reported a positive response of sage-grouse hens and chicks to small-scale habitat manipulations, which increased forb and insect abundance. However, they concluded that more research was needed to evaluate population response to management on the landscape level, but stressed that actions, which included reduction of sagebrush cover, should only be implemented using adaptive management processes.

SAGE-GROUSE CONSERVATION THREATS

The main threats to sage-grouse conservation include loss and fragmentation of sagebrush habitat as a result of anthropogenic disturbances, associated fluctuations in predation rates, disease, impacts of weather, wildfire risk, and spread of invasive species (U.S. Department of the Interior 2010, Knick and Connelly 2011). As habitat loss and fragmentation occur, increases in predation and disease can also become a problem (Hagen 2011).

West Nile virus was documented at infection rates of 4% to 29% across study sites in Montana (Walker et al. 2007). Although some sage-grouse may survive the infection of West Nile virus, birds remain highly susceptible (Walker et al. 2007).

As habitat becomes degraded, predation can have a greater impact on populations, particularly where invasive predator abundance has also increased (Baxter et al. 2007). For example, corvids may prey on sage-grouse nests and chicks (Patterson 1952, Coates 2007). Corvid densities in sage-grouse habitat have increased in response to anthropogenic influences, which have fragmented habitats and subsidized their expansion (Bui et al. 2010). If non-invasive vegetation and sagebrush cover can be restored through habitat management, the impact of ravens (*Corvus corax*) on nest success may be mitigated (Coates and Delehanty 2010). Other predators of adult birds and nests may include coyotes (*Canis latrans*), golden eagles (*Aquila chrysaetos*), and badgers (*Taxidea taxus*) (Patterson 1952, Schroeder et al. 1999, Coates 2007). Habitat management strategies designed to maintain both vertical and horizontal vegetation cover characteristics of sagebrush communities at the landscape level may afford the best long-term option for sage-grouse conservation (Connelly et al. 2011, Taylor et al. 2012).

Loss of sage-grouse habitat has typically been attributed to the conversion of land for agricultural purposes (Connelly et al. 2004, Knick and Connelly 2011). These losses have been further exacerbated because of the spread of invasive plants and increased energy development in the sagebrush ecosystem, which have impacted both habitat quality and changed historical fire regimes (Connelly et al. 2011). Wildfire and conversion of sagebrush shrublands to cheatgrass (*Bromus tectorum*) grasslands remains a serious threat to the shrub-steppe ecosystem (Earnst et al. 2009). These disturbances alter species interactions at the individual, community, and population level.

Wildfires

Although wildfires are a natural process, they can have dramatic effects and unintended consequences where anthropogenic disturbances have altered fire regimes (Allen et al. 2008). Suppression of wildfires has contributed to changed vegetation composition, including woodland expansion and increased woody fuels in shrub-steppe regions (Allen et al. 2008). In the case of sagebrush ecosystems, the effects of fire can be long-term and permanent (Knick et al. 2005).

Disturbance regimes that operate on rangelands have changed substantially, with lethal fires, which are characterized by areas of high vegetative mortality, dominating many areas where non-lethal fires were historically the norm; due to human expansion, landscapes are more susceptible to fire, insects, and disease than under historic convention (Quigley and Arbelbide 1997). Expansive fires fueled by homogenization of landscapes, characterized by woodland and cheatgrass-dominated understories, are outside the historical range of variation. The changes in fuel structure and fire regime caused by this homogenization may affect every trophic level (DeBano et al. 1998). In the case of sagebrush ecosystems, recovery processes can be slow, and the risk of repeated fires damaging ecosystems will remain high until altered fuel conditions are corrected (Keane et al. 2008).

It can take several decades under good environmental conditions to even partially reestablish the original plant base in sagebrush communities after a wildfire (Ziegenhagen 2003). Concomitantly, the dynamics and composition of wildlife species in the area can be dramatically and possibly permanently altered. Allen et al. (2008)

reported that post-fire, big sagebrush (*A. tridentata*) was completely eliminated from the seedbank, because the entire shrub litter was consumed by the burn.

Post-settlement fire exclusion, livestock grazing, and climate change account for much of the expansion of woodland species in shrub-dominated communities (Miller and Rose 1999, Bauer and Weisberg 2009). At a sagebrush steppe site in Oregon, the last large fire occurred in 1897, which was followed by many decades of fire suppression and subsequent juniper (*Juniperus occidentalis*) encroachment (Miller and Rose 1999). Precipitation rates, atmospheric CO_2, and hydrologic cycles also affect the expansion of pinyon-pine (*Pinus edulis*) and juniper communities (Bradley and Fleishman 2008).

In addition to immediate habitat loss and change in above ground biomass, wildfires can have a number of indirect effects on sagebrush habitats. In a study that focused on the impact of fire across a variety of avian species in the interior Columbia Basin, Earnest et al. (2009) reported that all species of birds except for the horned lark (*Eremophila alpestris*) decreased in population numbers post-fire.

Other effects included the spread of invasive species with little competition from native vegetation. Invasive non-native plants can directly affect native plants by becoming either monopolizers or donors of limiting resources. For example, a nitrogen fixer plant such as firetree (*Myrica faya*) can add nitrogen to a nitrogen-deficient site. They can also change ecosystems by altering soil stability, nutrient cycling, and trophic structure, which will affect the accumulation of litter, salt, or other soil resources, and change disturbance regimes (Vitousek 1990). After a burn in northwestern Nevada, shrub species declined, biotic soil crust cover presence was four times lower, and non-native species cover was five times higher than in non-burned sites (Haubensak et al. 2009).

Predators

Corvids, coyotes, badgers, and raptors have been identified as predators of sage-grouse (Patterson 1952, Schroeder et al. 1999, Coates 2007). There are no predators within the range of sage-grouse that depend on sage-grouse as their primary food source; many depend primarily on rodents and lagomorphs and feed on sage-grouse opportunistically (Patterson 1952, Hagen 2011). Population cycles of prey species can be highly correlated, which may also influence the predator-prey guild (Fedy and Doherty 2011). Yensen et al. (1982) reported that widespread conversion of desert shrublands to exotic annual-dominated communities by wildfires was shown to decrease the presence of important prey species, such as ground squirrels (*Spermophilus* spp.). This type of decline of prey species can increase predation on alternative prey sources, such as sage-grouse.

Invasive Plants

Rangelands that have lost native vegetation cover and had soil properties altered through extensive erosion events are highly susceptible to noxious weed invasion (Lacey et al. 1989, Pierson et al. 2011). Invasive plants are species that have a competitive edge, which spread rapidly, take over novel areas, and become the dominant vegetation (Valéry et al. 2008). Many species, including halogeton (*Halogeton glomeratus*), Russian thistle (*Salsola* spp.), annual mustards, bur buttercup (*Ceratocephala testiculata*), and cheatgrass invade landscapes throughout the western United States. Presence of these species can reduce soil biota and soil nutrients over time, leading to a decrease in biodiversity (Belnap et al. 2005).

Cheatgrass

Herbaceous succession after wildfires in big sagebrush communities is often dominated by population dynamics of cheatgrass (Young and Evans 1978). Cheatgrass is a self-pollinating exotic annual grass that has achieved widespread dominance in semiarid western North America and is actively invading salt desert habitats (Scott et al. 2010). The presence of this invasive species is correlated with anthropogenic influences. Bradley and Mustard (2006) reported that cheatgrass was 20% more likely to be found within 3 km of cultivation, 15% more likely to be found within 1 km of a powerline, and 13% more likely to be within 700 m of a road.

Cheatgrass has been positively related to landscape patchiness (Knick and Rotenberry 1997). Therefore, cheatgrass dominance can contribute to further fragmentation and loss of sagebrush habitats by facilitating spread of subsequent fires, carried by continuous fuels (Knick and Rotenberry 1997). One year after a fire in Nevada, cheatgrass plants were observed to increase by a factor of 10 over 3 years. The cheatgrass plants in the burned area were significantly more productive than those in adjacent unburned areas (Young and Evans 1978).

Cheatgrass can also function as a reservoir for pathogens, such as *Pyrenophora semeniperda*, that kill native plants (Beckstead et al. 2010). However, as this pathogen invades cheatgrass-dominated areas, it can also reduce cheatgrass presence through infecting the seeds and reproducing spores that are released back into the seed bank

(Beckstead et al. 2007). Therefore, as cheatgrass invades native plant communities, pathogens can reduce cheatgrass presence, but pathogen spillover can occur and have detrimental effects on native vegetation (Beckstead et al. 2010).

Halogeton

Another particularly abundant invasive plant across the Intermountain West is halogeton. Halogeton is a noxious weed introduced from Russia and parts of northwestern China (Hitchcock and Cronquist 1964). First discovered in Wells, Nevada in 1934, this poisonous, non-native succulent annual had spread to an estimated area of 607,000 ha in the Intermountain West by 1952 (Pierson 1952, Tisdale and Zappetini 1953). It is currently found as far east as the Missouri River and as far north as Canada (Young et al. 1999). Halogeton is poisonous to livestock (James 1971). The lethal dose for an unconditioned sheep is between 0.20-0.22 g halogeton/kg body weight. Halogeton poisoning becomes a problem when the plant is consumed by sheep in such quantities that the rumen microorganisms cannot metabolize the oxalate. At this point, oxalate is apparently absorbed faster than it can be excreted and intoxication occurs. As oxalate levels increase, water intake increases and food intake decreases. When a band of sheep grazes where halogeton poisoning may occur, they either live with little or no apparent effect or they die within the first few days (James and Butcher 1972).

Halogeton affords poor environmental protection for ungulates, game birds, and waterfowl in Utah and Wyoming (Dittberner and Olson 1983). This species has the potential for changing soil surfaces via salt pumping, which impedes moisture infiltration and enhances evaporation (Roundy 1987). After halogeton dies, it does not readily decompose, which increases fuel loads (Cronin 1965). Dried halogeton can also spread fire by moving flames from a burning plant into unburned areas (Yensen 1982). Several studies have investigated the relationship between fire and halogeton. In one particular study, halogeton plants increased one year after a fire that burned all aboveground vegetation. At the same site, halogeton abundance substantially increased in biomass two years after the fire (Halford 1981).

Bur Buttercup

Bur buttercup is an invasive forb that is native to southeastern Europe and central Asia. This plant was first found in Utah in 1932, and currently grows throughout the Intermountain West (Buchanan et al. 1978). Bur buttercup is an annual plant that only grows to 5 cm in height, but can carpet thousands of ha during the spring in the Great Basin region (Young et al. 1992). Due to successful germination in cooler temperatures, bur buttercup can invade large areas while other plant species are still dormant (Young et al. 1992). Bur buttercup is also toxic for livestock. Ranunculin is a toxic component in bur buttercup, with the highest concentration during the early flower growth stage (Nachman and Olsen 1983). Olsen et al. (1983) found bur buttercup to be lethal to sheep at the rate of 500 g of green plant per 45 kg sheep. Post-mortem findings include inflammation and edema of the rumen, hemorrhage in the kidneys, and excessive fluid in the thoracic and abdominal cavities (Olsen et al. 1983).

Juniper

Although juniper plants are a forage source for several wildlife species, such as mule deer (*Odocoileus hemionus*), its expansion across the western United States has led to a decrease in understory and sagebrush habitat. Juniper establishment may reduce forb cover and increase soil pH (Burkhardt and Tisdale 1969). Juniper regenerates through seed, which is often dispersed locally through gravity and fauna activity (Burkhardt and Tisdale 1976). Juniper distribution has expanded due to suppression of fires, changes in grazing regimes, and subtle changes in climate (Burkhardt and Tisdale 1976, Riegel et al. 2006).

Juniper is a competitive species that can survive up to several hundred years (Vaitkus and Eddleman 1991). Severe fires can kill junipers, however, fire suppression in the Intermountain West has led to an increase in juniper expansion (Miller and Tausch 2001). In 2002, juniper and pinyon species were estimated to span over 12 million ha in the western United States (West 1999, Miller and Tausch 2001). This was an increase from an estimated occupancy of less than 1.2 million ha pre-European settlement (Gedney et al. 1999).

Habitat Fragmentation and Climate Influences

Habitat loss and fragmentation have occurred extensively; and continuous degradation of landscapes is inevitable (Hansen et al. 2002, Stephens et al. 2004). This decrease in contiguous landscapes and increase in invasive species can lead to decreases in native flora and fauna species (Rolstad 1991). Climate models predict an increase in nightly and annual temperatures, with the highest projected seasonal change in winter (Christensen et al. 2007, Wagner 2009). This increase in winter temperatures is associated with a potential increase in rainfall and reduced snowfall. Warming in the western United States is projected to increase 2°C within the next 200 years (Christensen et al. 2007). These changes in temperatures and precipitation, in conjunction with a rapid increase in CO_2 levels, will likely lead to more extreme events, such as droughts (Christensen et al. 2007, Wagner 2009). Although this change in climate may be positively correlated with populations of native forbs, grasses, and shrubs, it is also likely that invasive species will greatly benefit from the projected changes in climate (Chambers and Pellant 2008, Inouye 2008, Dalgleish et al. 2010, Dalgleish et al. 2011). Drought tolerant species will likely out-compete plants that are less resistant to changes in climate variables. Population sizes of flora and fauna species may fluctuate throughout the landscape in response to habitat fragmentation and changes in climate (Chambers and Pellant 2008, Inouye 2008).

Little information that addresses the impacts of climate on sage-grouse populations is available. However, if the projected increase in temperature occurs in conjunction with lower amounts of snowfall, wildfires and invasive plant species will likely be more prevalent. Consequences of climate change and fragmentation of the landscape will alter the phenology of native species across many ecosystems (Parmesan 2006). These impacts may also stress dietary conditions and increase pressure on reproductive efforts (Blomberg et al. 2012), ultimately reducing sage-grouse populations.

Managing Invasive Plant Species

The first step in managing invasive plant species is to define the scope and magnitude of the invasion and areas impacted (Mack and Lonsdale 2002). Several programs, such as LANDFIRE National have been successful at mapping the extent of cheatgrass invasion in areas where the plant has become the dominant vegetation

(Provencher et al. 2009). However, this technology has difficulty in accurately mapping smaller amounts of cheatgrass because the program cannot detect cheatgrass when cover is <10%; although, cheatgrass is often present at a rate of 5%-10% across landscapes (Provencher et al. 2009). These techniques have not yet been applied to halogeton.

Grazing, fire, and seeding of forbs and shrubs are common management techniques used for vegetation manipulations and restoration. Overgrazing has been implicated as a cause in the spread of cheatgrass (Monaco et al. 2003). In a study conducted in northern Nevada rangelands, Diamond et al. (2009) used targeted grazing during the boot (phenological) stage, which reduced cheatgrass biomass and cover, thus leading to smaller fires. Jessop and Anderson (2007) seeded several previous burn sites with native vegetation and were successful in establishing perennial grasses and shrubs, which decreased the presence of cheatgrass. There are also several cases of unsuccessful establishment of seeded vegetation that was originally planted to compete with invasive species (Gautier 1983, Taskey et al. 1989).

Range management practices can have a dramatic effect on vegetation composition (Kauffman and Krueger 1984, Keeley 2006). Following the initial invasion of halogeton, subsequent invasion, abundance, and persistence of crested wheatgrass (*Agropyron cristatum*) range was influenced by four interrelated factors: intensity of spring grazing, season of grazing, salts in the soil, and total precipitation. Where halogeton was abundant, at least 2 years of deferred grazing was required to affect substantial reduction of the weed (Frischknetcht 1968). Robocker et al. (1969) documented that black halogeton seed germinated at a rate of 100% the first year and 2% after four years. Although zero germination occurred from brown seeds, brown seeds were 100% viable for two years and 15% viable at the end of 10 years. Holl (1954) reported that up to 50% of brown seeds germinated during years one and two. As well, wind and humans were observed to be important factors in localized movement of the seed. Once halogeton invades an area, the entire range will become seeded in a matter of a very few years (Stoddart et al. 1951). For this reason, halogeton may never be eliminated from the intermountain deserts, and the solution to the problem is good management of ranges and livestock (Stoddart et al. 1951).

Several methods of halogeton control have been assessed and utilized, including cultural control, biological control, and chemical control (Pavek 1992). Halogeton was less prevalent in paddocks with early grazing, April-June, and more prevalent in paddocks with late grazing, June-September (Robertson et al. 1970). A stem-boring moth was released in Pakistan to combat the spread of halogeton, but it was unsuccessful at establishment (Pemberton 1986). Halogeton can be killed by 2, 4-D and 2, 4, 5-T sprays, but many times repeated spraying is needed (Erickson et. al. 1951). In a study, nitrogen application was used on a variety of plants and halogeton doubled in quantity. This resulted in the elimination of this management practice where halogeton and cheatgrass were present (Goodman 1973).

Bur buttercup is a persistent weed that has been difficult to control throughout the Intermountain West. Treatment methods can include digging, hoeing, or mechanically removing bur buttercup plants prior to flower formation (Donaldson and Mazet 2010). Herbicides such as 2,4-D, Ally®, Banvel® + 2,4-D, Finale®, Liberty®, Roundup®, and Plateau®, as well as burning, can be useful control methods (Utah State University Cooperative Extension 2012, BASF Corporation, Research Triangle Park, NC).

Juniper mastication is a common technique used throughout the United States to reduce woodland expansion and increase understory biodiversity. Scattering slash piles evenly can reduce soil disturbance, and conserve nutrient and water resources (Brockway et al. 2002). Fire is another method used to rid a landscape of junipers and convert a landscape back to grasslands; however, it may take several rounds of fire to establish the desired plant community (Ashley and Rasmussen 2005).

Management Techniques for Sagebrush Habitats

Several methods have been proposed to counteract the threat of wildfires and spread of invasive species. These methods often integrate the same biological, chemical, and mechanical processes, which have been implicated in the degradation and loss of sagebrush landscapes (Leopold 1948). Land managers have used several methods to mitigate threats to sage-grouse and sagebrush habitats. Several scientists recommend that managers avoid burning Wyoming big sagebrush (*A. tridentata* ssp. *wyomingensis*) to enhance sage-grouse habitat, but rather implement carefully planned treatments that maintain sagebrush (Beck et al. 2009).

To reduce the threat of wildfires eradicating vast expanses of important sagebrush habitats, wildlife managers have advocated the use of greenstriping. Greenstrips generally consist of long narrow pieces of land that have been mechanically and chemically treated, and seeded with plants that are less prone to spreading fire. By creating a seedbed for fire retardant vegetation and seeding these strips, fire is less likely to spread across critical habitat.

Mastication has been used to reduce fuels components, such as woody vegetation, like pinyon pine and juniper. Owen et al. (2009) recommended mastication over slash pile burning because of the minimal disturbance to soils. This treatment tends to lower soil temperatures and raise soil moisture because of the insulating properties of the mulch left in place. In comparison, methods such as slash burning may degrade soil properties and lower plant community richness. Owen et al. (2009) reported that plots with tree mastication had higher plant cover, water availability, and species richness than untreated plots or pile burns. However, cheatgrass presence increased after tree mastication (Owen et al. 2009).

Chain harrowing is commonly used in the greenstripping process to prepare the seedbed and decrease the spread of wildfire (Pyke and Pellant 2002). The chain harrowing is accomplished by using Ely chains. Ely chains are long anchor chains with railroad iron ties attached within each link. Ely chaining can reduce the amount of sagebrush from greater than 20% to less than 5% cover (Summers 2005). Cain (1972) reported that when 70-85% of big sagebrush plants were removed, the native understory browse, grasses, and forbs increased. This method of chaining is beneficial for reducing shrubs while leaving soils intact for future plantings.

In rangeland treatments, herbicides are commonly used to reduce competition for seeding in areas where invasive species, such as cheatgrass, are a concern (Pellant 1996). Plateau® (Ammonium salt of imazapic (±)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-methyl-3-pyridinecarboxylicacid) is a common herbicide used in agricultural and rangeland settings to control invasive species, such as cheatgrass, bur buttercup, halogeton, and annual mustards (BASF Chemical Company 2008). This herbicide is a rain-fast substance, which controls grasses and broadleaf weeds and vine species. It accumulates in the meristematic region of plants and proceeds to kill susceptible plants within a few weeks. Most native forbs, grasses, and shrubs are tolerant of the herbicide.

Eddington (2006) reported that Plateau® reduced cheatgrass to less than 4% for 2 years following the treatment in southeastern Utah. During this experiment, sagebrush seedstalks were reduced the first year after treatment, but recovered during the second year. Sheley et al. (2007) reported that medusahead was greatly reduced on a study area in Utah after a single application of the herbicide. Plateau® also reduced leafy spurge (*Euphorbia esula*) while increasing native forb cover in experimental trials conducted in eastern Idaho (Seefeldt et al. 2007).

Landscapes that become patchy due to agriculture, energy development, juniper encroachment, and invasive plant species may exhibit limited regions of high quality sagebrush, which provide important seasonal habitats. Land throughout the sage-grouse range will continue to be affected by anthropogenic events; therefore, protecting these habitats as a basis for future restoration may be important to conserving sagebrush obligate species.

Forage Kochia

Managers have sought to use surrogate species that would both outcompete invasive species and provide an ecological bridge to facilitate the restoration of native species (Buman et al. 1988, Taskey et al. 1989). Crested wheatgrass has long been used in rangeland reseedings in sagebrush ecosystems because of its ability to compete with cheatgrass and provide early season grazing (Francis and Pyke 1996, Rummell 1946). However, once a site is seeded with crested wheatgrass, the conversion is largely considered permanent (Marlette and Anderson 1986). Forage kochia, a semi-shrub, has been suggested as another alternative plant to use in rangeland restoration projects. This plant was initially brought into the U. S. to compete with halogeton (Tilley et al. 2006). Forage kochia was introduced to the US as P.I.314 from Stavapol Botanical Gardens, USSR in May 1966. It is highly preferred on rangelands due to its forage production, quality, palatability, and competition with annuals (Stevens et al. 1985). Forage kochia has a large deep taproot and grows readily in basic soils. It has been found to establish itself on a variety of shrublands, mainly because it is highly salt and drought tolerant, and can endure extreme temperatures. Forage kochia is categorized as a non-invasive plant (Clements et al. 1997).

Forage kochia can compete with invasive annuals and was found to have 10-fold higher moisture content than cheatgrass and crested wheatgrass in late August (Pellant 1994). Although forage kochia can burn when enough ignitable fuels are present in the surrounding area, the high moisture content of forage kochia has made it useful in greenstrips to reduce the spread of wild fires. There have been several cases in Utah and Idaho in which flames from wildfires have reached forage kochia greenstrips and subsequently fire was 80-100% extinguished (Harrison et al. 2002).

Forage kochia has a high protein content, over 13% in the summer months. After the initial plants are established, a consistent yearly seed crop is produced (Stevens et al. 1985). In a study that compared cattle fed in a dry-lot versus cattle that consumed forage kochia in the fall and winter, backfat increased in year 1 for the cattle consuming forage kochia, and it was cheaper than feeding alfalfa hay in a drought (Waldron et al. 2006). Due to its structure and nutrients, forage kochia may have the potential to be a desirable plant for forage material and cover to a number of species, such as sage-grouse.

RESEARCH PURPOSE AND OBJECTIVES

Box Elder County provides habitat for one of the four largest sage-grouse populations in Utah (Beck et al. 2003). The Grouse Creek Watershed, located in western Box Elder County in northwestern Utah, exhibits a landscape that is highly fragmented. The region is at increased risk of wildfire and invasive species, as identified by the West Box Elder Adaptive Resource Management (BARM) Local Working Group (2007). Of particular concern is the impact of wildfires on sage-grouse winter habitats in Box Elder County (BARM 2007).

Badger Flat, located just south of the town of Grouse Creek, is a relatively flat region of 4,800 ha ranging between 1500-1800 m elevation that has been identified as important winter habitat for sage-grouse (Thacker 2010). Agriculture, roads, energy development, invasive species, and juniper expansion in the surrounding area have decreased sage-grouse occupancy of the site over time. The contemporary environmental conditions of Badger Flat may provide managers with insights about how sage-grouse may use similar degraded habitats in other areas of the western U.S. affected by fragmentation and climate change, in addition to how these degraded sites may be best managed to protect residual habitats.

Because of Badger Flat's importance as sage-grouse winter habitat and its high wildfire risk, the BARM local working group has identified the use of greenstripping with forage kochia as a priority conservation strategy (BARM 2007). Although greenstripping through the planting of forage kochia has been successfully used to retard the spread of wildfires, little is known about the impact of greenstripping on sage-grouse habitat use and vital rates.

The purpose of my research was to evaluate the response of sage-grouse and vegetation to greenstripping with forage kochia. Because Badger Flat and the extended Grouse Creek Watershed exhibit a high degree of habitat fragmentation as an artifact of long-term anthropogenic presence and may forecast ecological conditions of sagebrush habitats across the western U.S. based on anthropogenic factors and climate change, I was interested in describing how sage-grouse might use these impacted habitats.

My specific research questions were:

1. What effect will greenstripping through chain harrowing, juniper mastication, seeding forage kochia, and the application of Plateau herbicide have on vegetation composition within sagebrush communities?

2. How will the above treatments and observed changes in vegetation affect sage-grouse habitat use patterns and survival rates?

3. What are the structural vegetation metrics of nest and brood sites selected by sage-grouse, and do these differ from random sites?

4. Do sage-grouse use forage kochia as cover and/or food?

5. How do anthropogenic structures and seasonal variability of temperatures and precipitation affect sage-grouse habitat-use in highly fragmented, degraded habitats?

LITERATURE CITED

Allen, E., R. S. Nowak, and J. C. Chambers. 2008. Effects of a spring prescribed burn on the soil seed bank in sagebrush steppe exhibiting pinyon-juniper expansion. Western North American Naturalist 68:265-277.

Ashley, R. J., and G. A. Rasmussen. 2005. Managing native invasive juniper species using fire. Weed Technology of America 19:517-522.

BARM (West Box Elder Adaptive Resource Management Local Working Group). 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. Unpublished Report. Salt Lake City, Utah, USA.

BASF Chemical Company. 2008. BASF Chemical Corporation. Plateau Herbicide Label. www.basf.com. Accessed 2011 February 21.

Bauer, J., and P. J. Weisberg. 2009. Fire history of a central Nevada pinyon-juniper woodland. Canadian Journal of Forest Research 39:1589-1599.

Baxter, R. J., K. D. Bunnell, J. T. Flinders, and D. L. Mitchell. 2007. Impacts of predation on greater sage-grouse in Strawberry Valley, Utah. Transactions of the 72nd North American Wildlife and Natural Resources Conference 72:258-269.

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, and J. W. Connelly. 2009. Recovery of Greater sage-grouse habitat features in Wyoming big sagebrush following prescribed fire. Restoration Ecology 17:393-403.

Beckstead, J., B. M. Connolly, M. B. Huck, L. E. Stret, and S. E. Meyer. 2010. Cheatgrass facilitates spillover of a seed bank pathogen onto native grass species. Journal of Ecology 98:168-177.

Beckstead, J., S. E. Meyer, C. J. Molder, and C. Smith. 2007. A race for survival: can *Bromus tectorum* seeds escape *Pyrenophora semeniperda*-caused mortality by germinating quickly? Annals of Botany 99:907–914.

Belnap, J., S. Phillips, S. Sherrod, and A. Moldenke. 2005. Soil biota can change after exotic plant invasion: does this affect ecosystem processes? Ecology 86:3007-3017.

Blomberg, E. J., J. S. Sedinger, D. V. Nonne, and M. T. Atamian. 2012. Seasonal reproductive costs contribute to reduced survival of female greater sage-grouse. Journal of Avian Biology 43:1-10.

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.

Bradley, B., and J. F. Mustard. 2006. Characterizing the landscape dynamics of an invasive plant and risk of invasion using remote sensing. Ecological Applications 16:1132-1147.

Briske, D. D., B. T. Bestelmeyer, T. K. Stringham, and P. L. Shaver. 2008. Recommendations for the development of resilience-based state-and-transition models. Rangeland Ecology Management 61:359-367.

Brockway, D. G., Gatewood, R. G., and R. B. Paris. 2002. Restoring grassland savannas from degraded pinyon-juniper woodlands: effects of mechanical overstory reduction and slash treatment alternatives. Journal of Environmental Management 6:179-197.

Buchanan, B. A., K. T. Harper, and N. C. Frischknecht. 1978. Allelopathic effects of bur buttercup tissue on germination and growth of various grasses and forbs in vitro and in soil. Great Basin Naturalist 38:90-96.

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

Buman, R. A., S. B. Monsen, and R. H. Abernathy. 1988. Seedling competition between mountain rye, 'Hycrest' crested wheatgrass, and downy brome. Journal of Range Management 41:30-34.

Burkhardt, J. W., and E. W. Tisdale. 1969. Natural and successional status of western juniper vegetation in Idaho. Journal of Range Management 22:264-270.

Burkhardt, J. W., and E. W. Tisdale. 1976. Causes of juniper invasion in southwestern Idaho. Ecology 57: 472-484.

Cain, D. R. 1972. The Ely Chain. Bureau of Land Management. Ely, Nevada.

Chambers, J. C., and M. Pellant. 2008. Climate change impacts on northwestern and intermountain United States rangelands. Rangelands 30:29-33.

Christensen, J. H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R. K. Kolli, W.-T. Kwon, R. Laprise, V. Magaña Rueda, L. Mearns, C. G. Menéndez, J. Räisänen, A. Rinke, A. Sarr, and P. Whetton. 2007: Regional Climate Projections *in* S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller, editors. Climate change 2007: the physical science basis.

Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, New York, USA.

Clements, C. D., K. J. Gray, and J. A. Young. 1997. Forage kochia: to seed or not to seed. Rangelands 19:29-31.

Coates, P. S. 2007. Greater sage-grouse (Centrocercus urophasianus) nest predation and incubation behavior. Dissertation, Idaho State University, Pocatello, USA.

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

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

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

Connelly, J. W., S. T. Knick, C. E. Braun, W. L. Baker, E. A. Beever, T. Christiansen, K. E. Doherty, E. O. Garton, S. E. Hanser, D. H. Johnson, M. Leu, R. F. Miller, D. E. Naugle, S. J. Oyler-McCance, D. A. Pyke, K. P. Reese, M. A. Schroeder, S. J. Stiver, B. L. Walker, and M. J. Wisdom. 2011. Pages 549-563 *in* S. T. Knick and J. W. Connelly, editors. Conservation of Greater Sage-Grouse: a synthesis of current trends and future management. Greater Sage-Grouse: ecology and conservation of a landscape species and habitats. University of California Press, Berkeley, USA.

Crawford, J. A., and R. S. Lutz. 1985. Sage grouse population trends in Oregon, 1941-1983. The Murrelet 66: 69-74.

Cronin, E. 1965. Ecological and physiological factors influencing chemical control of *Halogeton glomeratus*. U.S. Dept. of Agriculture, Washington.

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. 2009. Greater sage-grouse ecology, chick survival, and population dynamics, Parker Mountain, Utah. Dissertation, Utah State University, Logan, USA.

Dahlgren, D. K., T. A. Messmer, and D. N. Koons. 2010. Achieving better estimates of Greater sage-grouse chick survival in Utah. Journal of Wildlife Management 74:1286-1294.

Dalgleish, H. J., D. N. Koons, and P. B. Adler. 2010. Can life-history trais predict the response of forb populations to changes in climate variability? Journal of Ecology 98:209-217.

Dalgleish, H. J., D. N. Koons, M. Hooten, C. Moffet, and P. B. Adler. 2011. Climate influences the demography of three dominant sagebrush steppe plants. Ecology 92:75-85.

DeBano, L. F., Neary, D. G., and P. F. Ffolliott. 1998. Fire’s effects of ecosystems. John Wiley and Sons, Hoboken, New Jersey, USA.

Diamond, J. C., A. Call, and N. Devoe. 2009. Effects of targeted cattle grazing on fire behavior of cheatgrass-dominated rangeland in the northern Great Basin, USA. International Journal of Wildland Fire 18: 944-950.

Dittberner, P. L., and M. R. Olson. 1983. The plant network (PIN) database: Colorado, Montana, North Dakota, Utah, and Wyoming. FWS/OBS-83/86. U.S. Department of the Interior, Fish and Wildlife Service. Washington, D. C., USA.

Donaldson, S., and W. Mazet. 2010. A Northern Nevada homeowner's guide to identifying and managing but buttercup. Fact Sheet 10-20. University of Nevada Cooperative Extension. Reno, USA.

Earnst, S., H. L. Newsome, W. L. LaFramboise, and N. LaFramboise. 2009. Avian response to wildfire in Interior Columbia Basin Shrubsteppe. The Condor 111:370-376.

Eddington, D. B. 2006. Effects of cheatgrass control on Wyoming big sagebrush in Southeastern Utah. Thesis, Brigham Young University, Provo, Utah, USA.

Erickson, L. C., E. W. Tisdale, H. L. Morton, and G. Zappettini. 1951. Halogeton, intermountain range menace, University of Idaho Agricultural Experiment Station and Forest Wildlife and Range Experiment Station cooperating, Moscow, Idaho, USA.

Fedy, B. C., and K. E. Doherty. 2011. Population cycles are highly correlated over long time series and large spatial scales in two unrelated species: greater sage-grouse and cottontail rabbits. Oecologia 165: 915-924.

Francis, M. G., and D. A. Pyke. 1996. Crested wheatgrass-cheatgrass seedling competition in a mixed-density design. Journal of Range Management 49:432-438.

Frischknecht, N. 1968. Factors influencing halogeton invasion of crested wheatgrass range. Journal of Range Management 21:8-12.

Gautier, C. R. 1983. Sedimentation in burned cheatgrass watersheds: is emergency revegetation justified? Water Resources Bulletin 19:793-802.

Gedney, D. R., Azuma, D. L., Bolsinger, C. L., and N. McKay. 1999. Western juniper in Oregon. General Technical Report PNW-GTR-464, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, Oregon, USA.

Goodman, P. 1973. Physiological and ecotypic adaptations of plants to salt desert conditions in Utah. The Journal of Ecology 61:473-494.

Gregg, M. A., and J. A. Crawford. 2009. Survival of greater sage-grouse chicks and broods in the Northern Great Basin. Journal of Wildlife Management 73:904-913.

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.

Hagen, C. A. 2011. Predation on Greater Sage-Grouse: facts, process, and effects. Pp. 95-110 *in* S. T. Knick and J. W. Connelly, editors. Greater Sage-Grouse: ecology and conservation of a landscape species and its habitats. Studies in Avian Biology (vol. 38), University of California Press, Berkeley, USA.

Halford, D. 1981. Repopulation and food habits of *Peromyscus maniculatus* on a burned sagebrush desert in southeastern Idaho. Northwest Science 55:44-49.

Hansen, A. J., R. Rasker, B. Maxwell, J. J. Rotella, J. D. Johnson, A. W. Parmenter, U. Langner, W. B. Cohen, R. L. Lawrence, and M. P. V. Kraska. 2002. Ecological causes and consequences of demographic change in the new west. BioScience 52:151-162.

Harrison, R. D., B. L. Waldron, K. B. Jensen, R. Page, T. A. Monaco, W. H. Horton, and A. J. Palazzo. 2002. Forage kochia helps fight range fires. Rangelands 24:3-7.

Haubensak, K., C. D'Antonio, and D. Wixon. 2009. Effects of fire and environmental variables on plant structure and composition in grazed salt desert shrublands of the Great Basin (USA). Journal of arid environments 73:643.

Hitchcock, C. L., and A. Cronquist. 1964. Vascular plants of the Pacific Northwest. Part 2: Salicaceae to Saxifragaceae. University of Washington Press, Seattle, USA.

Holl, R. 1954. A study of the ecology and control of halogeton in Idaho: Part II. Journal of Range Management 7:243-244.

Inouye, D. W. 2008. Effects of climate change on phenology, frost damage, and floral abundance of montane wildflowers. Ecology 89:353-362.

James, L. F. 1971. Oxalate toxicosis. Clinical Toxicology 5:239-251.

James, L. F., and J. E. Butcher. 1972. Halogeton poisoning of sheep: effect of high level oxalate intake. Journal of Animal Science 35:1233-1238.

Jessop, B., and V. Anderson. 2007. Cheatgrass invasion in salt desert shrublands: Benefits of postfire reclamation. Rangeland Ecology Management 60:235-243.

Kauffman, J. B., and W. C. Krueger. 1984. Livestock impacts on riparian ecosystems and streamside management…a review. Journal of Range Management 37:430-438.

Keane, R. E., J. K. Agee, P. Fel, J. E. Keeley, C. Key, S. G. Kitchen, R. Miller, and L. A. Schulte. 2008. Ecological effects of large fires on US landscapes: benefit or catastrophe? International Journal of Wildland Fire 17:696-712.

Keeley, J. E. 2006. Fire management impacts on invasive plants in the western United States. Conservation Biology 20:375-384.

Knick, S. T., and J. W. Connelly. 2011. Greater sage-grouse: ecology and conservation of a landscape species and its habitats. University of California Press, Berkeley, USA.

Knick, S. T., A. L. Holmes, and R. F. Miller. 2005. The role of fire in structuring sagebrush habitats and bird communities. Studies in Avian Biology 30:1-13.

Knick, S. T., and J. T. Rotenberry. 1997. Landscape characteristics of disturbed shrubsteppe habitats in southwestern Idaho (U.S.A.). Landscape Ecology 12:287-297.

Lacey, J. R., C. B. Marlow, and J. R. Lane. 1989. Influence of spotted knapweed (*Centaurea maculosa*) on surface runoff and sediment yield. Weed Technology 3:627-631.

Leopold, A. 1948. A Sand County almanac. Oxford University Press. New York, New York, USA.

Mack, R. N., and W. M. Lonsdale. 2002. Eradicating invasive plants: hard-won lessons for islands. Pages 164-172 *in* C. R. Veitch and M. N. Clout, editors. Turning the tide: the eradication of invasive species. IUCN SSC Invasive Species Specialist Group. IUCN, Gland, Switzerland and Cambridge, United Kingdom.

Marlette, G. M., and J. E. Anderson. 1986. Seed banks and propagule dispersal in crested-wheatgrass stands. Journal of Applied Ecology 23:161-175.

Miller, R. F., and J. A. Rose. 1999. Fire history and Western juniper encroachment in sagebrush steppe. Journal of Range Management 52:550-559.

Miller, R. F., and R. T. Tausch. 2001. The role of fire in juniper and pinyon woodlands: a descriptive analysis. Pages 15-30 i*n* K.E.M. Gallery and T.P. Wilson, editors.

Proc. Invasive Species Workshop: The Role of Fire in the Control and Spread of Invasive Species. Miscellaneous Publication No.11, Tall Timbers Research Station, Tallahassee, Florida, USA.

Monaco, T. A., B. L. Waldron, R. L. Newhall, and W. H. Horton. 2003. Re-establishing perennial vegetation in cheatgrass monocultures. Rangelands 25:26-29.

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.

Nachman, R. J., and J. D. Olsen. 1983. Ranunculin: A toxic constituent of the poisonous plant bur buttercup (*Ceratocephalus testiculatus*). Journal of Agricultural and Food Chemistry 31:1360-1362.

Olsen, J. D., T. E. Anderson, J. C. Murphy, and G. Madsen. 1983. Bur buttercup poisoning of sheep. Journal of the American Veterinary Medical Association 183:538-543.

Owen, S. M., C. H. Sieg, C. A. Gehring, and M. A. Bowker. 2009. Above- and belowground responses to tree thinning depend on the treatment of tree debris. Forest Ecology and Management 259:71-80.

Parmesan, C. 2006. Ecological and evolutionary responses to recent climate change. Annual Review of Ecology, Evolution, and Systematics 37:637-669.

Patterson, R. L. 1952. The sage grouse in Wyoming. Wyoming Game and Fish Comm. Sage Books, Inc., Denver, Colorado, USA.

Pavek, D. S. 1992. *Halogeton glomeratus*. Fire effects information system. USDA Forest Service, Rocky Mountain Research Station. Fort Collins, Colorado, USA.

Pellant, M. 1994. History and applications of the intermountain greenstripping program. Pages 63-68. *in* S. B. Monsen and S. G. Kitchen, comps. Proceedings-symposium on ecology and management of annual rangelands. 18-21 May 1992. Boise, ID. General Technical Report INT-GTR-313. USDA Forest Service, Intermountain Research Station, Ogden, Utah, USA.

Pellant M. 1996. Cheatgrass: the invader that won the West. Interior Columbia Basin Ecosystem Management Project. Bureau of Land Management, Idaho State Office, Boise, Idaho, USA.

Pemberton, R. W. 1986. The distribution of halogeton in North America. Journal of Range Management 39:281-282.

Pierson, R. K. 1952. Halogeton control plans of the Bureau of Land Management. Western Weed Control Conference, Reno, Nevada, USA.

Pierson, F. B., C. J. Williams, S. P. Hardegree, M. A. Weltz, J. J. Stone, and P. E. Clark. 2011. Fire, plant invasions, and erosion events on western rangelands. Rangeland Ecology and Management 64:439-449.

Provencher, L, K. Blankenship, J. Smith, J. Campbell, and M. Polly. 2009. Comparing locally derived and LANDFIRE geo-layers in the Great Basin, USA. Fire Ecology 5:126-132.

Pyke, D. A. 2011. Restoring and rehabilitating sagebrush habitats. Studies in Avian Biology 38:531–548.

Pyke, D. A., and M. Pellant. 2002. Strategic plan for the coordinated intermountain restoration project: U.S. Geological Survey, Biological Resources Discipline, Information and Technology Report, USGS/BRD/ITR-2002-0011, 14 p.

Quigley, T. M., and S. J. Arbelbide. 1997. An assessment of ecosystem components in the interior Columbia Basin and portions of the Klamath and Great Basins. General Technical Report. PNW-GTR-405. Portland, OR: USDA Forest Service, Pacific NW Research Stations. 4 Vol.

Riegel, G. M., R. F. Miller, C. N. Skinner, S. E. Smith. 2006. Northeastern plateaus bioregion. Pages 225-263 *in* N. Sugihara, J. W. Van Wagtendonk, K. E. Shaffer, J. Fites-Kaufman, and A. E. Thode. Fire in California ecosystems. University of California Press, Berkeley, USA.

Robertson, J. H., D. L. Neal, K. R. McAdams, and P. T. Tueller. 1970. Changes in crested wheatgrass ranges under different grazing treatments. Journal of Range Management 23:27-34.

Robocker, W. C., M. C. Williams, R. A. Evans, and P. J. Torell. 1969. Effects of age, burial, and region on germination and viability of halogeton seed. Weed Science 17:63-65.

Rolstad, J. 1991. Consequences of forest fragmentation for the dynamics of bird populations: conceptual issues and the evidence. Biological Journal of the Linnean Society 42:149-163.

Roundy, B. A. 1987. Seedbed salinity and the establishment of range plants. Pages 68-81 *in* G. W. Frasier and R. A. Evans, editors. Proceedings of symposium-seed and seedbed ecology of rangeland plants. USDA, Agr. Res. Erv.; Nat. Tech. Inform. Serv. Springfield, Virginia, USA.

Rummell, R. S. 1946. Some effects of competition from cheatgrass brome on crested wheatgrass and bluestem wheatgrass. Ecology 27:159-167.

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

Schroeder, M. A., J. R. Young, and C. E. Braun. 1999. Sage grouse (*Centrocercus urophasianus*). Pages 1-28 *in* A. Poole and F. Gill, editors. The birds of North America No. 425. The Birds of North America, Inc., Philadelphia, Pennsylvania, USA.

Schupp, E. W. 2000. Process, scale, and wildland repair: a framework. Ecology 81:3264-3265.

Scott, J., K.R. Merrill, V.J. Anderson, and S.E. Meyer. 2010. Local population differentiation in Bromus tectorum L. in relation to habitat-specific selection regimes. Evolutionary Ecology 24:1061-1080.

Seefeldt, S., J. Taylor, and S. Van Vleet. 2007. Reducing *Euphorbia esula* with a combination of sheep grazing and imazapic. Journal of Arid Environments 69:432-440.

Sheley, R. L., M. F. Carpinelli, and K. J. Reever Morgan. 2007. Effects of imazapic on target and nontarget vegetation during revegetation. Weed Technology 21:1071-1081.

Stephens, S. E., D. N. Koons, J. J. Rotella, and D. W. Willey. 2004. Effects of habitat fragmentation on avian nesting success: a review of the evidence at multiple spatial scales. Biological Conservation 115:101-110.

Stevens, R., K. R. Jorgensen, E. D. McArthur, and J. N. Davis. 1985. 'Immigrant' Forage Kochia. Rangelands 7:22-23.

Stiver, S. J., A. D. Apa, J. R. Bohne, S. D. Bunnell, P. A. Deibert, S. C. Gardner, M. A. Hilliard, C. W. McCarthy, and M. A. Schroeder. 2006. Greater sage-grouse comprehensive conservation strategy. Western Association of Fish and Wildlife Agencies, Cheyenne, Wyoming, USA.

Stoddart, L. A., H. Clegg, B. S. Markham, and G. Stewart. 1951. The halogeton problem on Utah's ranges. Journal of Range Management 4:223-227.

Summers, D. D. 2005. Vegetation response of a Wyoming big sagebrush community to six mechanical treatments in Rich County, Utah. Thesis, Brigham Young University, Provo, Utah, USA.

Taskey, R.D., C.L. Curtis, and J. Stone. 1989. Wildfire, ryegrass seeding, and watershed rehabilitation. Pages 149-161 *in* N.H. Berg, technical coordinator. Proceedings of the symposium on fire and watershed management, October 26-28, 1998, Sacramento, California. General Technical Report PSW-GTR-109. U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, California, USA.

Taylor, R. L., B. L. Walker, D. E. Naugle, and L. S. Mills. 2012. Managing multiple vital rates to maximize greater sage-grouse population growth. Journal of Wildlife Management 76:336-347.

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

Tilley, D. J., D. Ogle, L. St John, B. L. Waldron, and R. D. Harrison. 2006. Plant guide: forage kochia. USDA-Natural Resources Conservation Service – Plant Materials Program.

Tisdale, E. and G. Zappetini. 1953. Halogeton studies on Idaho ranges. Journal of Range Management 6:225-236.

U.S. Department of the Interior. 2010. Federal Register Notice. US Fish and Wildlife Service, Washington, D. C., USA.

Utah State University Cooperative Extension. 1997. Utah State University Cooperative Extension. www.utahcbcp.org. Accessed 2011 March 1.

Utah State University Cooperative Extension. 2012. Range Plants of Utah: Bur buttercup. Extension.usu.edu/rangeplants/htm/bur-buttercup/. Accessed 2012 October 12.

Vaitkus, M. R., and L. E. Eddleman. 1991. Tree site and understory phytomass production in a western juniper woodland. The Great Basin Naturalist 51:236-243.

Valéry, L., H. Fritz, J. Lefeuvre, and D. Simberloff. 2008. In search of a real definition of the biological invasion phenomenon itself. Biological Invasions 10:1345-1351.

Vander Haegen, M. W., F. C. Dobler, and D. J. Pierce. 2000. Shrubsteppe bird response to habitat and landscape variables in Eastern Washington, U.S.A. Conservation Biology 14:1145-1160.

Vitousek, P. 1990. Biological invasions and ecosystem processes: Towards an integration of population biology and ecosystem studies. Oikos 57:7-13.

Wagner, F. H., editor. 2009. Climate warming in western North America: evidence and environmental effects. University of Utah Press, Salt Lake City, Utah, USA.

Waldron, B. L., D. R. Zobell, K. C. Olson, K. B. Jensen, and D. L. Snyder. 2006. Stockpiled forage kochia to maintain beef cows during winter. Rangeland Ecology Management 59:275-284.

Walker, B. L., D. E. Naugle, K. E. Doherty, and T. E. Cornish. 2007. West Nile virus and greater sage-grouse: estimating infection rate in a wild bird population. Avian Diseases 51:691-696.

West, N. E. 1999. Juniper-pinyon savannas and woodlands of Western North America. Pages 288-308 *in* R.C. Anderson, J.S. Fralish, and J.M. Baskin, editors. Savannas, barrens, and rock outcrop plant communities of North America. Cambridge University Press, London, United Kingdom.

West 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. Unpublished Report. Salt Lake City, Utah, USA.

Yensen, D.. 1982. A grazing history of southwestern Idaho with emphasis on the Birds of Prey Study Area, Rev. U.S. Dept. of the Interior Bureau of Land Management, Boise, Idaho, USA.

Yensen, E., D. L. Quinney, K. Johnson, K. Timmerman, and K. Steenhof. 1992. Fire, vegetation changes, and population fluctuations of Townsend's ground squirrels. American Midland Naturalist 128:299-312.

Young, J., and R. Evans. 1978. Population dynamics after wildfires in sagebrush grasslands. Journal of Range Management 31:283-289.

Young, J. A., E. Martens, and N. E. West. 1992. Germination of bur buttercup seeds. Journal of Range Management 45:358-362.

Young, J. A., P. C. Martinelli, R. E. Eckert, Jr., and R. A. Evans. 1999. Halogeton. Miscellaneous Publication 1553. Agricultural Research Service, USDA, Washington, D. C.

Ziegenhagen, L. L. 2003. Shrub reestablishment following fire in the mountain big sagebrush (Artemisia tridentata ssp. vaseyana) alliance. Thesis, Oregon State University, Corvallis, USA.

CHAPTER 2

GREATER SAGE-GROUSE VITAL RATES AND HABITAT USE PATTERNS IN FRAGMENTED LANDSCAPES

ABSTRACT

Greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) seasonal habitat use may differ regionally and locally as an artifact of historical and contemporary land use patterns. Protection and rehabilitation of important seasonal habitats has been identified as a priority conservation strategy for maintaining range-wide populations. One of Utah's largest sage-grouse populations occupies sagebrush (*Artemisia* spp.) habitats in Box Elder County, northwestern Utah. These habitats are considered vulnerable to fragmentation and increased frequency of wildfire because of invasive plant species. Some of the landscape exhibits environmental conditions predicted under various Great Basin climate change scenarios. From 2010-2012, I monitored 53 sage-grouse in the Badger Flat area of the Grouse Creek Watershed, in Box Elder County, to determine how the species has adapted to local ecological and anthropogenic factors that could be further exacerbated by climate change. In addition to measuring structural habitat characteristics, I evaluated effective grass height as a metric of sage-grouse habitat selection in regions impacted by invasive annual vegetation. Sage-grouse nest success and adult survival rates were lower than previously reported in the region and range-wide. Nest predation was positively correlated with shorter distances to roads. Sage-grouse in this study preferred shorter, denser shrub cover in the winter, exhibiting a potential preference for black sagebrush (*A. nova*). These shrubs were exposed above

snow levels during both wet and dry winters. Seasonal movements suggested a local adaptation to fragmented habitats and weather patterns. Lowered overall productivity during may increase sage-grouse extirpation risks as an artifact of fragmentation and climate change.

INTRODUCTION

Greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) currently occupy less than 56% of their historical range (Schroeder et al. 2004), which encompassed 14 U.S. states and 3 Canadian provinces (Knick and Connelly 2011). Sage-grouse are a sagebrush (*Artemisia* spp.) obligate species that require large contiguous patches of sagebrush across the landscape to complete their life cycle (Connelly et al. 2011). Population declines have been largely attributed to the loss and fragmentation of sagebrush habitats across western North America (Connelly and Braun 1997, Leonard et al. 2000, U.S. Department of the Interior 2010).

Sage-grouse population trends largely reflect variations in annual and long-term productivity, survival, and recruitment (Crawford et al. 2004, Connelly et al. 2011). Nest success, as well as adult hen and chick survival, have been identified as major parameters affecting population growth (Crawford et al. 2004, Dahlgren et al. 2010, Taylor et al. 2012). These metrics are typically influenced by habitat structure (Aldridge and Boyce 2007).

Habitat characteristics, such as percent grasses, forbs, and shrubs are typically used to assess sage-grouse habitat quality. Previous studies have also used effective grass height as a metric of vertical obstruction and habitat quality (Duebbert and Lokemoen

1976, Dechant et al. 2002). Effective grass height may be a more useful metric of grass cover in landscapes that are grazed or have grasses with various heights of culms and basal or grazed leaves.

In degraded landscapes, although vegetation may approximate range-wide habitat guidelines (Connelly et al. 2000), sage-grouse vital rates (i.e., nest and brood success, and survival rates) may be impacted by natural and anthropogenic fragmentation (Beck et al. 2006, Knerr 2007, Dahlgren et al. 2010, Thacker et al. 2011). These fragmented habitats may be at increased risk of degradation by invasive species, and therefore are more susceptible to wildfires (Brooks et al. 2004, Pyke 2011).

Wildfires could result in catastrophic habitat loss in areas, such as sage-grouse Management Zone IV, which encompasses the northern part of the Great Basin (Stiver et al. 2006). Wildfire risks could be further escalated by potential changes in climate, which may result in an increased frequency of dry winters (Christensen et al. 2007, Wagner 2009). Increased dry winters and increased annual temperatures may lead to a higher proportion of invasive species and dry fuels (Chambers and Pellant 2008, Inouye 2008, Dalgleish et al. 2010, Dalgleish et al. 2011).

Climate models project an increase in average monthly temperatures and a decrease in winter snowfall throughout the Rocky Mountain and Great Basin regions (Mote 2009). Although some flora and fauna can acclimate to changes in climate, other species may not be as successful in adapting to permanent environmental changes (Moore and Huntington 2008, Walsh 2008, Barber et al. 2009). Fragmentation is also likely to increase throughout North America, and continuous tracts of sagebrush steppe will be reduced as anthropogenic development expands (Knick and Connelly 2011). Better information is needed regarding sagebrush obligate species use of impacted habitats and effects of these habitats on vitals rates.

Sage-grouse hens may move farther distances to nest in fragmented landscapes (Schroeder et al. 1999, Beck et al. 2006, Knerr 2007). Extensive seasonal movements may translate into lower success rates and reproductive output, and ultimately reduced recruitment (Beck et al. 2006). To mitigate the potential effects of climate change on sage-grouse in fragmented habitats, managers will need more information regarding sage-grouse abilities to adapt to changing environmental conditions and the effect of these conditions on vital rates.

Estimated sage-grouse nest success rates reported range-wide vary from 12% to 86% (Trueblood 1954, Gregg 1991, Heath et al. 1998, Connelly et al. 2011). Most nests are lost as a result of predation (Hagen 2011). Although nest predation or predation of adults has not been directly implicated as influencing range-wide sage-grouse population declines (Taylor et al. 2012), predation rates may increase in response to habitat fragmentation and negatively affect local sage-grouse populations (Gregg et al. 1994). If sage-grouse choose nesting sites in fragmented and degraded habitats that are obscured to visual predators (birds), but are more exposed to olfactory predators, nest success could be further compromised (Conover et al. 2010).

Coyotes (*Canis latrans*) and red foxes (*Vulpes vulpes*) prefer to move along roads and other anthropogenic structures, which decreases their energy expenditure compared to regions with high snow cover (Crête and Larivière 2003, McDonald et al. 2008). Coyote and red fox activity may vary based on their exposure to human activity (Sovada et al. 1995). When dense vegetation cover is present, coyotes have been known to use fencelines and washes (Bradley and Fagre 1988, Grinder and Krausman 2001). Badger (*Taxidea taxus*) presence has also been associated with linear disturbance, highways, open range, and agricultural land (Apps et al. 2002). Coyotes can reduce the impacts of other mesopredators on upland birds; therefore, managers should consider predator interactions when making decisions (Sovoda et al. 1995, Mezquida et al. 2006).

Sage-grouse hens may move farther distances to nest in fragmented landscapes with roads (Schroeder et al. 1999, Lyon and Anderson 2003, Beck et al. 2006, Knerr 2007). Extensive seasonal movements may translate into lower vital rates and ultimately reduced recruitment (Beck et al. 2006). Productivity and nest initiation rates by hens are lower when a road disturbance is near and higher when they are undisturbed (Lyon and Anderson 2003).

The Utah Division of Wildlife Resources (UDWR) reported that sage-grouse population trends in Utah parallel declines reported range wide (UDWR 2009). Occupied habitats range from high elevation plateaus exhibiting contiguous sagebrush communities to lower elevation areas dominated by natural and anthropogenic fragmented habitats that have been further degraded by invasive plants. Sage-grouse habitats in northwestern Utah exemplify the latter situation. However, this area contains one of the largest sage-grouse populations in the state (UDWR 2009).

Sage-grouse populations in western Box Elder County have been monitored since 1959 (UDWR 2009); and more detailed research of sage-grouse habitat and movement patterns began in 2002 in response to information requests from the West Box Elder County Adaptive Resource Management (BARM) sage-grouse local working group (BARM 2007). In western Box Elder County during 2005 and 2006, the overall nest success rate was 38% (Knerr 2007). Overall brood success rate was 44% and average juvenile recruitment rate was 24% (Knerr 2007). Although these vitals rates were within range-wide variation (Connelly et al. 2011), the habitat conditions in the area are believed to have deteriorated because of extended droughts and wildfires (BARM 2007, UDWR 2009). From 2000-2004 precipitation was below the 30-year average (BARM 2007). To mitigate the potential effects of extreme weather patterns on sage-grouse in fragmented habitats, managers will need more information regarding sage-grouse vital rates relative to corresponding adaptations to changing environmental conditions.

My objectives were to document adult, nesting, and brood-rearing habitat characteristics and survival rates in habitats that approximate environmental conditions predicted for the Great Basin. I also analyzed the effects of fragmentation caused by roads and utility poles upon sage-grouse vital rates. Finally, I determined the seasonal effect of annual variation in weather on sage-grouse populations.

STUDY AREA

My study area encompassed the western portion of Box Elder County in northwestern Utah, USA. The study site encompassed 120,100 ha of the Grouse Creek Watershed. It was bounded on the south side by Tom’s Cabin Road, the north side by the Idaho state line, the east side by the Grouse Creek Mountains, and the west side by the Nevada state line (Fig. 2-1). During the study, sage-grouse were largely confined to these boundaries. Badger Flat is a region in the south-central portion of the Grouse Creek Watershed. Badger Flat had been previously designated as important winter habitat for sage-grouse (BARM 2007, Thacker 2010). The sage-grouse population in western Box

Elder County is one of the six largest in Utah and is hunted on a permit-only basis (UDWR 2009).

Land ownership in this area consisted of a mosaic of public and private holdings. The U.S. Bureau of Land Management (BLM) and the Utah School and Institutional Trust Land Administration (SITLA) managed the public land, 41% and 5% respectively (Fig. 2-2). The primary land use is irrigated alfalfa (*Medicago sativa*) production and grazing by domestic cattle (*Bos tarus*). Grazing at Badger Flat occurred annually from March-April and October each year.

One weather station was assembled in late 2010 at a southern location and another was disassembled in 2010 at a more northern location within the Grouse Creek Watershed. Therefore, continuous weather data from one source is not available. However, information from the newer weather station was recorded during 2011 and 2012.

The study site was categorized by a sagebrush ecosystem with surrounding woodlands and interspersed meadows (BARM 2007). Habitat in the region is highly fragmented by roads, agriculture, and other anthropogenic structures. The region has limited contiguous patches of sagebrush, with invasive species interspersed throughout the region and large patches of woodlands dissecting sagebrush ecosystems. Elevations throughout the Grouse Creek Watershed ranged from 1500-2300 m.

Primary shrub species included Wyoming big sagebrush (*A. tridentata* ssp. *wyomingensis*), black sagebrush (*A. nova*), shadscale (*Atriplex confertifolia*), rabbitbrush (*Chrysothamnus* spp., *Ericameria* spp.), snowberry (*Symphoricarpos albus*), and Utah juniper (*Juniperus osteoperma*). Common grasses included Sandberg bluegrass (*Poa* *secunda*), Kentucky bluegrass (*Poa pratensis*), cheatgrass (*Bromus tectorum*), and wheatgrasses (*Agropyron* spp., *Elymus* spp.). Common forbs were blue-eyed mary (*Collinsia parviflora*), wild onion (*Allium acuminatum*), phlox (*Phlox* spp.), astragalus (*Astragalus* spp.), arrowleaf balsamroot (*Balsamorhiza sagittata*), tansymustard (*Descurainia pinnata)*, bur buttercup (*Ceratocephala testiculata)*, halogeton (*Halogeton glomeratus)*, and blue mustard (*Chorispora tenella*). The soil type across sage-grouse range was categorized as loam, gravelly loam, or very gravelly loam.

METHODS

Trapping and radio-telemetry

All sage-grouse monitored during this study were live-trapped and radio-collared on Badger Flat, a region of approximately 4,800 ha within the Grouse Creek Watershed (Fig. 2-1). Using an all-terrain vehicle and spotlight method (Connelly et al. 2003), I captured male and female birds (n=45) February-May 2010, November 2010-May 2011, and February-May 2012 with a long-handled hoop net. I used a small bag and a 22-kg spring scale (Eagle Claw, Denver, Colorado, USA) to document individual weights. The age class and sex of each bird were determined based on weight and primary feather characteristics (Dalke et al. 1963). All methods followed protocols approved by the Utah State University Institutional Animal Care and Use Committee (IACUC #1194).

Battery-powered Advanced Telemetry Systems™ (Advanced Telemetry Systems, Isanti, MN, USA) 16-g radio transmitters (149.000-152.000MHz) were placed on adult and juvenile sage-grouse. Transmitters had a battery life of 22 months (24 hrs on). I located birds weekly throughout the breeding season and winter to determine use or avoidance of treatment areas. Locations of birds were mapped within 5 m accuracy using a Garmin™ (Garmin, Olathe, KS, USA) global positioning system (GPS) set to Universal Transverse Mercator (UTM) NAD83 units.

Birds were relocated using Communications Specialist, Inc.™ (Orange, California, USA) receivers and Telonics (Telonics, Inc., Mesa, AZ) hand-held Yagi antennae. I monitored birds weekly from February-August 2010, January-August 2011, and January-August 2012 within Badger Flat. All hens and broods were monitored throughout the Grouse Creek Watershed from breeding season until 50 days post hatching to obtain nesting and brood-rearing data.

I located sage-grouse mortalities as quickly as possible once the transmission signal was detected. Location and vegetation characteristics of mortality sites were documented. Notes about potential predator species, such as claw marks, bite marks, scat, and tracks, were also documented. It was often difficult to identify predator species due to scavenger activity.

Habitat Use Patterns on Badger Flat

I monitored sage-grouse habitat use on Badger Flat relative to vegetation conditions over time to determine habitat selection preferences. Throughout the winter, spring, and early summer, I recorded weekly bird use locations using a handheld global positioning system (GPS) in UTM NAD 83 coordinate system with an accuracy of less than 5 m. These locations were used to determine seasonal habitat use and movement patterns. I used ArcGIS 10.0 (ESRI, Redlands, CA) to select 20 random locations per month. Vegetation structure measurements were collected along 2 perpendicular 20 m line transects for all locations. During the winter months each year, GPS location, shrub cover, snow depth, slope, aspect, and overall vegetation type were documented using a line-intercept method (Canfield 1941). During May-July each year, I documented GPS location, slope, aspect, shrub cover, ground cover, and overall vegetation type.

I documented shrub canopy cover using a line intercept method (Canfield 1941). From a central point, I placed a 10 m measuring tape in a random cardinal direction. The measuring tape was then strung out 10 m again in 3 more directions, all 90 degrees apart. Live shrub canopy was measured along the tape; gaps in shrub cover less than 5 cm were counted as continuous and gaps greater than 5 cm were excluded. Percent ground cover, including grass, forbs, bare ground, litter, and rock were measured using a 20 x 50 cm Daubenmire frame (Daubenmire 1959), which was placed every 2.5 m along the 10 m measuring tape.

I also recorded heights of grasses and forbs that were in the Daubenmire frames throughout May-July each year. An effective grass height was used due to discrete differences in tall culms and short basal or grazed leaves. Grazing creates two distinct heights of grasses, one low height that is due to herbivore consumption and a taller height that remains if the herbivore did not consume the entire bunch. Using an effective height is more functional to estimate grass height than using droop height, since most of the grasses consist of both tall culms and shorter basal or grazed leaves. If greater than 60% of grass was basal leaves or leaves grazed to a consistent low height, the height of the basal or grazed leaves was recorded as the grass height. If greater than 60% of the grass was un-grazed or taller culms of the plant, the tall culms were measured as grass height. If 40%-60% of the grass was split between the basal or grazed leaves and the tall culms, an average height between the two distinct sections, basal and tall culms, of plant was used for the grass height. Comparison of measurements taken at use and random location points was used to determine sage-grouse selection for vegetation species and structure.

Nesting and Brood-Rearing Ecology

I located radio-collared hens bi-weekly throughout the breeding season from 2010-2012. During nesting season, hens were located twice a week throughout the study area to determine nest initiation and success rates. I visually monitored hens with binoculars from at least 10 m to avoid observer disturbance.

At each nest site, vegetation was measured along 2 perpendicular 30-m transects after hatching. Locations were recorded using GPS, and slope, aspect, shrub cover, ground cover, and overall vegetation type were documented at each location. From a central point, a 15-m measuring tape was placed in 4 directions, starting with a random direction, all 90 degrees apart. I documented shrub canopy cover utilizing a line intercept method (Canfield 1941). Live shrub canopy was measured along the tape; gaps in shrub cover less than 5 cm were counted as continuous and gaps greater than 5 cm were excluded. Percent ground cover, including grass, forbs, bare ground, litter, and rock were measured using a 20 x 50 cm Daubenmire frame (Daubenmire 1959) that was placed every 3 m along each 15-m transect.

Heights of grasses and forbs that were present within the Daubenmire frames were also recorded. I recorded effective grass height. The Daubenmire frame was placed every 3 m along each 15-m transect at nest sites. Random sites 80 m away from the nest site in a random cardinal direction were designated and measurements of vegetation with replicated techniques were taken at these sites.

I used a Robel pole at nest sites and random comparison sites to measure vertical obstruction (Robel et al. 1970). Vertical obstruction in towards the nest was measured by kneeling so eye-level was 1 m from the ground at a horizontal distance of 4 m from the Robel pole, which was placed in the center of the nest. Vertical obstruction from the nest was measured by marking the point at which the Robel pole became visible when it was placed 4 m away from the center of the nest, and I knelt at the nest site so that my eye-level was 1 m above the center of the nest. This data was used to compare nesting habitat metrics to random sites.

I located broods twice a week for 50 days post-hatching. A GPS location within 5 m accuracy and number of chicks was recorded. Brood-rearing habitat was measured along 2 perpendicular 20-m transects. Measurements for percent forb, grass, litter, bare ground, rock, and shrubs were the same as methods for nest sites. However, I used a 20 m x 20 m transect with Daubenmire frame placed every 2.5 m, instead of every 3 m. Effective grass height was used. Random sites 80 m away from the brood site in a random cardinal direction were designated and replicate measurements of vegetation were taken for comparison with the brood-use sites. This data provided information about brood-rearing habitats.

Data Analysis

Habitat Use

I assessed habitat use for males and females on Badger Flat using logistic regression (PROC LOGISTIC, SAS® System for Windows 9.3, Cary, NC). All habitat characteristics, including percents and heights of shrubs, forbs, grasses, and percentages of bare ground, litter, and rock were categorized as random effects and analyzed with backwards elimination to determine male and female preference for ground cover characteristics. A significance level of 0.05 was required for a variable to stay in the model. The same statistical analysis of logistic regression was used for determining preferred habitat characteristics at nest sites and brood sites. In winter 2010-2011 and 2011-2012, only shrub height and percent shrub composition parameters were analyzed using logistic regression.

Survival

Nest survival, juvenile survival, and adult survival were assessed using a staggered entry model in the RMark package in program R (Laake and Rexstad 2008). Akaike's criterion (Akaike 1973, Burnham and Anderson 2002) was used to evaluate influencing factors and relative support of competing generalized linear models of survival rates. Descriptive statistics were documented for brood survival due to low sample size.

Anthropogenic Effects

Analysis of correlations between survival statistics and road presence was completed. I mapped 2-track (bare ground) and gravel roads based on Utah GIS Portal data and newly created shapefiles (Fig. 2-3). Buffer zones were created every 50 m surrounding each road. Buffer zone analysis of sage-grouse use locations in comparison to road location was completed (Fig. 2-4, Fig. 2-5).

I used a t-test ($\alpha = 0.05$) to compare the log-transformed mean distances from predated and successful nests to dirt/paved roads and 2-track roads. I also used a t-test to compare the mean distances from dirt/paved roads and 2-track roads to sage-grouse mortality sites and random points. I also used a t-test to compare mean distances from successful and predated nests to utility poles. The dirt/paved roads had a higher traffic volume than the 2-track roads. I used the Rcmdr package in program R to assess statistical comparisons (Fox 2005, Laake and Rexstad 2008).

Hot spot analysis was completed to display the sage-grouse use of varying degrees of fragmentation. Hot spots were analyzed by creating patches of 500 ha increments due to fragmentation by roads. Patch size of 0-500 ha was given an index of 1. Patch size 501-1,000 ha was given an index of 2, and so forth up to 7,000 ha. Therefore, lower indices and lighter colors indicate regions of smaller intact land patches. A fixed Euclidian distance band of 200 m was specified, in which each feature was analyzed within the context of the neighbor patches that were within 200 m. Sage-grouse locations were mapped in relation to hot spots across the study area (Fig. 2-6).

I completed a viewshed analysis in ArcGIS by creating a layer file of utility poles and producing a map of visible regions from the utility poles (Fig. 2-7) based on a digital elevation model. Viewshed analysis is a useful tool for assessing potential threats by avian predators on sage-grouse populations (Aspbury and Gibson 2004). Golden eagles and other large predatory birds can view prey items, such as cottontail rabbits (*Sylvilagus* spp.) and sage-grouse, from a distance of ≥2 km (Aspbury and Gibson 2004, Miller 2008). Therefore, I clipped my image to display the viewshed within 2 km of each utility pole. I plotted 50 random points within the 2 km buffer and determined visibility to random points, nest sites, and mortality sites from the tops of utility poles using the Viewshed tool. I used the Near tool in ArcGIS to calculate distances from all nests and mortality sites to nearest utility pole.

RESULTS

Captures

Between March and May 2010, I captured and radio-collared 12 sage-grouse. Of these 12 birds, 1 was a juvenile female, 1 was an adult female, 2 were juvenile males, and 8 were adult males. Female weights ranged from 1150-1450 g. Male weights ranged from 2200-2900 g. Eight adult female sage-grouse that were captured for a previous study in 2008 were still alive in 2010 (Thacker 2010). Between November 2010-May 2011, I captured and radio-collared 25 sage-grouse. Of these 25 birds, 6 were juvenile females, 3 were adult females, 2 were juvenile males, and 14 were adult males. Female weights ranged from 1200-1750 g. Male weights ranged from 1900-2950 g. In 2012, between February and April, I captured and radio-collared 8 additional sage-grouse. Of these 8 birds, 2 were juvenile females, 1 was an adult female, 1 was a juvenile male, and

4 were adult males. Female weights ranged from 1100-1400 g and male weights ranged from 2200-2600 g. All birds were trapped on the Badger Flat study site.

Badger Flat Habitat Use

Habitat factors, including shrub cover, ground cover, slope, and aspect were recorded at 120 bird use locations and 120 random sites throughout each summer, 2010-2012, within the Badger Flat region (Table 2-1). Effective grass height was slightly higher at random sites (13.9 cm) than at sage-grouse use (11.1 cm) sites (se=0.32, odds ratio point estimate=0.889, P =0.001). All other vegetation covariates did not differ.

The average percent cover of invasive vegetation (55.7%, 95% CL = 43.6-79.2) did not differ from percent cover of non-invasive vegetation (44.3%, 95% CL = 36.7-66.1, P = 0.55) across all Badger Flat use sites and random sites from May-July 2010-2012. The most common invasive species were bur buttercup, halogeton, clasping pepperweed (*lepidium perfoliatum*), and cheatgrass.

Environmental factors, including shrub cover, snow depth, slope, and aspect were recorded at 160 bird use locations and 160 random sites during the winter and spring months of 2011 and 2012 (Table 2-2). Percent shrub cover was slightly higher (13.9%) at sage-grouse use sites than at random (12.7%) sites (odds ratio point estimate=1.043, se=0.38, P =0.016). Shrub height was slightly lower at use sites (30.5 cm) than at random (34.5 cm) sites (odds ratio estimate=0.975, se=0.78, P =0.017). Average snow depth was 0.86 cm at sage-grouse use sites and 0.83 cm at random sites.

Nest Success and Brood Success

In 2010, eight hens initiated nests. Two hens re-nested once. The earliest initiation date was May 5, 2010 and latest initiation date was May 28, 2010. Clutch size ranged from 1 to 7 eggs. One hen hatched 7 chicks, but the brood was predated within the first week. Two hens were successful in hatching broods, each with 6 chicks. These broods survived to 50 days post-hatching.

In 2011, eight hens initiated nests. The earliest initiation date was May 8, 2011 and the latest initiation date was June 10, 2011. Clutch size ranged from 3 to 8 eggs. Three hens had successful nests. One brood was predated within the first week after hatching. Two broods survived to 50 days post-hatching.

In 2012, nine hens initiated nests. One hen re-nested twice and one hen re-nested once. The earliest initiation date was April 14, 2012 and the latest initiation date was May 21, 2012. Clutch size ranged from 2 to 7 eggs. Four hens had successful nests. One brood was predated within the first week post-hatching. Two broods survived to at least 50 days post-hatching. Nest success rates from 2010-2012 ranged from 15.1%-19.1% for a full 35 days of laying and incubation (Table 2-3) based upon Mayfield daily survivorship estimate.

Nest and Brood Habitat Use

Nest sites were located throughout the Grouse Creek Watershed at elevations ranging from 1572 m to 2324 m. Nest elevations were similar each year. In general, nest vegetation factors did not differ from random sites. However, nest shrub diameter was larger at nest (109.8 cm) sites than at random (77.8 cm) sites (df=1, $P = 0.0046$, se=0.0135). Brood site elevations throughout the study area ranged from 1549-3002 m. Percent of rock cover was lower at sage-grouse brood sites (14.6%) than at random (19.5%) sites (odds ratio point estimate=0.953, se=0.38, P = 0.0135).

The average percent cover of invasive vegetation across all brood sites (51.0%, 95% CL = 42.7-63.4) did not differ from invasive vegetation at random sites (52.7%, 95% CL = 41.1-68.5, P = 0.44). The most common invasive species were bur buttercup, halogeton, clasping pepperweed, tansymustard, and cheatgrass.

The average percent cover of invasive vegetation across all nest sites (37.8%, 95% CL = 25.5-50.2) did not differ from random sites (34.5%, 95% CL = 21.3-48.7, P = 0.88). The most common invasive species were bur buttercup, blue mustard, tansymustard, and cheatgrass.

Juvenile and Adult Survival

The highest ranked model with the lowest AIC value included only the effect of sex in the model. Therefore, using sex as the primary covariate, yearly survival estimates between 2010-2011 for males was 0.22 (95% CL = 0.08-0.45), and for females was 0.73 (95% CL = 0.42-0.91). Yearly survival estimates between 2011- 2012 for males was 0.39 (95% CL = 0.12-0.74), and for females was 0.84 (95% CL = 0.38-0.98).

Movement

Average elevation of male and female sage-grouse locations from 2010-2012 within the study area was 1840 m. Average slope of brood sites from 2010-2012 was 9.4 degrees. Average slope of nest sites from 2010-2012 was 13.9 degrees. Average nest elevation was 1846 m and average brood site elevation was 1974 m.

Most sage-grouse that were caught on Badger Flat stayed within the Grouse Creek Watershed (Fig. 2-1). The birds stayed in the southern region in the winter months and began to expand their range to more northern territories in the late spring and summer months (Fig. 2-1). Elevation of sage-grouse locations ranged from 1533-3002 m. Telemetry data that was collected 2011-2012 showed that sage-grouse were present within the Badger Flat region throughout the winter, spring, and early summer months.

Most of the radio-collared sage-grouse (91%) remained on the southern region of the Grouse Creek watershed in the winter months and migrated to more northern regions between May and July. Sage-grouse were present on the Badger Flat region from November until late June 2010, July 2011, and early June 2012. Total precipitation from January-May and January-August was higher in 2011 than 2012 (11.4 cm and 20.9 cm, 7.6 cm and 17.3 cm, respectively). Average daily temperatures were also higher throughout the late spring and early summer months in 2012 than in 2011 (3.75 - 6.28 ^{o}C, -0.34 – 17.72 ^{o}C, respectively). The difference in seasonal movement behavior may have been an artifact of higher winter snowfall and late spring precipitation in 2010 and 2011, as well as drought conditions in 2012.

Anthropogenic Influences

Most adult and juvenile bird mortalities (86%) were located within 450 m of a road (Fig. 2-4). Most unsuccessful nests (85%) were located within 350 m of roads. Successful nests were more evenly distributed across buffer zones in relation to road presence (Fig. 2-5).

Roads were categorized into 2-track roads and major gravel/paved roads. Gravel/paved roads had higher traffic volume and larger road-width than 2-track roads. There was no difference in the mean distance between mortality sites and 2-track roads (483.7 m, CL = 258.2-709.2) compared to gravel/paved roads (999.7 m, CL = 339.2-1660.3, *P* = 0.13, df = 42, t = 1.56). There was no difference in the mean distance from mortality sites to 2-track roads (483.7 m, CL = 258.2-709.2) compared with random points to 2-track roads (556.1 m, CL = 335.1-702.2, *P* = 0.27, df = 42, t = 1.1). Predated nests were closer to 2-track roads (281.2 m, CL = 70.0-340.6) than successful nests (436.4 m, CL = 345.4-567.4, *P* = 0.006, df = 28, t = 3.32). There was no difference between the mean distance from gravel/paved roads to predated nests (2172.7 m, CL = 1306.1-3410.2) and successful nests (2304.9, CL = 1788.9-3660.5, *P* = 0.47, t = 0.75, df=28).

Hot spots analysis indicated that sage-grouse used various fragmented habitats throughout the watershed (Fig. 2-6). The smallest contiguous patch of land, excluding the town of Grouse Creek, was <1 ha. The largest contiguous patch of land with interspersed roads, but without bisecting roads, was 6,555 ha. The median patch of land with interspersed roads, but without bisecting roads, was 130 ha. There were 921 km of roads in the 150,200 ha watershed.

Viewshed analysis can be used for assessing potential avian predation risks (Aspbury and Gibson 2004). I created a map of the transmission poles within the Grouse Creek Watershed and produced a viewshed map, which illustrates visible and obscured regions from the tops of the transmission poles within 2 km of the transmission poles (Fig. 2-7). The average distance from adult and juvenile mortality sites to transmission poles was 1958.8 m (CI = 1207.4-2655.0, df = 21). Based on the clipped 2 km buffered viewshed, 14/15 mortality sites were visible from the tops of transmission poles within the 2 km buffer. The average distance from predated nests to transmission poles (2166.2 m, CI = 1401.7-2930.7) did not differ from the average distance from successful nests to transmission poles (2143.8 m, CI = 1058.8-3316.3, df = 28, $P = 0.79$). Based on the viewshed, 4/6 successful nests, 9/10 predated nests, and 35/50 random points were visible from the transmission poles within the 2 km buffer.

DISCUSSION

Badger Flat Habitat Use

Badger Flat has the sixth largest known occupied lek in Box Elder County (UDWR 2009). This area consisted of a mosaic of dominant Wyoming big sagebrush, black sagebrush, rabbitbrush, shadscale, and interspersed grasses and forbs. Although an important breeding and wintering area for sage-grouse, Badger Flat has been impacted by anthropogenic structures and invasive plants. Shrub cover, grass cover, and forb cover (11.5-15.2%, 9.4-15.3%, 1.9-4.8%, respectively) were all lower in late spring and summer than recommended guidelines for sage-grouse habitat (Connelly et al. 2000). Shrub cover in winter (11.5-15.5%) was also within the lower range of recommended percent sagebrush cover levels (Connelly et al. 2000).

However, shrub cover, forb cover, and grass cover (22.6-29.9%, 9.7-18.2%, 7.9-13.2%, respectively) throughout the rest of the Grouse Creek Watershed were within the suggested guideline ranges for sage-grouse habitat (Connelly et al. 2000). My vegetation estimates were similar to those reported at adult bird use sites by Knerr (2007), who researched sage-grouse habitat use within the Grouse Creek Watershed.

Previous studies have reported the effects of habitat structure on nest and brood-rearing site selection (Connelly et al. 2000, Crawford et al. 2004). However, few studies have reported effect of overall habitat use by adult and juvenile males and females.

Previous studies have used droop height of grasses, which is the height at which the tallest vegetative culms droop, excluding the flowering culms, to describe habitat quality (Gregg et al. 1994, Sveum et al. 1998). Although this method may be useful for gauging the tallest part of grass plants, an overall effective height may be more beneficial for understanding the grass composition at grazed sites where many short-grazed culms persist in concert with tall un-grazed culms. I measured an effective grass height based on the percentages of basal or grazed leaves and tall culms, including the seedheads.

Throughout the summer, the effective grass height was slightly higher at random sites than at adult and juvenile use sites. Other studies have hypothesized that grass height may be correlated with reduced predation (Gregg et al. 1994). It is possible that grass height across Badger Flat does not provide as much cover as other vegetation and use sites are selected for other reasons.

Each year several hens traveled to alfalfa fields in mid to late summer. The alfalfa fields were irrigated daily and contained large quantities of invertebrates. These findings were similar to other studies, which have noted that sage-grouse will consume alfalfa in late summer and early autumn (Wallestad and Eng 1975, Knerr 2007, Thacker 2010). The use of alfalfa fields as habitat could indicate adaptations to alternative habitat in fragmented landscapes.

Throughout the winter and spring seasons, sage-grouse were more likely to be present at sites with slightly higher shrub cover and slightly shorter shrubs. Other studies have indicated that sage-grouse prefer to use regions of >20% shrub cover in the winter (Eng and Schladweiler 1972, Connelly et al. 2000). Badger Flat is a matrix of primarily Wyoming big sagebrush and black sagebrush with other shrubs interspersed across the landscape. Black sagebrush typically has shorter growth height than Wyoming big sagebrush. Therefore, it is probable that sage-grouse are foraging or roosting at sites within black sagebrush communities more than stands of Wyoming big sagebrush throughout the winter and spring. These results are similar to other studies, which have noted that sage-grouse prefer black sagebrush as a dietary source and cover for roosting sites (Dahlgren et al. 2006, Thacker 2010). The average snow depth at sage-grouse use locations was less than 1 cm and the average shrub height was 30.5 cm, which allows for almost 30 cm of vegetation for foraging and protective cover. Sage-grouse move shorter distances when forage is available and females use denser stands of sagebrush during milder winters (Beck 1977). In drier years, black sagebrush will be available for foraging, but greenness and invertebrate quantity, which is an important factor for brood-rearing, may be reduced by early summer due to reduced water availability. If more extreme events occur and snow levels rise, black sagebrush may not be available, which may lead to higher consumption of taller shrubs or larger movements to reach regions of accessible forage materials.

Nest Success and Brood Success

Nest success rates reported in the literature range from 12%-86% (Trueblood 1954, Gregg 1991, Schroeder et al. 1999). Although the nest success rates (15.1-19.1%) across the Grouse Creek Watershed were within the lower range of rates observed for other sage-grouse populations, they were lower than those previously observed for the area (Knerr 2007). Most of the hens I studied demonstrated strong fidelity to nesting sites (i.e., < 400 m from previous nests). Nest fidelity has been previously observed in other regions of the sage-grouse range (Berry and Eng 1985). Continued fragmentation may lead to a decrease in nest site availability and productivity.

Both mammalian and avian species predated nests, which was determined through scat, tracks, and damaged egg structure. Although most predated nests appeared to be caused by mammalian predators, caution must be used when making assumptions because sites may have scavengers post predation that lead to inconclusive observations.

Nest initiation dates ranged from 5-28 May 2010, 8 May-10 June 2011, and 14 April-21 May 2012. These initiation dates likely reflect weather variation across years. Years with higher temperatures and lower precipitation were associated with earlier vegetation germination periods in late spring and early summer and earlier dormant or dead vegetation periods in mid-summer. Early germination led to more vegetation and invertebrate forage availability at an earlier date. Similar results were found at other sites in Utah (Robinson 2007). Weather and associated habitat factors could be the cause that led to earlier nest initiation dates (Neave and Wright 1969).

Each year, brood survival was poor, with only two broods surviving to 50 days post-hatching. I could not determine the fate of the broods that did not remain with the hen because transmitters had not been placed on the chicks. However, brood-mixing (Guttery 2011) or mortality was likely to be the fate of these broods.

Nest and Brood Habitat Use

All nest sites were located within sagebrush or mixed shrub (i.e., shadscale, rabbitbrush, snowberry) communities. Sage-grouse hens preferred larger diameter shrubs, which is common among sage-grouse nest sites (Sveum et al. 1998, Knerr 2007). Larger shrub diameter can create more vertical cover, which may reduce avian predation pressure. Other studies in the area reported that hens preferred taller shrubs and perennial grass cover for nest sites (Knerr 2007). Hens nested earlier in drier years, and later, with a wider range of nesting dates, in wetter years, which was similar to other populations in Utah (Robinson 2007). Drier years could indicate a reduction in insect abundance or green vegetation, which is required for early brood-rearing (Drut et al. 1994). Nesting earlier in the season may allow hens to access better early brood-rearing habitat. Nests may have been within similar elevation ranges each year due to nest site fidelity. If habitat becomes more degraded, nest fidelity may no longer be an option and hens may have to travel further distances to nest (Beck 1977).

Areas with less rock cover had higher rates of forbs, grasses, litter, and bare ground. Broods preferred these areas with less rock cover, which could be attributed to the preference for more vegetation that may also have higher invertebrate content. Broods also showed a preference for irrigated alfalfa fields, which have higher invertebrate populations. Other studies have shown that sage-grouse consume alfalfa and other vegetation species associated with alfalfa fields (Peterson 1970, Wallestad and Eng

1975, Knerr 2007). Insects are also an important dietary component for sage-grouse broods (Johnson and Boyce 1990). One brood remained in a cheatgrass field for the first 2 weeks post-hatching in 2010 before relocating to an alfalfa field. The cheatgrass field had a large population of green stink bugs (*Acrosternum hilare*) that could be a foraging source for sage-grouse.

Juvenile and Adult Survival

Juvenile and adult survival estimates vary across the sage-grouse distribution range (Musil et al. 1993, Zablan et al. 2003). The male survival rates across the Grouse Creek Watershed were lower than rates reported range-wide, while the female survival rates were comparable to results produced by other studies (Musil et al. 1993, Connelly et al. 1994, Zablan et al. 2003, Musil and Connelly 2005). Three mortalities were located on leks and several other mortalities were located within more open habitat characterized by lower vertical and horizontal vegetation cover. Female survival rate was higher than male survival rates throughout the study. This dichotomy may be due to physiological demands and breeding behavior. Weather, disease, and habitat fragmentation also have impacts upon survival rates (Connelly et al. 2000, Moynahan et al. 2006). Sage-grouse may use lower quality habitat when high quality habitat is not available. However, this may lead to an increase in mortalities at local scales.

Anthropogenic Influences

Most sage-grouse mortalities were within 350 m of roads. Predated nests were closer to roads than successful nests. In particular, predated nests were closer to 2-track roads than successful nests. Studies have reported a 40-60% decrease in sagebrush obligate species within 100 m of dirt roads (Ingelfinger and Anderson 2004). Other studies have documented a large (28%) impact of roads and pipelines on sagebrush habitat, which may deter sage-grouse presence (Connelly et al. 2004). Roads and other linear disturbances can provide corridors for mammalian predators (Grinder and Krausman 2001, Apps et al. 2002). Therefore, caution must be used when creating even small linear disturbances. Agricultural land and open fields can increase predation pressure from mammalian and avian species (Apps et al. 2002, Coates and Delehanty 2010). Increase of invasive species can also reduce shrub density, change the fire regime, and increase predation pressure on prey species, such as sage-grouse (Earnst et al. 2009, Connelly et al. 2011).

Most of the nest and mortality sites were located within 2 km of utility poles. Tall structures have been identified as potential threats to sage-grouse by increasing avian predation (Aspbury and Gibson 2004). Viewshed analysis can be instrumental in identifying potential threats and placing energy developments in regions where topography may help reduce avian predation.

Fragmentation from anthropogenic structures and invasive species can decrease native species at the local and regional levels (Crooks 2002, Frey and Conover 2006, Marvier et al. 2004). Nest and brood success rates greatly influence sage-grouse population sizes. Therefore, effects of fragmentation and anthropogenic structures should be acknowledged and further research should be conducted to assess the impact of these influences.

Seasonal Effects of Weather

In 2010, the highest concentration of captures was in mid-March, which coincided with the highest lek attendance period. Sage-grouse were readily trapped in December 2010 because of minimal snow cover. However, sage-grouse were less accessible and trapping success rates were low in January and February 2011 because of higher amounts of snow cover. Sage-grouse also move farther distances to roost and forage when snow levels are higher (Beck 1977), which may have decreased my ability to trap them. My sage-grouse trapping success rates increased in March 2011. In 2012, sage-grouse were strutting at the Badger Flat lek site by January and peak lek attendance was in February and March. My highest trapping success rates in 2012 were in February. I applied minimal (< 5 minutes per bird) handling time to sage-grouse to reduce physiological stress impact.

Wildlife behavior patterns can reflect seasonal changes in weather (Robinson 2007). Weather factors, including summer temperatures, yearly precipitation, and late winter snowfall can greatly affect sagebrush steppe plant demographics (Dalgleish et al. 2011). Higher daily temperatures can also lead to increased invasive plant species and spread of wildfire (Ajmal et al. 2001). Response to weather variables led to earlier vegetation germination times in 2010 and 2012. Low precipitation rates in 2012 also led to an earlier, drier period at lower elevations, which consequently led to higher rates of plant litter and dormant vegetation during the early summer months within the Badger Flat parcel. These effects likely led to an earlier 2nd stage migration from the xeric southern Badger Flat region to more northern regions or croplands with daily irrigation.

Throughout each summer, broodless hens and male sage-grouse made rapid movements from the southern region towards the northern regions. Almost all individuals within the population that were trapped on Badger Flat remained on the southern region for 5-7 months, likely due to foraging material, which is correlated with greenness. They then traveled through the central region within 1 or 2 weeks, and then remained in the northern regions for several months. Previous studies in the area reported similar movements (Knerr 2007). Knerr (2007) reported that males moved further than females during the summer. This may be due to nesting and brood-rearing behavior. Land in the central region consists primarily of anthropogenic structures and large stands of juniper trees. Migration behavior patterns indicate avoidance towards anthropogenic structures or activity and large juniper stands.

MANAGEMENT IMPLICATIONS

Habitat fragmentation and anthropogenic expansion will continue throughout the western U.S. within the near future. Although my study demonstrated that individual sage-grouse may adapt to seasonal variation in environmental conditions, long-term impacts, such as climate change, may increase the extirpation potentials in at-risk habitats. Currently, the habitat based on vegetation structure is suitable in the Grouse Creek Watershed to maintain current populations. However, individuals within the population have responded to the spread of invasive species, juniper expansion, and anthropogenic disturbance by making rapid seasonal migration movements from the southern to the northern portion of the watershed. Sage-grouse broods demonstrated an ability to utilize alternative habitats, such as alfalfa fields and cheatgrass stands, which exhibited more mesic conditions. Although individual local adaptations may be beneficial to sage-grouse populations, if range-wide fragmentation and pressures increase, the entire population may not be resilient. If habitat becomes too degraded or fragmented, predation influences may increase and populations of sage-grouse and other sagebrush obligate prey species may diminish. Caution must also be used when planning predator removal strategies because removing one predator, such as coyotes, may increase populations of other meso-predators.

My research demonstrated that anthropogenic disturbances, such as roads and areas void of vegetation cover might play a role in increased adult mortality and nest predation rates. It is important to focus efforts on reducing fragmentation and providing high quality sagebrush habitat throughout the western United States. I recommend that managers focus on long term monitoring of sage-grouse habitats and minimizing of sagebrush-steppe fragmentation. Further research is needed to quantify impact of various stages of habitat loss and fragmentation.

LITERATURE CITED

Ajmal, K. M., G. Bilquees, and D. J. Weber. 2001. Seed germination characteristics of *Halogeton glomeratus*. Canadian Journal of Botany 79:1189-1194.

Akaike, H. 1973. Information theory and an extension of the maximum likelihood principle. Pages 267-281 *in* B. N. Petrov and F. Csaki, editors. Second international symposium on information theory. Akademiai Kiado, Budapest, Hungary.

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

Apps, C. D., N. J. Newhouse, and T. A. Kinley. 2002. Habitat associations of American badgers in southeastern British Columbia. Canadian Journal of Zoology 80:1228-1239.

Aspbury, A. S., and R. M. Gibson. 2004. Long-range visibility of greater sage grouse leks: a GIS-based analysis. Animal Behaviour 67:1127-1132.

Barber, V. A., G. P. Juday, R. D'Arrigo, E. Berg, B. Buckley, H. Huntington, T. Jorgensen, D. McGuire, T. Osterkamp, B. Riordan, A. Whiting, G. Wiles, and M. Wilmking. 2009. A synthesis of recent climate warming effects on terrestrial ecosystems of Alaska. Pages 110-142 *in* F. H. Wagner, editor. Climate warming in western North America: evidence and environmental effects. The University of Utah Press, Salt Lake City, USA.

BARM (West Box Elder Adaptive Resource Management Local Working Group). 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. Unpublished Report. Salt Lake City, Utah.

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

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

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.

Bradley, L. C., and D. B. Fagre. 1988. Coyote and bobcat response to integrated ranch management practices in south Texas. Journal of Range Management 41:322-327.

Brooks, M. L., C. M. D'Antonio, D. M. Richardson J. B. Grace, J. E. Kelley, J. M. DiTomaso, R. J. Hobbs, M. Pellant, and D. Pyke. 2004. Effects of invasive alien plants on fire regimes. BioScience 54:677-688.

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

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

Chambers, J. C., and M. Pellant. 2008. Climate change impacts on northwestern and intermountain United States rangelands. Rangelands 30:29-33.

Christensen, J. H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R. K. Kolli, W.-T. Kwon, R. Laprise, V. Magaña Rueda, L. Mearns, C. G. Menéndez, J. Räisänen, A. Rinke, A. Sarr, and P. Whetton. 2007: Regional climate projections *in* Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller, editors. Climate change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, New York, USA.

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

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

Connelly, J. W., 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. Conservation of Greater sage-grouse: a synthesis of current trends and future management. Cooper Ornithological Society scientific series: Studies in Avian Biology. University of California Press, Berkeley, California, USA.

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

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, Idaho, USA.

Connelly, J. W., K. P. Reese, W. L. Wakkinen, M. D. Robertson, and R. A. Fisscher. 1994. Sage grouse ecology report. Idaho Department of Fish and Game, Job Completion Report W-160-R-19, Subproject 9, Boise, Idaho, 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.

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

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

Crête, M., and S. Larivière. 2003. Estimating the costs of locomotion in snow for coyotes. Canadian Journal of Zoology 81:1808-1814.

Crooks, K. R. 2002. Relative sensitivities of mammalian carnivores to habitat fragmentation. Conservation Biology 16:488-502.

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

Dahlgren, D. K., T. A. Messmer, and D. N. Koons. 2010. Achieving better estimates of Greater sage-grouse chick survival in Utah. Journal of Wildlife Management 74:1286-1294.

Dalgleish, H. J., D. N. Koons, and P. B. Adler. 2010. Can life-history trais predict the response of forb populations to changes in climate variability? Journal of Ecology 98:209-217.

Dalgleish, H., D. Koons, M. Hooten, C. Moffet, and P. B. Adler. 2011. Climate influences the demography of three dominant sagebrush steppe plants. Ecology 92:75-85.

Dalke, P. D., D. B. 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 27:811-841.

Daubenmire, R. F. 1959. A canopy-coverage method of vegetational analysis. Northwest Science 33:43-66.

Dechant, J. A., M. L. Sondreal, D. H. Johnson, L. D. Igl, C. M. Goldade, M. P. Nenneman, and B. R. Euliss. 2002. Effects of management practices on grassland birds: grasshopper sparrow. Northern Prairie Wildlife Research Center, Jamestown, North Dakota, USA.

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

Duebbert, H. F., and J. T. Lokemoen. 1976. Duck nesting in fields of undisturbed grass-legume cover. Journal of Wildlife Management 40:39-49.

Earnst, S., H. L. Newsome, W. L. LaFramboise, and N. LaFramboise. 2009. Avian response to wildfire in Interior Columbia Basin Shrubsteppe. The Condor 111:370-376.

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

Fox, J. 2005. The R Commander: a basic statistics graphical user interface to R. Journal of Statistical Software 14:1-42.

Frey, N., and M. R. Conover. 2006. Habitat use by meso-predators in a corridor environment. Journal of Wildlife Management 70:1111-1118.

Gregg, M. A. 1991. Use and selection of nesting habitat by sage grouse in Oregon. Thesis, Oregon State University, Corvallis, USA.

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

Grinder, M. I., and P. R. Krausman. 2001. Home range, habitat use, and nocturnal activity of coyotes in an urban environment. Journal of Wildlife Management 65:887-898.

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.

Hagen, C. A. 2011. Predation on sage-grouse: facts, effects, and process. Pages 95-100 *in* S. T. Knick and J. W. Connelly, editors. Greater sage-grouse: ecology and conservation of a landscape species and its habitat. Studies in Avian Biology 38. University of California Press, Berkeley, USA.

Heath, B. J., R. Straw, S. H. Anderson, J. Lawson, and M. J. Holloran. 1998. Sage-grouse productivity, survival, and seasonal habitat use among three ranches with different livestock grazing, predator control, and harvest management practices. Pitmann-Robertson Project Completion Report. Wyoming Game and Fish Department, Cheyenne, Wyoming, USA.

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

Inouye, D. W. 2008. Effects of climate change on phenology, frost damage, and floral abundance of montane wildflowers. Ecology 89:353-362.

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.

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

Knick, S. T., and J. W. Connelly. 2011. Greater sage-grouse: ecology and conservation of a landscape species and its habitats. University of California Press, Berkeley, USA.

Laake, J. and E. Rexstad. 2008. RMark – an alternative approach to building linear models in MARK. Pages C-1-C-115 *in* E. Cooch and G. C. White, editors. Program MARK: A Gentle Introduction. Ninth edition.

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

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.

Marvier, M., P. Kareiva, and M. G. Neubert. 2004. Habitat destruction, fragmentation, and disturbance promote invasion by habitat generalists in a multispecies metapopulation. Risk Analysis 24:869-878.

McDonald, P. T., C. K. Nielsen, T. J. Oyana, and W. Sun. 2008. Modeling habitat overlap among sympatric mesocarnivores in southern Illinois, USA. Ecological Modeling 215:276-286.

Mezquida, E. T., S. J. Slater, and C. W. Benkman. 2006. Sage-grouse and indirect interactions: Potential implications of coyote control on sage-grouse populations. The Condor 108:747-759.

Miller, S. S. 2008. Eagles. The Rosen Publishing Group, Inc., New York, New York, USA.

Moore, S. E., and H. P. Huntington. 2008. Arctic marine mammals and climate change: impacts and resilience. Ecological Adaptations 18:157-165.

Mote, P. W. 2009. Variability and trends in mountain snowpacks in western North America. Pages 51-62 *in* F. H. Wagner, editor. Climate warming in western North America: evidence and environmental effects. The University of Utah Press, Salt Lake City, USA.

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.

Musil, D. D., and J. W. Connelly. 2005. Sage-grouse ecology report. Idaho Department of Fish and Game, Job Completion Report W-160-R-32, Subproject 53, Boise, USA.

Musil, D. D., J. W. Connelly, and K. P. Reese. 1993. Movements, survival, and reproduction of sage grouse translocated into Central Idaho. Journal of Wildlife Management 57:85-91.

Neave, D. J., and B. S. Wright. 1969. The effects of weather and DDT spraying on a ruffed grouse population. The Journal of Wildlife Management 33:1015-1020.

Peterson, J. G. 1970. The food habits and summer distribution of juvenile sage grouse in central Montana. Journal of Wildlife Management 34:147-155.

Pyke, D. A. 2011. Restoring and rehabilitating sagebrush habitats. Pages 531-548 *in* S. T. Knick and J. W. Connelly, editors. Greater sage-grouse: ecology and conservation of a landscape species and its habitats. Studies in Avian Biology. Volume 38. University of California Press, Berkeley, USA.

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.

Robinson, J. D. 2007. Ecology of two geographically distinct greater sage-grouse populations inhabiting Utah's west desert. Thesis, Utah State University, Logan, USA.

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

Schroeder, M. A., J. R. Young, and C. E. Braun. 1999. Sage grouse (*Centrocercus urophasianus*). Pages 1-28 *in* A. Poole and F. Gill, editors. The birds of North America, No. 425. The Birds of North America, Incorporated, Philadelphia, Pennsylvania, USA.

Sovada, M. A., A. B. Sargeant, and J. W. Grier. 1995. Differential effects of coyotes and red foxes on duck nest success. The Journal of Wildlife Management 59:1-9.

Stiver, S. J., A. D. Apa, J. R. Bohne, S. D. Bunnell, P. A. Deibert, S. C. Gardner, M. A. Hilliard, C. W. McCarthy, and M. A. Schroeder. 2006. Greater sage-grouse comprehensive conservation strategy. Western Association of Fish and Wildlife Agencies, Cheyenne, Wyoming, USA.

Sveum, C. M., J. A. Crawford, and W. D. Edge. 1998. Use and selection of brood-rearing habitat by sage grouse in south central Washington. Great Basin Naturalist 58:344-351.

Taylor, R. L., B. L. Walker, D. E. Naugle, and L. S. Mills. 2012. Managing multiple vital rates to maximize greater sage-grouse population growth. Journal of Wildlife Management 76:336-347.

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

Thacker, E. T., D. R. Gardner, T. A. Messmer, M. R. Guttery, and D. K. Dahlgren. 2011. Using gas chromatography to determine winter diets of greater sage-grouse in Utah. Journal of Wildlife Management 76:588-592.

Trueblood, R. W. 1954. The effect of grass reseeding in sagebrush lands on sage grouse populations. Thesis, Utah State University, Logan, USA.

U.S. Department of the Interior. 2010. Federal Register Notice. US Fish and Wildlife Service.

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, USA.

Wagner, F. H. 2009. Climate warming in western North America: evidence and environmental effects. The University of Utah Press, Salt Lake City, USA.

Wallestad, R., and R. L. Eng. 1975. Foods of adult sage grouse in central Montana. Journal of Wildlife Management 39:628-630.

Walsh, J. E. 2008. Climate of the arctic marine environment. Ecological Adaptations 18:3-22.

Zablan, M. A., C. E. Braun, and G. C. White. 2003. Estimation of Greater sage-grouse survival in North Park, Colorado. Journal of Wildlife Management 67:144-154.

Table 2-1. Comparison of vegetation at greater sage-grouse (*Centrocercus urophasianus*) use and random sites on Badger Flat, Utah, May-July 2010-2012.

Use(1)Rndm(0)	Year	%shrub cover	shrub ht (cm)	%forb	forb ht (cm)	%grass	grass ht (cm)	%rock	%bare	%litter
1	2010	11.35	34.75	4.27	4.08	14.29	12.07	16.75	30.42	34.34
0	2010	15.35	30.62	4.80	6.15	9.51	19.46	21.00	28.08	36.61
1	2011	8.96	29.99	3.70	5.91	13.72	12.20	21.32	34.33	26.91
0	2011	12.51	40.48	4.30	6.77	15.32	12.75	20.03	32.48	27.75
1	2012	14.80	39.76	1.91	3.43	9.44	8.98	25.57	27.16	35.93
0	2012	8.22	35.79	2.61	3.56	12.38	9.58	20.34	24.70	39.96

Table 2-2. Comparison of vegetation at greater sage-grouse (*Centrocercus urophasianus*) use and random sites on Badger Flat, Utah, January-April 2011-2012.

Site	Year	% shrub cover	shrub ht (cm)	snow depth (cm)
Use	2011	15.22	30.26	0.99
Random	2011	11.54	34.13	0.85
Use	2012	12.62	30.66	0.74
Random	2012	11.47	34.39	0.81

Table 2-3. Greater sage-grouse nest success rates across the Grouse Creek Watershed, UT, 2010-2012.

Year	Nest success for 27 days	95% CL	Nest success for 35 days	95% CL
2010	24.1%	0.15-0.62	15.1%	0.11-0.55
2011	26.5%	0.19-0.63	17.5%	0.12-0.56
2012	28.0%	0.23-0.58	19.1%	0.13-0.55

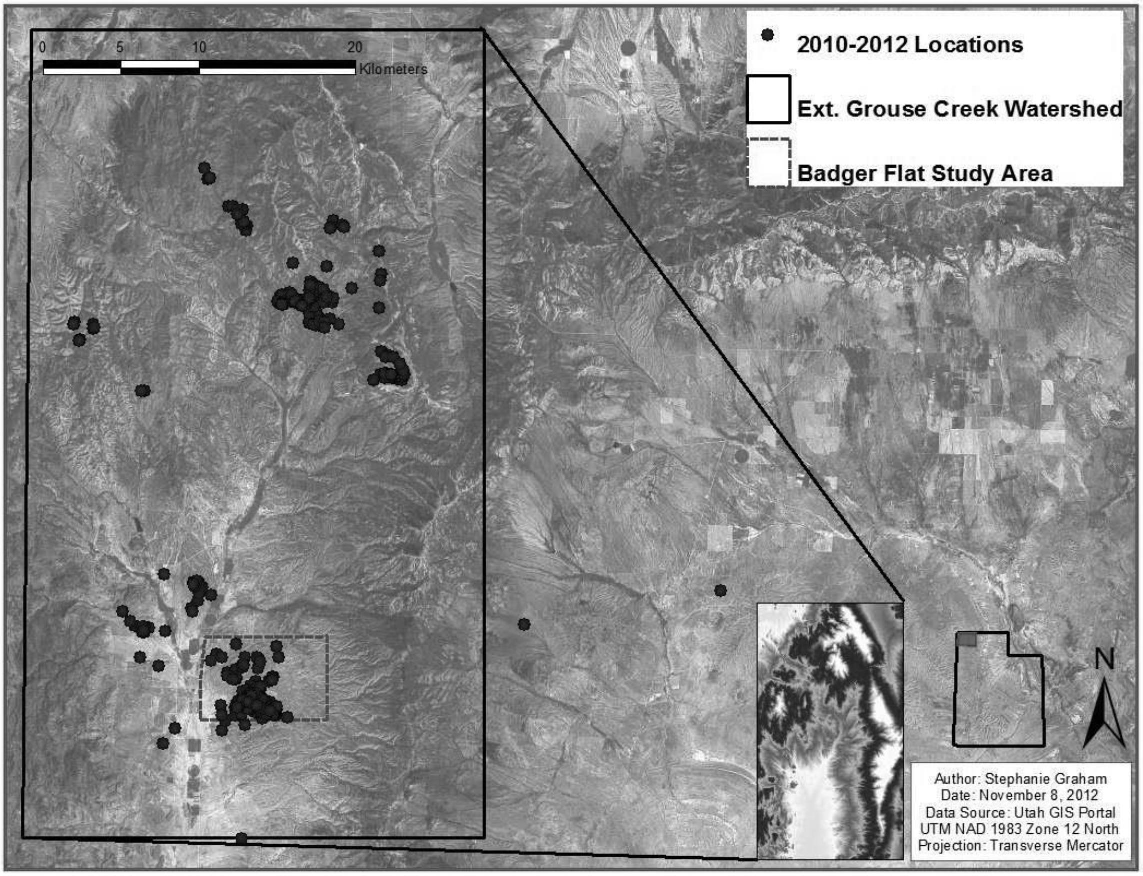

Figure 2-1. Greater sage-grouse locations in western Box Elder County, Utah, 2010-2012.

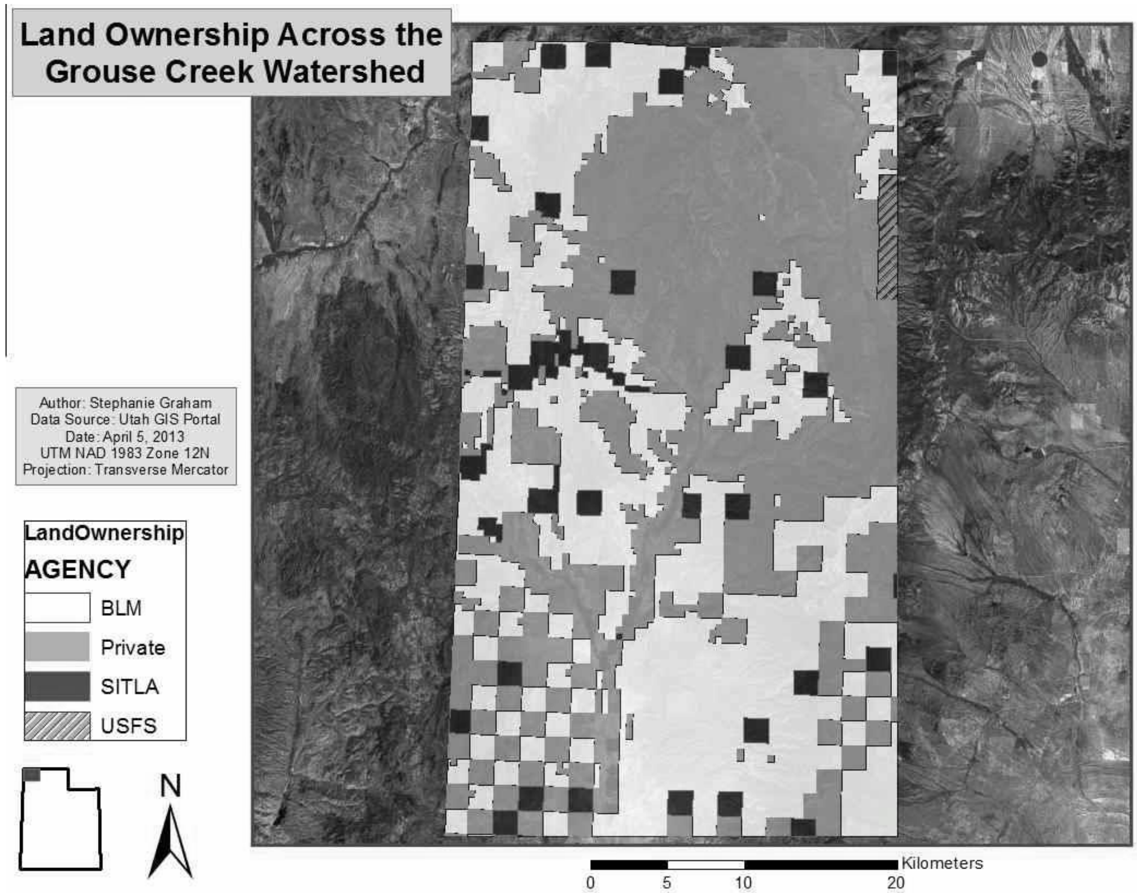

Figure 2-2. Map of private and public land ownership in west Box Elder County, UT, 2013.

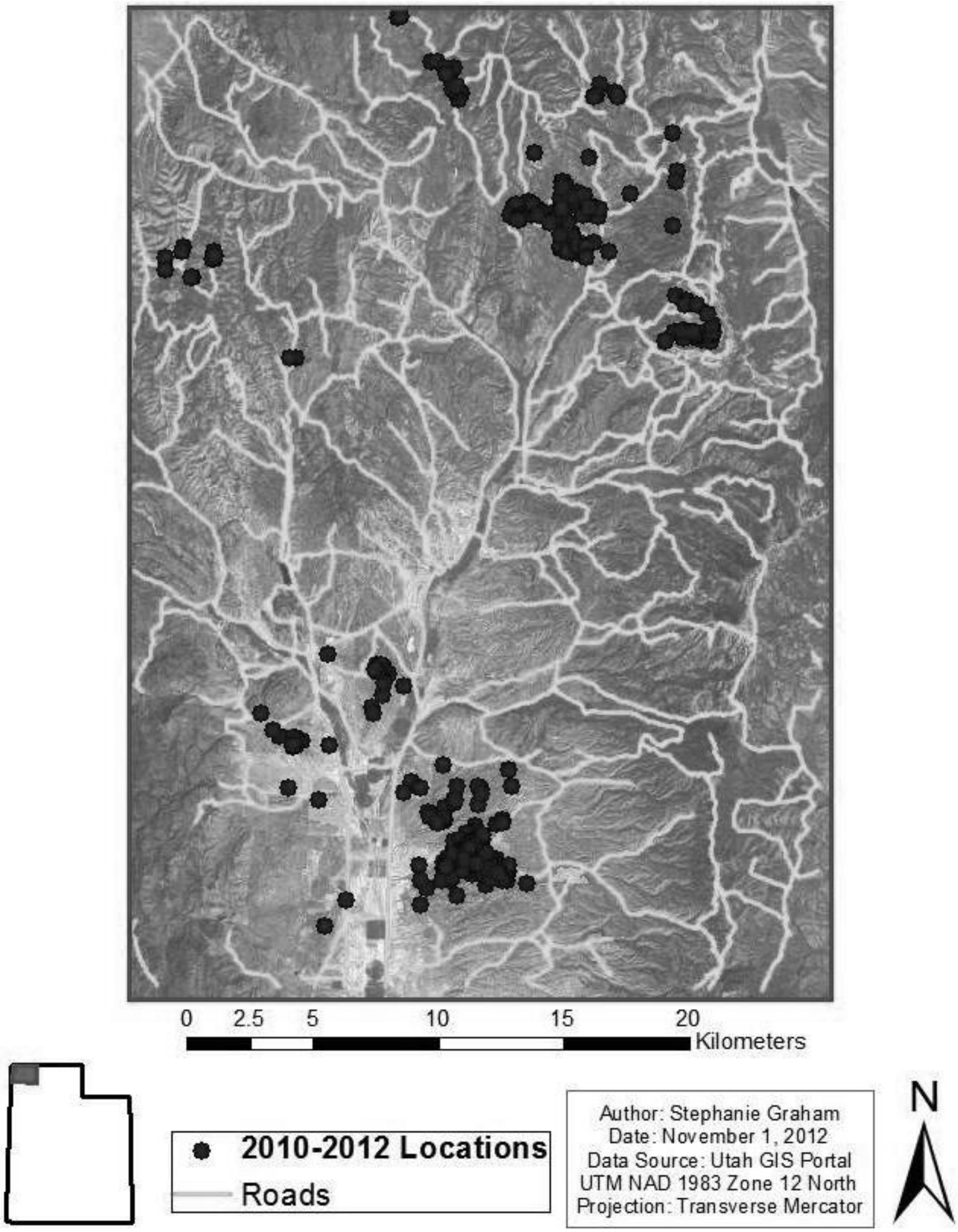

Figure 2-3. Greater sage-grouse locations in relation to roads, western Box Elder County, Utah, 2010-2012.

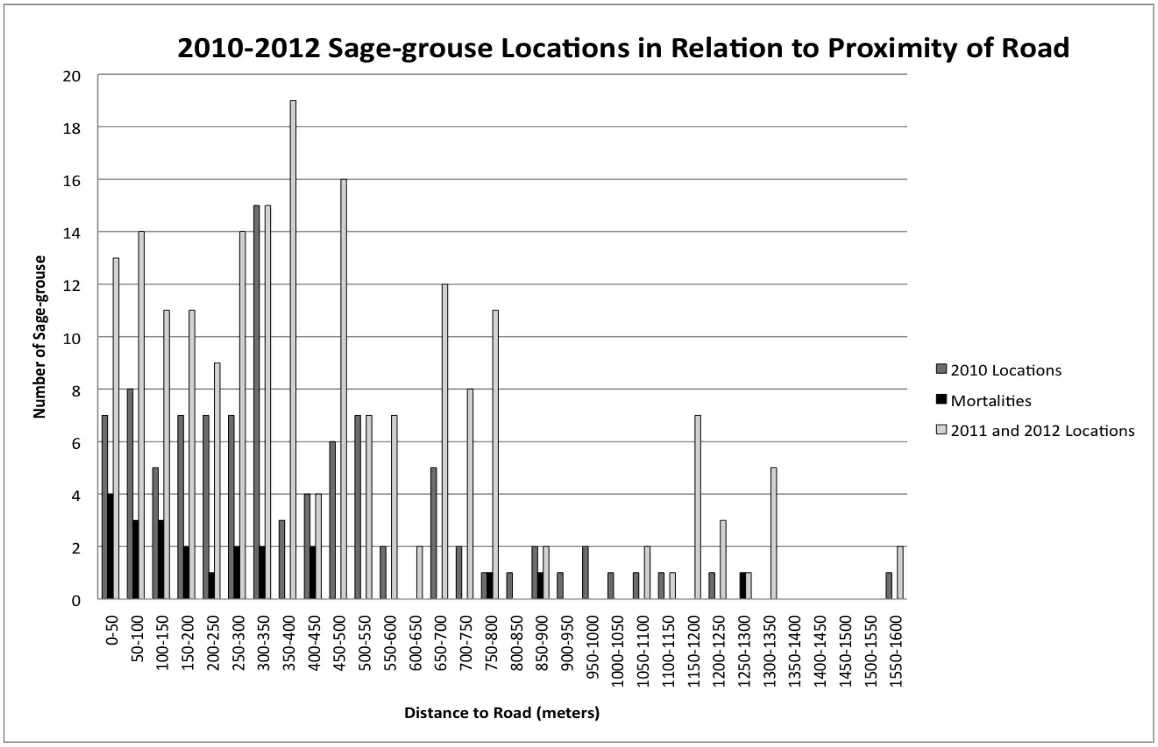

Figure 2-4. Buffer zone analysis of Greater sage-grouse locations, western Box Elder County, Utah. 2010-2012.

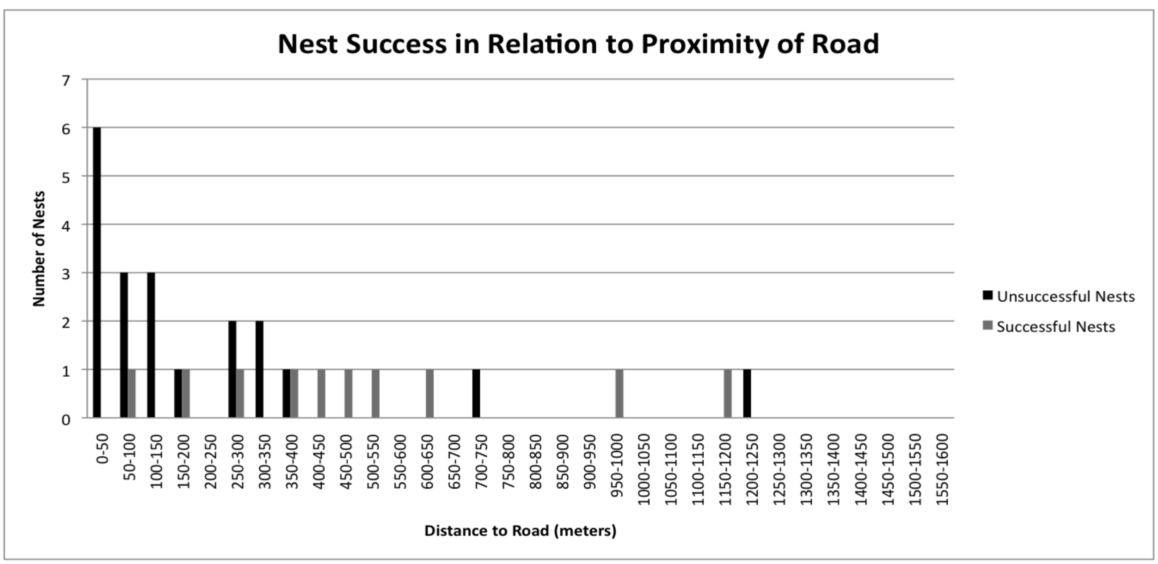

Figure 2-5. Buffer zone analysis of Greater sage-grouse nest locations, western Box Elder County, Utah. 2010-2012.

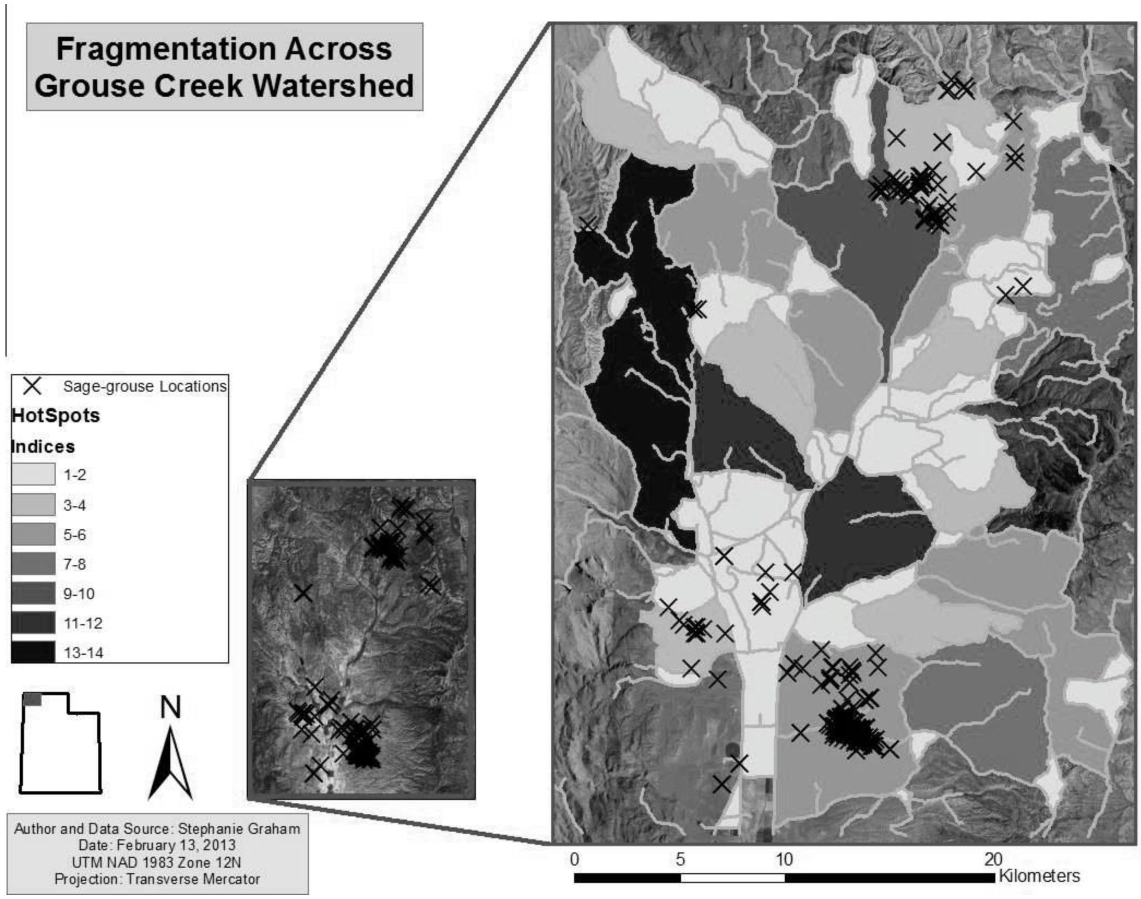

Figure 2-6. Hot spot analysis. Lower index numbers correspond with smaller contiguous patches of land. Higher index numbers correspond with larger, less fragmented regions of land. Sage-grouse locations are found in different regions of the highly fragmented landscape.

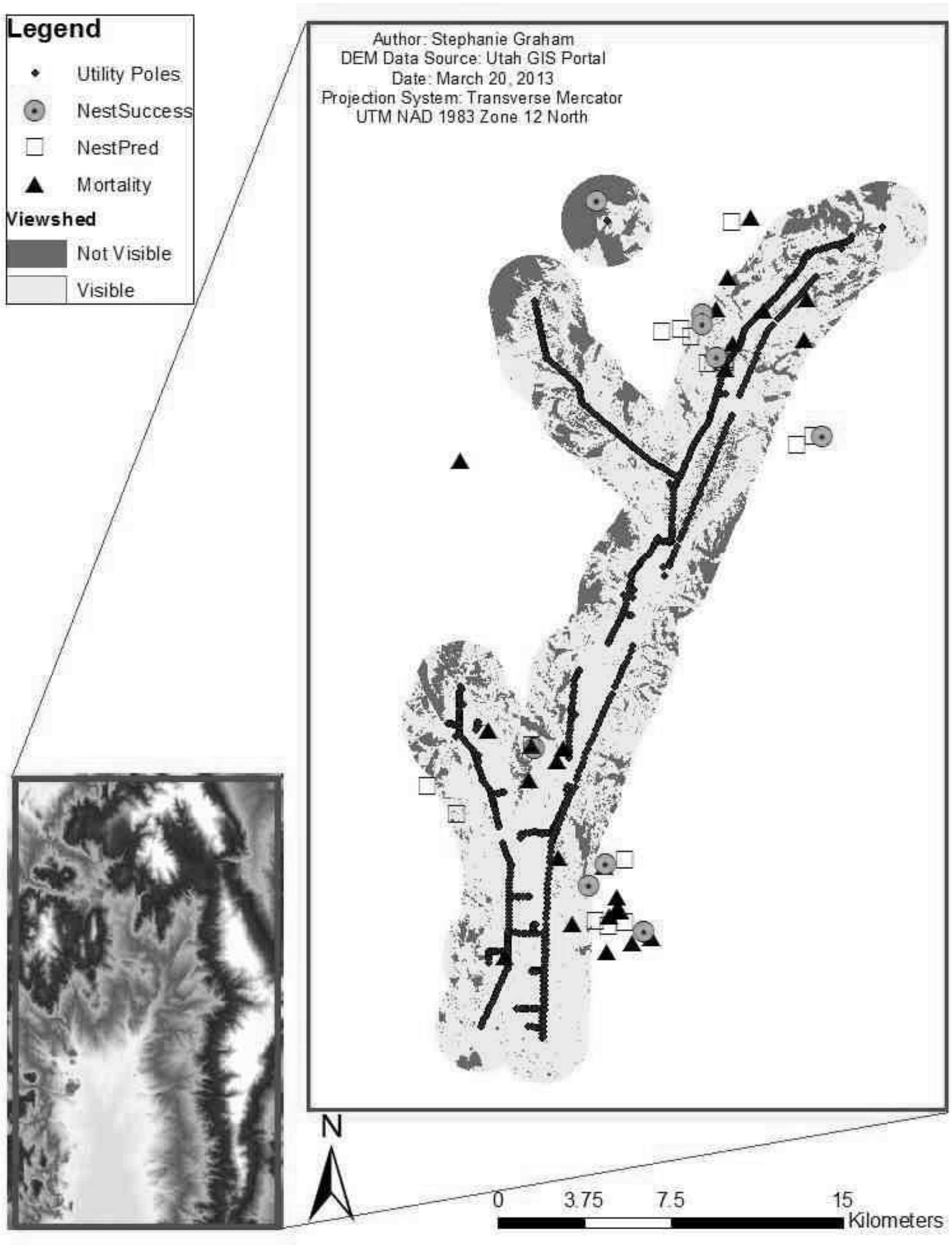

Figure 2-7. Viewshed analysis, which shows visible landscape regions from tops of utility poles, western Box Elder County, UT, 2010-2012. Viewshed is restricted by a 2 km buffer.

CHAPTER 3

GREATER SAGE-GROUSE USE OF FORAGE KOCHIA GREENSTRIP FIREBREAKS: IMPLICATIONS FOR SPECIES CONSERVATION

ABSTRACT

The loss and fragmentation of sagebrush (*Artemisia* spp.) habitats have been implicated as a primary cause of range-wide declines in greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) populations. In the Great Basin Region of the western United States, the introduction and spread of cheatgrass (*Bromus tectorum*) and other invasive species have increased the frequency of wildfires, exacerbating sage-grouse habitat loss. Greenstrips, which are firebreaks planted with fire-retardant vegetation, such as forage kochia (*Bassia prostrata*), have been used to mitigate wildfire threats. No information has been published regarding sage-grouse use of forage kochia firebreaks or the impacts of forage kochia firebreaks on sagebrush habitats. To evaluate sage-grouse use of forage kochia greenstrips, I monitored habitat-use patterns of 53 radio-collared sage-grouse from 2010-2012 on seasonal range that had been greenstripped in northwestern Box Elder County, Utah. I used permanent transects to compare vegetation responses in treated and untreated plots. Shrub densities in the treatments were reduced because of the chain harrowing used to prepare the seedbed. Two years post-treatment, the frequency of invasive vegetation species between treated and untreated sites did not differ (P = 0.81). Spatial analysis and distance sampling revealed that sage-grouse used untreated areas more heavily than treated areas. However, sage-grouse used the greenstripped areas as an extension of their lek. Although forage

kochia was successfully established in the greenstrips, it is premature to conclude that treatments provided the desired wildfire firebreak. Further research is needed to determine forage kochia's role as an ecological bridge in restoring sage-grouse habitat. In the interim, greenstripping of sagebrush habitat occupied by sage-grouse should be planned to minimize the loss of existing sagebrush canopy cover, particularly on winter range. Ecological assessments should be made prior to applying this land management treatment in order to assess the potential of sagebrush recovery post-treatment.

INTRODUCTION

Sagebrush (*Artemisia* spp.) ecosystems have been lost or degraded throughout western North America because of anthropogenic activities, including agriculture, urbanization, and energy development (Connelly et al. 2004). These impacts have been further exacerbated by invasive plant species, which have changed historical fire regimes (Holechek 1981, Whisenant 1990, Knick 1999). In many regions, shrublands have declined 20-50% (Noss and Peters 1995, U.S. Department of the Interior 1996).

Sagebrush ecosystems can easily transition to alternate states dominated by woodlands or annual grasslands (Miller and Rose 1999, Baker 2006). These new communities can replace areas previously dominated by sagebrush; and without proper management techniques, the original sagebrush habitats may be lost forever (Pyke 2011). Fragmentation of shrub-steppe and the pattern of agricultural conversion on several soil types have been detrimental for many sagebrush obligate species (Vander Haegan et al. 2000). Greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) are an indicator of the potential effects of the loss and fragmentation of sagebrush ecosystems on other sagebrush obligate species (Stiver et al. 2006).

Currently, sage-grouse occupy < 56% of their historical range in western North America (Schroeder et al. 2004). In Utah, sage-grouse originally occupied approximately 33% of the state's land area. The species now inhabits an estimated 13% of the state (Beck et al. 2003). These declines are a concern to land and wildlife managers throughout the species' range, not only because of species conservation, but implications regarding the ecological condition and status of sagebrush ecosystems upon which sage-grouse and other sagebrush-obligate species depend (Schroeder et al. 1999).

Although wildfires are a natural process in sagebrush ecosystems, they can have dramatic effects and unintended consequences where anthropogenic disturbances have altered fire regimes (Allen et al. 2008). In the case of sagebrush ecosystems, the effects of fire can be long-term and permanent (Baker 2006). It can take up to 36 years under good conditions to reestablish up to 25% of the original plant base in sagebrush communities after a wildfire (Ziegenhagen 2003). Concomitantly, the suppression of wildfires has contributed to woodland expansion and changed vegetation composition across landscapes (Miller and Rose 1999, Allen et al. 2008).

The dynamics and composition of plant, soil, and wildlife communities can be dramatically and possibly permanently altered by wildfires. In a study that focused on the impact of fire across a variety of avian species in south-central Washington, all species of birds except for the horned lark (*Eremophila alpestris*) decreased in population post-fire (Earnst et al. 2009). Allen et al. (2008) reported that post-fire, big sagebrush (*A. tridentata*) was completely eliminated from the seedbank because the burn consumed the entire shrub litter. Wildfires can also alter soil properties, nutrient cycling, and increase invasive plant species (Young and Evans 1978, Vitousek 1990, Haubensak et al. 2009).

To reduce the wildfire threats to important sage-grouse habitats, wildlife managers have advocated the use of greenstriping (Vollmer 2005). Greenstrips generally consist of long narrows strips or bands of land that have been seeded with plants that are fire-retardant. These strips of fire retardant vegetation are seeded in a serpentine manner across the landscape, in sufficient widths to reduce fuel loads and impede an actual fire, which facilitates fighting it (Vollmer 2005).

The greenstripping process typically involves the reduction of competition from woody species by mastication (Owen et al. 2009), the application of a herbicide to reduce invasive plant competition, followed by tilling through the use of a chain-harrow to prepare the seedbed, and concluding with aerially broadcasting fire-retardant vegetation species. Mastication is preferred to other methods, such as slash burning, because it results in higher plant cover, water availability, and species richness (Owen et al. 2009). Chain harrowing is used in conjunction with mastication to reduce shrub cover while leaving soils intact for future plantings (Cain 1972, Summers 2005). After a disturbance to the soil, invasive species can be prevalent (Halford 1981, Young et al. 1992, Scott et al. 2010). Herbicides are commonly used to reduce the invasion of weed species after soil has been tilled. Plateau® (BASF Chemical Corporation, Research Triangle Park, NC) is a rain-fast systemic residual herbicide that has been used to control invasive grasses, broadleaf weeds, and vine species.

Crested wheatgrass (*Agropyron cristatum*) has been planted throughout the western U.S. because it competes well with cheatgrass and has a high fire tolerance

(Pellant 1994). However, crested wheatgrass can monopolize an area, impeding native plant restoration efforts. (Hansen and Wilson 2006, Newhall et al. 2011).

Forage kochia (*Bassia prostrata*), an introduced semi-shrub, has been suggested as another alternative plant to use in rangeland restoration projects. This plant was initially brought into the U. S. to compete with halogeton (*Halogeton glomeratus*) (Tilley et al. 2006). It is highly preferred on rangelands due to its forage production and quality, palatability, and competition with annuals (Stevens et al. 1985). Forage kochia has a high protein content, over 13% in the summer months. After the initial plants are established, a consistent yearly seed crop is produced (Stevens et al. 1985). Forage kochia competes well with invasive annuals and exhibited a 10-fold higher moisture content than cheatgrass and crested wheatgrass in late August (Pellant 1994). Its high moisture content enhances the plants' fire retardant properties and its attractiveness for use in greenstrips. Because of its drought tolerance, structure, high moisture content, fire-retardancy, and nutrients, forage kochia may be a desirable ecological bridge species for the protection and restoration of degraded sage-grouse habitats that are susceptible to wildfires.

Box Elder County, located within the Great Basin Region of western U.S., has one of the four largest sage-grouse populations in the state of Utah (Beck et al. 2003). Impacts of wildfire and associated effects on sage-grouse winter habitats have been identified as a major species conservation threat by the West Box Elder Adaptive Resource Management (BARM) sage-grouse local working group (BARM 2007). This threat may be further exacerbated by climate change. Climate models project an increase in average monthly temperatures and a decrease in spring snowfall throughout the Rocky

Mountain and Great Basin regions (Mote 2009). These conditions may facilitate the spread of cheatgrass and other annuals that have high recruitment rates in an already stressed sagebrush ecosystem (Dalgleish et al. 2010).

Mitigating the impact of fragmentation, wildfire, and spread of invasive species under climate change, as well as increasing wildlife cover and forage, will require more information about the effects of restoration techniques on ecological site conditions, plant composition, and wildlife communities. Greenstripping may be one technique for minimizing the effects of wildfire. Little research has been conducted to assess the effects of greenstripping with forage kochia on sage-grouse populations and sagebrush habitats. The objective of my study was to determine the effects of greenstripping with forage kochia on sage-grouse habitats and subsequent habitat-use.

STUDY AREA

My study was conducted in western Box Elder County, located in northwestern Utah, USA. It is within Management Zone IV, which is part of the range-wide sage-grouse conservation region that encompasses the northern part of the Great Basin (Stiver et al. 2006). The study site encompassed approximately a 4,800 ha area within the Grouse Creek Watershed, commonly referred to as Badger Flat (Fig. 3-1). Badger Flat was managed by the U.S. Bureau of Land Management as part of a domestic livestock grazing allotment. The primary land use was open range winter grazing by domestic cattle (*Bos taurus*). Badger Flat provided important sage-grouse winter habitat (Knerr 2007, BARM 2007, Thacker 2010).

The study site was categorized as relatively flat shrubland interspersed with ephemeral wet meadow and bordered by juniper (*Juniperus osteoperma*) woodlands at higher elevations. Elevations ranged from 1500-1800m. Average daily summer temperatures ranged from 21˚C to 27˚C. Average daily winter temperatures ranged from -7˚C to 2˚C. Average precipitation was 29 cm per year. Total precipitation from January-May 2011 was 18.00 cm. Total precipitation from January-May 2012 was 11.63 cm.

Primary shrub species included Wyoming big sagebrush (*A. tridentata*), black sagebrush (*A. nova*), shadscale (*Atriplex confertifolia*), rabbitbrush (*Chrysothamnus* spp., *Ericameria* spp.), and juniper. Common grasses include sandberg bluegrass (*Poa secunda*), Kentucky bluegrass (*Poa pratensis*), cheatgrass (*Bromus tectorum*), and wheatgrasses (*Agropyron* spp., *Elymus* spp., *Pseudoroegneria* spp.). Common forbs included blue-eyed mary (*Collinsia parviflora*), wild onion (*Allium acuminatum*), phlox (*Phlox* spp.), astragalus (*Astragalus* spp.), tansymustard (*Descurainia pinnata)*, bur buttercup (*Ceratocephala testiculata)*, halogeton, and blue mustard (*Chorispora tenella*).

METHODS

Greenstripping

Approximately 6% (286 ha) of Badger Flat was greenstripped in 2010. The greenstrips were 91.4 m wide (Fig. 3-2, Fig. 3-3). The treatments were implemented using the following protocols: 1) August 1 – 15, mastication of juniper within greenstrip area (Fig. 3-3); 2) August 16 – mid September, chain harrow greenstrip (seedbed preparation/removal of shrubs); 3) Sept 2-12, spray Plateau herbicide – 59.1mL

Plateau/ha, 0.38 l MSO (methylated seed oil)/ha, applied in 15.3 l water/ha; 4) December 13, aerially apply forage kochia seed 5.06 bulk kg/ha. Seed was cold stored for 2 years and therefore the treatment rate was higher (5.06 bulk kg/ha) than normal (2.8 bulk kg/ha). Forage kochia seed that is stored for 1 year has greater viability than forage kochia that is stored for ≥2 years (Kitchen and Monsen 2001). In addition, the greenstrip seedbed was double chained in areas where shrubs remained after the initial chaining in order to ensure proper seedbed preparation. The greenstrip treatment encompassed sage-grouse breeding and winter habitats near an active lek.

Vegetation Responses

I established six random paired plots, six in the treatment and six in the non-treatment areas within the Badger Flat polygon in 2010 (Fig. 3-4). All vegetation measurements were recorded during the last week in May and the first 2 weeks of June. Within each plot, I used a line-intercept and point-intercept method to determine shrub cover and overall vegetation species composition (Canfield 1941). Live shrub canopy cover was measured along the tape; gaps in shrub cover less than 5 cm were counted as continuous and gaps greater than 5 cm were excluded (Connelly et al. 2003). Plant species or ground cover was documented every 1 m along the 100 m measuring tape by dropping a pin down at each meter mark. In 2011 and 2012, I increased the number of paired plots and associated transects to eight. The line-intercept and point-intercept transects were randomly located within each paired plot. I used the vegetation surveys to document effects of the treatment and changes in vegetation structure over time.

In mid-August 2011 and 2012, I placed eight 100 m transects at random locations within the treatment. A 1m x 1m frame was placed on the ground every 5 m of each 100 m transect. All forage kochia plants within the 1m x 1m frame were recorded. These measurements were recorded to determine the success of the seeding and change in cover over time.

Trapping and Radio-Telemetry

Sage-grouse were captured with a long-handled hoop net and radio-collared at night on Badger Flat from February-May during 2010-2012 using all-terrain vehicles and a spotlight method (Connelly et al. 2003). Captured birds were weighed using a small bag and a 22 kg spring scale (Eagle Claw, Denver, Colorado, USA). The age class and sex of each bird were documented based on weight and primary feather characteristics (Dalke et al. 1963). All methods followed protocols approved by the Utah State University Institutional Animal Care and Use Committee (IACUC #1194, COR #2BAND6891). Battery-powered Advanced Telemetry Systems™ (Advanced Telemetry Systems, Isanti, MN, USA) 16 g radio transmitters (149.000-152.000MHz) were placed on adult and juvenile sage-grouse allowing for relocation. The transmitters had a battery life of 22 months (24 hours on). I relocated birds weekly throughout the breeding season and winter to determine use or avoidance of treatment areas. Locations of birds were acquired within 5 m accuracy using a Garmin™ (Garmin, Olathe, KS, USA) global positioning system (GPS) set to Universal Transverse Mercator (UTM) NAD83 units.

Birds were relocated using Communications Specialist, Inc.™ (Orange, California, USA) receivers and Telonics (Telonics, Inc., Mesa, AZ) hand-held Yagi antennae. I monitored birds weekly from February-August 2010, January-August 2011, and January-August 2012 within Badger Flat.

I located sage-grouse mortalities as quickly as possible once mortality signals were detected. Location and vegetation characteristics of mortality sites were documented. Notes about potential predator species, such as claw marks, bite marks, scat, and tracks, were also documented. Often, it was difficult to determine predator species due to scavenger activity.

Sage-grouse Response

I recorded sage-grouse locations throughout Badger Flat to determine if and when the birds used treated and untreated areas. I used ArcGIS 10.0 (ESRI, Redlands, CA) to create a map with sage-grouse locations in relation to the treatment. I conducted a buffer analysis, in which I created 30 m buffer polygons around the treatment feature class. These buffers were created to determine if an edge effect was created because of the treatment and how it may have affected sage-grouse use.

I used a distance sampling technique to compare the quantities of fecal pellets in treatment and non-treatment areas (Buckland et al. 1993). Distance sampling is a practical technique that is often a more efficient method than reporting densities based on live animal captures and locations (Palomares 2001). I surveyed 12 100-m distance sampling transects in May 2010 and 16 500-m distance sampling transects in May 2011 and 2012. In 2010, I conducted the distance sampling transects along the same 100 m sections that were used for the line-intercepts and point-intercepts. Because of the lack of goodness-of-fit and coefficient of variation, I was not able to use my results from 2010.

In 2011 and 2012, I increased the number of transects to 16 and made each transect 500 m in order to increase my sampling size, reduce the coefficient of variation, and improve the goodness of fit. Two observers walked at a steady pace along all transects and recorded pellets within 7 m of transect line. Perpendicular distances from pellets to transect line and to starting point were recorded. Pellet age was also classified based on color and white ring around the outside of each pellet. Pellets that appeared to be greater than one year were not included in analysis. All distance sampling was completed during the last week of May and first 2 weeks of June.

Data Analysis

Vegetation Response

I evaluated shrub response to the treatment and species composition on Badger Flat through analysis of variance of a 2-way factorial in a split-plot design with repeated measures (PROC MIXED, SAS® System for Windows 9.3, Cary, NC). Greenstrip treatment or non-treatment and year were fixed effects. Interactions between fixed effects were analyzed. Random effects consisted of plots nested within treatment or non-treatment (plot(trt)). Methods were repeated in 2010, 2011, and 2012. Denominator degrees of freedom were calculated using the Satterhwaite method. Akaike information criterion (AIC) values were used to designate covariance structure for repeated measures (Burnham and Anderson 2002). Assumptions of normality and homoscedasticity were checked and model assumptions were met.

I categorized data from the point-intercept into bare ground, litter, rock, invasive, and non-invasive plants. I was particularly interested in assessing the number of invasive plants across treatment and years. Since there were many zeros for the proportion of invasive species, I analyzed the point-intercept data with a binomial distribution (PROC GLIMMIX, SAS® System for Windows 9.3, Cary, NC) and maximum likelihood estimated parameters based on the Laplace approximation. I also used this method and descriptive statistics to calculate forage kochia densities across the treatment site.

Sage-grouse Response

The buffer analysis was utilized to determine if there was an edge effect (ArcGIS 10.0, ESRI, Redlands, CA). Based on the output feature buffers, I categorized groups of sage-grouse locations into 30 m buffers that surrounded the treatment. I also used observational data to determine sage-grouse habitat use. I used Program DISTANCE 6.0 release 2 (Thomas et al. 2010) to determine density estimates of sage-grouse pellets in treated and untreated sites based on fecal pellets. In 2010 the sample size was inadequate and I discarded data from that year. I used a density model to determine the effect of the greenstrip treatment on sage-grouse pellet presence in 2011 and 2012. Sage-grouse pellet densities can indicate sage-grouse use of an area. The density model used pellet densities as a function of treatment effect, and year effect was included as a covariate. I ran models that were truncated and non-truncated. Results were similar between the two models; therefore I used the model without truncation. The top model with the lowest coefficient of variation and lowest AIC (Akaike 1973) was the half normal cosine model with Poisson distribution. The model was post-stratified using interaction of treatment and year and a global detection function.

RESULTS

Sage-grouse Captures

I captured and radio-collared 45 birds between 2010-2012 (Table 3-1). Eight adult female sage-grouse that were radio-collared in 2008 as part of a previous study were included in my sample (Thacker 2010).

Vegetation Response

Pre-treatment vegetation measurements were recorded in 2010. Post-treatment vegetation measurements were recorded in 2011 and 2012. Shrub height did not change from 2010-2012. Average shrub diameter and percent shrub cover decreased in response to the treatment and year. The average shrub diameter decreased from 18.7 ± 0.9 cm in 2010 to 15.2 ± 1.1 cm in 2011 and 12.0 ± 0.9 cm in 2012 (P=0.03). Percent shrub cover varied in response to treatment and year. Percent shrub cover encompassed 10.4%±1.3 in 2010, 5.5%±1.2 in 2011 and 5.3%± 1.0 in 2012 (P=0.01). Percent shrub cover was greater in the non-treatment areas (8.1%± 0.9) than in the treatment areas (2.7%± 0.6, P=0.0003).

Vegetation transects varied in percent composition of rock, bare ground, litter, invasive vegetation, and non-invasive vegetation (Fig. 3-6). Throughout the paired plots, non-invasive vegetation was more prevalent than invasive vegetation. However, some transects exhibited up to 46% invasive vegetation. Common invasive plants along the paired plots in my study area included halogeton, cheatgrass, and bur buttercup. Percent invasive vegetation did not differ between years (P=0.92) or treated and untreated plots (P=0.81).

Forage kochia seedlings emerged in July 2011. Seventy-three and 68 out of 160 plots contained forage kochia in 2011 and 2012, respectively. In 2011 and 2012, 573 and 570 plants had emerged in the plots, respectively. Forage kochia frequencies did not differ between years (P=0.94). In 2011, 45.6% of plots contained forage kochia, and 42.5% of plots contained forage kochia in 2012.

Sage-grouse Habitat-Use Responses

Radio-collared sage-grouse inhabited Badger Flat both pre- and post-treatment (Fig. 3-1). In 2011 and 2012, sage-grouse expanded their lekking ground to encompass a larger portion of the treated area (Fig. 3-5). Buffer analysis revealed that there was no edge effect of the treatment based on sage-grouse locations.

Fecal pellets were observed in both treatment and non-treatment plots. Through analysis of distance sampling, the top model for density estimates with the best coefficient of variation and lowest AIC value was the half normal cosine with Poisson distribution. Based on my sampling design and analysis, I estimated 163 pellets per ha in the non-treatment area (9.2%CV, 95% CL = 136.13-194.92) and 105.6 pellets per ha in the treatment area (16.0%CV, 95% CL = 77.29-144.17) in 2011. There were more fecal pellets in both the non-treatment area (1125.1 pellets per ha, 5.9%CV, 95% CL = 1002.90-1262.30) and treatment area (617.9 pellets per ha, 7.3%CV, 95% CL = 535.61-712.89) in 2012.

DISCUSSION

Previous research has demonstrated the beneficial effect of site-specific land treatments on sage-grouse habitat-use (Sime 1991, Dahlgren et al. 2006, Guttery 2011).

However, Dahlgren et al. (2006) concluded that treatments in sagebrush should be limited in scope and area, such as enhancing early brood-rearing habitat foraging conditions. Prior to my research, no information has been published quantifying sage-grouse responses to greenstripping. My study demonstrated that sage-grouse preferred non-treated over treated areas with the exception for the lekking season. Further, the greenstrip seedbed preparation reduced the sagebrush canopy cover in the treated area immediately post-treatment. Two years after treatment, the sagebrush shrub canopy had not recovered. It is common for sagebrush to take >10 years to recover post-mechanical treatment (Boyd and Svejcar 2011) and long-term monitoring can address this response.

The increased risk of wildfires destroying important sage-grouse winter range based upon current plant community and climate (BARM 2007, Thacker 2010) prompted the BLM to plant forage kochia greenstrips in the Badger Flat study site. Although greenstrips can be beneficial to protecting sagebrush habitat, seedbed preparation prior to seeding greenstrips also created a disturbance to the land. In my study area, sagebrush canopy cover exhibited residual impacts of the double chaining used to prepare the seedbed. Double chaining can remove 75-80% sagebrush (Cain 1972) and prepare the seedbed. Two years post-treatment sagebrush canopy cover was still lower than percent cover prior to treatment.

Wildlife managers also have expressed concern that introduced plant species used in rangeland rehabilitation programs may outcompete desired native species, while creating new monocultures if used extensively to rehabilitate areas impacted by wildfires. For instance, crested wheatgrass has been used as a rehabilitation species because of its ability to compete with other invasives (Francis and Pyke 1996). However, crested wheatgrass can monopolize an area and make permanent ecological changes across the landscape (Marlette and Anderson 1986). Similar concerns have been expressed about the use of forage kochia in the rehabilitation of occupied sage-grouse habitats (J. Connelly, Idaho Department of Fish and Game, personal communication).

To minimize the potential negative effects associated with the disturbance, only 6% of the land across Badger Flat was treated. My results 2 years post-treatment suggest that the forage kochia planted in the greenstrips on Badger Flat was non-invasive, with seedlings largely confined to the prepared seedbeds. Harrison et al. (2002) reported that the scientific literature adequately documented the non-invasive qualities of forage kochia; thus, forage kochia has the potential to replace invasive annuals (McArthur et al. 1989), while maintaining native plant communities (Clements et al. 1997).

Chain harrowing and juniper mastication reduced sagebrush densities during seedbed preparation. There was a slight reduction in shrub diameter and percent cover, but not shrub height. This observation would be expected, given that the harrow is dragged across the landscape with the intent of removing standing vegetation while preparing the seedbed for planting.

Chain harrowing is often used to prepare seedbeds for plantings (Clary 1988). Areas of the study site that had been chained multiple times had a larger proportion of forage kochia seedlings. Because chaining creates a soil disturbance, managers must be wary that this practice can facilitate the spread of invasive vegetation species. Fairchild et al. (2005) documented that one-way chaining reduces stand density less than two-way chaining. However, Clary (1988) noted that double chaining resulted in a higher number of native shrubs 3 years post-treatment and fire than single chaining. Therefore, double chaining may initially reduce the shrub cover at my study site, but native shrubs may be more likely to regenerate after two-way chaining. Previous studies have shown that mechanical treatments can increase invasive species (Rauzi 1974). To mitigate this risk, BLM applied a single season application of Plateau, which is an herbicide that suppresses invasives. This herbicide has been successful in reducing up to 79% invasive annual grasses (Bekedam 2005); however, managers are also concerned that the herbicide would reduce native plant species (Baker et al. 2009). I did not detect any difference in invasive plant densities between the treated and control areas. However, without herbicide application, the density of invasive annuals in the treated areas could have been much higher (Eddington 2006).

Spring precipitation in 2011 was higher than in 2012. The higher amounts of snowfall and rainfall provided optimal conditions for forage kochia emergence and growth in 2011 (Haferkamp et al. 1990).

We used a higher seeding rate, 5.06 bulk kg/ha compared to 2.8 bulk kg/ha for most plantings, because the seed had been cold stored for 2 years. The higher rate of seeds likely led to the higher germination rate (46%). Germination rates range from 0-60% for year-old and 2 year-old seed (Kitchen and Monsen 2001, Creech 2012). The forage kochia densities across the greenstrip did not differ from 2011 to 2012. Forage kochia seeds that are stored in permanent cold conditions can provide a 10-fold greater germination rate than seeds stored in non-temperature controlled areas (Kitchen and Monsen 2001). For this reason, we planted cold-stored seed. Studies have shown that forage kochia can be planted at different rates, but that higher application rates yield higher plant densities (Page et al. 1994).

Sage-grouse remained on the site and used a portion of the treated area for lekking (Fig. 3-5). Lek grounds are breeding areas that have been characterized as open sites ranging from grassy meadows to gravel pits and other man-made clearings (Connelly et al. 1981, Dalke et al. 1963). The open area created by the greenstrip allowed sage-grouse to expand their lek region to encompass a larger breeding area on the study site.

Predators prefer to move along roads and other anthropogenic structures, which decreases their energy expenditure (Crête and Larivière 2003, McDonald et al. 2008). A larger lek could lead to increased visibility and acoustics of male sage-grouse by hens as well as predators (Boyko et al. 2004).

No edge effect was associated with the treatment based on buffer analysis. Fecal pellets were found in both treatment and non-treatment areas. However, untreated areas had a higher density estimate of pellets than treated areas. Sage-grouse may use the greenstrip as a strutting area, but they may spend a majority of their time roosting and defecating in untreated areas, which could explain the difference in density estimates among treated and untreated sites. Untreated areas provide more cover from predators (Gregg et al. 1994) and extreme weather factors, such as wind (Riley et al. 1992). Therefore, untreated areas may be used more often when the sage-grouse are not strutting. The increase in overall fecal pellet densities from 2011 and 2012 could be due to the number of birds present on Badger Flat.

Forage kochia is a drought-resistant plant that is useful in minimizing the impact of fire (Pellant 1994). Climate models indicate an increase in daily and nightly temperatures and an increase in evapotranspiration rates throughout the western US (Wagner 2009). Human expansion, fragmentation, and reduction of water resources are inevitable. Therefore, an ecological bridge species that is drought-resistant and can reduce spread of fire and subsequent invasive plants is necessary to protect remaining sagebrush ecosystems. Sagebrush shrublands are susceptible to transitioning to invasive annual grasslands, which may increase fire occurrence, alter carbon sources, and thus continue to spread invasive vegetation species (Bradley et al. 2006, Brooks and Pyke 2001). Creating greenstrips with forage kochia can help maintain sagebrush habitats by reducing the spread of wildfire and thus reducing the ecological transition from sagebrush shrublands to annual grasslands that are dominated by invasive species. Protecting sagebrush habitats is critical for maintaining sagebrush obligate species and overall biodiversity.

MANAGEMENT IMPLICATIONS

Prior to beginning any work in sagebrush areas occupied by sage-grouse, managers must define clear measurable objectives and use management techniques that have demonstrated benefits to sage-grouse populations (Connelly et al. 2000, Dahlgren et al. 2006, Guttery 2011). Landscape triage must be prioritized, in which various states of ecosystems are categorized for active or passive restoration. Restoration activities may only be needed if invasive plants are dominant and diverse functional plant communities do not exist (Pyke 2011).

The Badger Flat site preparations and seeding rates produced the desired vegetation responses in that forage kochia seedlings emerged and invasion of annual grasses and forbs in disturbed soils was mitigated. Two years post-treatment, forage kochia remained confined to the seedbed; however the double chaining of the seedbed and herbicide use may have continued to impact recovery for the desired sagebrush canopy cover. Correspondingly, outside of increased use of the treated areas during lekking areas, sage-grouse preferred non-treated areas.

Caution should be exercised when creating any sort of disturbance to the landscape. Disturbances may increase areas for sage-grouse to strut; however, they may also increase predation pressures and decrease cover for nesting and brood-rearing. When creating greenstrips, no more than 6% of the land should be manipulated and greenstrips should not exceed 100 m in width. This size of treatment allows for effective fire suppression while still allowing sagebrush habitat to remain largely intact. Other researchers have suggested that overall treatment areas should be minimal and should focus on increasing diverse sagebrush communities (Connelly et al. 2000).

Herbicides should be used in conjunction with chaining and planting to minimize the spread of invasive vegetation species. Multiple herbicide applications may be necessary based on the individual ecological site. Germination of forage kochia seed is more likely to occur with winter plantings and cold-stored or fresh seed. Planting of forage kochia with old seed or seed that was not in a cold temperature controlled environment is not recommended.

Long-term monitoring should continue to assess changes in sage-grouse behavior and vegetation response over time. Observer bias should be minimized to obtain accurate responses. An increase in distance sampling transects and line-intercept transects might also lead to a better goodness-of-fit.

Although human expansion, fragmentation, change in soil composition, and spread of invasive species is inevitable, ecological bridges can be formed to help protect sagebrush habitats and maintain biodiversity. I recommend that land managers continue to monitor the treatment and wildlife response to this greenstrip treatment. Research should also address dietary elements of forage kochia (see Chapter 4). I also encourage land managers to use adaptive management techniques in order to maintain ecologically diverse regions, reduce fragmentation, and mitigate threats to wildlife.

LITERATURE CITED

Akaike, H. 1973. Information theory and an extension of the maximum likelihood principle. Pages 267-281 *in* B. N. Petrov and F. Csaki, editors. Second international symposium on information theory. Akademiai Kiado, Budapest, Hungary.

Allen, E., R. S. Nowak, and J. C. Chambers. 2008. Effects of a spring prescribed burn on the soil seed bank in sagebrush steppe exhibiting pinyon-juniper expansion. Western North American Naturalist 68:265-277.

Baker, W. L. 2006. Restoration of sagebrush ecosystems. Wildlife Society Bulletin 34:177-185.

Baker, W. L., J. Garner, and P. Lyon. 2009. Effect of imazapic on cheatgrass and native plants in Wyoming big sagebrush restoration for gunnison sage-grouse. Natural Areas Journal 29:204-209.

BARM (West Box Elder Adaptive Resource Management Local Working Group). 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. Unpublished Report. Salt Lake City, Utah, USA.

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

Bekedam, S. 2005. Establishment tolerance of six native sagebrush steppe species to imazapic (Plateau®) herbicide: implications for restoration and recovery. Thesis, Oregon State University, Corvallis, USA.

Boyd, C. S., and T. J. Svejcar. 2011. The influence of plant removal on succession in Wyoming big sagebrush. Journal of Arid Environments 75:734-741.

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

Bradley, B. A., R. A. Houghton, J. F. Mustard, and S. P. Hamburg. 2006. Invasive grass reduces aboveground carbon stocks in shrublands of the Western US. Global Change Biology 12:1815-1822.

Brooks, M.L., and D.A. Pyke. 2001. Invasive plants and fire in the deserts of North America. Pages 1–14 *in* K.E.M. Galley and T.P. Wilson, editors. Proceedings of the Invasive Species Workshop: The Role of Fire in the Control and Spread of Invasive Species. Fire Conference 2000: The First National Congress on Fire Ecology, Prevention, and Management. Miscellaneous Publication No. 11, Tall Timbers Research Station, Tallahassee, Florida, USA.

Buckland, S. T., D. R. Anderson, K. P. Burnham, and J. L. Laake. 1993. Distance sampling. Chapman and Hall, London, United Kingdom.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multi-model inference: a practical information-theoretic approach. Second edition. Springer-Verlag, New

York, New York, USA.

Cain, Donald R. 1972. The Ely Chain. Bureau of Land Management. Ely, Nevada.

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

Clary, W. P. 1988. Plant density and cover response to several seeding techniques following wildfire. Research Note INT-384, USDA, Forest Service, Intermountain Research Station, Ogden, Utah, USA.

Clements, C. D., K. J. Gray, J. A. Young. 1997. Forage kochia: to seed or not to seed. Rangelands 19: 29-31.

Connelly, J. W., W. J. Arthur, and O. D. Markham. 1981. Sage grouse leks on recently disturbed sites. Journal of Range Management 34:153-154.

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

Connelly, J. W., 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, 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.

Creech, C. F. 2012. Effects of planting date, harvest date, and environmental conditions on germination of forage kochia accessions. Thesis, Utah State University, Logan, USA.

Crête, M., and S. Larivière. 2003. Estimating the costs of locomotion in snow for coyotes. Canadian Journal of Zoology 81:1808-1804.

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

Dalke, P. D., D. B. 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.

Dalgleish, H. J., D. N. Koons, and P. B. Adler. 2010. Can life-history traits predict the response of forb populations to changes in climate variability? Journal of Ecology 98: 209-217.

Earnst, S., H.L. Newsome, W.L. LaFramboise, and N. LaFramboise. 2009. Avian response to wildfire in Interior Columbia Basin Shrubsteppe. The Condor 111:370-376.

Eddington, D. B. 2006. Effects of cheatgrass control on Wyoming big sagebrush in Southeastern Utah. Thesis, Department of Plant and Animal Science, Brigham Young University, Provo, Utah, USA.

Fairchild, J. A., J. N. Davis, and J. D. Brotherson, and USDA Forest Service. 2005. Big sagebrush response to one-way and two-way chaining in southeastern Utah. *In* N. L. Shaw, M. Pellant, S. B. Monsen, comps. Sage-grouse habitat restoration symposium proceedings; 2001 June 4–7; Boise, ID. Proceedings RMRS-P 38. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado, USA.

Francis, M. G., and D. A. Pyke. 1996. Crested wheatgrass-cheatgrass seedling competition in a mixed-density design. Journal of Range Management 49:432-438.

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

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. Thesis, Utah State University, Logan, USA.

Haferkamp, M. R., D. C. Ganskopp, K. L. Marietta, and B. W. Knapp. 1990. Environmental influences on germination of utricles and seedling establishment of ‘immigrant’ forage kochia. Journal of Range Management 43:518-522.

Halford, D. 1981. Repopulation and food habits of *Peromyscus maniculatus* on a burned sagebrush desert in southeastern Idaho. Northwest Science 55:44-49.

Hansen, M. J., and S. D. Wilson. 2006. Is management of an invasive grass *Agropyron cristatum* contingent on environmental variation? Journal of Applied Ecology 43:269-280.

Harrison, R. D., B. L. Waldron, K. B. Jensen, R. Page, T. A. Monaco, W. H. Horton, and A. J. Palazzo. 2002. Forage kochia helps fight range fires. Rangelands 24:3-7.

Haubensak, K., C. D’Antonio, and D. Wixon. 2009. Effects of fire and environmental variables on plant structure and composition in grazed salt desert shrublands of the Great Basin (USA). Journal of Arid Environments 73:643.

Holechek, J. L. 1981. Brush control impacts on rangeland wildlife. Journal of Soil and Water Conservation 36:265-269.

Kitchen, S. G., and S. B. Monsen. 2001. Forage kochia seed germination response to storage time and temperature. Journal of Range Management 54:299-306.

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

Knick, S. T. 1999. Requiem for a sagebrush ecosystem? Northwest Science 73:53-57.

Marlette, G. M., and J. E. Anderson. 1986. Seed banks and propagule dispersal in crested-wheatgrass stands. Journal of Applied Ecology 23:161-175.

McArthur, E. D., A. C. Blauer, and R. Stevens. 1989. Forage kochia competition with cheatgrass in central Utah, Symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management, April 5-7, Las Vegas, Nevada. USA.

McDonald, P. T., C. K. Nielsen, T. J. Oyana, and W. Sun. 2008. Modelling habitat overlap among sympatric mesocarnivores in southern Illinois, USA. Ecological Modelling 215:276-286.

Miller, R. F., and J. A. Rose. 1999. Fire history and Western juniper encroachment in sagebrush steppe. Journal of Range Management 52:550-559.

Mote, P. W. 2009. Variability and trends in mountain snowpacks in western North America. Pages 51-62 *in* F. H. Wagner, editor. Climate warming in western North America: evidence and environmental effects. The University of Utah Press, Salt Lake City, USA.

Newhall, R. L., V. P. Rasmussen, and B. M. Kitchen. 2011. Introducing big sagebrush into a crested wheatgrass monoculture. Natural Resources and Environmental Issues 17, Utah State University, Uintah County Extension, Vernal, UT, *In* T. A. Monaco et al. comps. 2011. Proceedings – Threats to Shrubland Ecosystem Integrity; 2010 May 18-20; Logan, UT. Natural Resources and Environmental Issues, Volume XVII. S.J. and Jessie E. Quinney Natural Resources Research Library, Logan, Utah, USA.

Noss, R. F., and R. L. Peters. 1995. Endangered Ecosystems. A status report on America's vanishing habitat and wildlife. Defenders of Wildlife, Washington, D.C., USA.

Owen, S. M., C. H. Sieg, C. A. Gehring, and M. A. Bowker. 2009. Above- and belowground responses to tree thinning depend on the treatment of tree debris. Forest Ecology and Management 259:71-80.

Page, R. J., V. P. Rasmussen, H. H. Horton, R. L. Newhall, D. E. Wilson, G. W. Kidd, and T. C. Roberts, Jr. 1994. White rocks road immigrant forage kochia trial seedings. Rangelands 16:167-168.

Palomeres, F. 2001. Comparison of 3 methods to establish rabbit abundance in a Mediterranean environment. Wildlife Society Bulletin 29: 578-585.

Pellant, M. 1994. History and applications of the intermountain greenstripping program. Pages 63-68 *in* S. B. Monsen and S. G. Kitchen, comps. Proceedings-symposium on ecology and management of annual rangelands. 18-21 May 1992. Boise, ID. General Technical Report INT-GTR-313. USDA Forest Service, Intermountain Research Station, Ogden, Utah, USA.

Pyke, D. A. 2011. Restoring and rehabilitating sagebrush habitats. Studies in Avian Biology 38:531–548.

Rauzi, F. 1974. Mechanical and chemical range renovation in southeastern Wyoming. Journal of Range Management 27:48-52.

Riley, T. Z., C. A. Davis, M. Ortiz, and M. J. Wisdom. 1992. Vegetative characteristics of successful and unsuccessful nests of lesser prairie chickens. The Journal of Wildlife Management 56: 383-387.

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

Schroeder, M. A., J. R. Young, and C. E. Braun. 1999. Sage grouse (*Centrocercus urophasianus*). Pages 1-28 *in* A. Poole and F. Gill, editors. The birds of North America, No, 425. The Birds of North America, Inc., Philadelphia, Pennsylvania, USA.

Scott, J., K. R. Merrill, V. J. Anderson, and S. E. Meyer. 2010. Local population differentiation in *Bromus tectorum L*. in relation to habitat-specific selection regimes. Evolutionary Ecology 24:1061-1080.

Sime, C. A. 1991. Sage grouse use of burned, non-burned, and seeded vegetation communities on the Idaho National Engineering Laboratory, Idaho. Thesis, Montana State University, Bozeman, USA.

Stevens, R., K. R. Jorgensen, E. D. McArthur, and J. N. Davis. 1985. 'Immigrant' Forage Kochia. Rangelands 7:22-23.

Stiver, S. J., A. D. Apa, J. R. Bohne, S. D. Bunnell, P. A. Deibert, S. C. Gardner, M. A. Hilliard, C. W. McCarthy, and M. A. Schroeder. 2006. Greater sage-grouse comprehensive conservation strategy. Western Association of Fish and Wildlife Agencies, Cheyenne, Wyoming, USA.

Summers, D. D. 2005. Vegetation response of a Wyoming big sagebrush community to six mechanical treatments in Rich County, Utah. Thesis, Brigham Young University, Provo, Utah, USA.

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

Thomas, L., S. T. Buckland, E. A. Rexstad, J. L. Laake, S. Strindberg, S. L. Hedley, J. R. B. Bishop, T. A. Marques, and K. P. Burnham. 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. Journal of Applied Ecology 47:5-14.

Tilley, D. J., D. Ogle, L. St. John, and B. L. Waldron. 2006. Plant Guide: Forage Kochia. <http://www.plant-materials.nrc.usda.gov>. Accessed 10 Dec 2012.

U.S. Department of the Interior. 1996. Effects of military training and fire in the Snake River Birds of Prey National Conservation Area. BLM/DARNG Research Project Final Report, U. S. Geological Survey, Biological Resources Division, Snake River Field Station, Boise, Idaho, USA.

Vander Haegen, M. W., F. C. Dobler, D. J. Pierce. 2000. Shrubsteppe bird response to habitat and landscape variables in Eastern Washington, U.S.A. Conservation Biology 14:1145-1160.

Vitousek, P. 1990. Biological invasions and ecosystem processes: towards an integration of population biology and ecosystem studies. Oikos 57:7-13.

Vollmer, J. 2005. New technology for fuel breaks and green strips in urban interface and wildlife areas. Pages 1-7 *in* B. W. Butler, and M. E. Alexander, editors. Eighth International Wildland Firefighter Safety Summit-Human Factors-10 Years Later. Missoula, Montana, USA.

Wagner, F. H. 2009. Climate warming and environmental effects in the west: evidence for the twentieth century and implications for the twenty-first. Pages 143-160 *in* F. H. Wagner, editor. Climate warming in western North America: evidence and environmental effects. The University of Utah Press, Salt Lake City, USA.

Whisenant, S. G. 1990. Changing fire frequencies on Idaho's Snake River Plains: ecological and management implications. Pages 4-10 *in* E. D. McArthur, E. M. Romney, S. D. Smith, and P. T. Tueller, editors. Proceedings-symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management. United States Department of Agriculture Forest Service, General Technical Report INT-276.

Young, J., and R. Evans. 1978. Population dynamics after wildfires in sagebrush grasslands. Journal of Range Management 31: 283-289.

Young, J. A., E. Martens, and N. E. West. 1992. Germination of bur buttercup seeds. Journal of Range Management 45:358-362.

Ziegenhagen, L. L. 2003. Shrub reestablishment following fire in the mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*) alliance. Thesis, Oregon State University, Corvallis, USA.

Table 3-1. Greater sage-grouse captures at Badger Flat, Box Elder County, UT.

	March-May 2010	Nov 2010-May 2011	Feb-April 2012
N Juvenile Female	1	6	2
N Adult Female	1	3	1
Female Weight (g)	1150-1450	1200-1750	1100-1400
N Juvenile Male	2	2	1
N Adult Male	26.5%8	14	4
Male Weight (g)	2200-2900	1900-2950	2200-2600

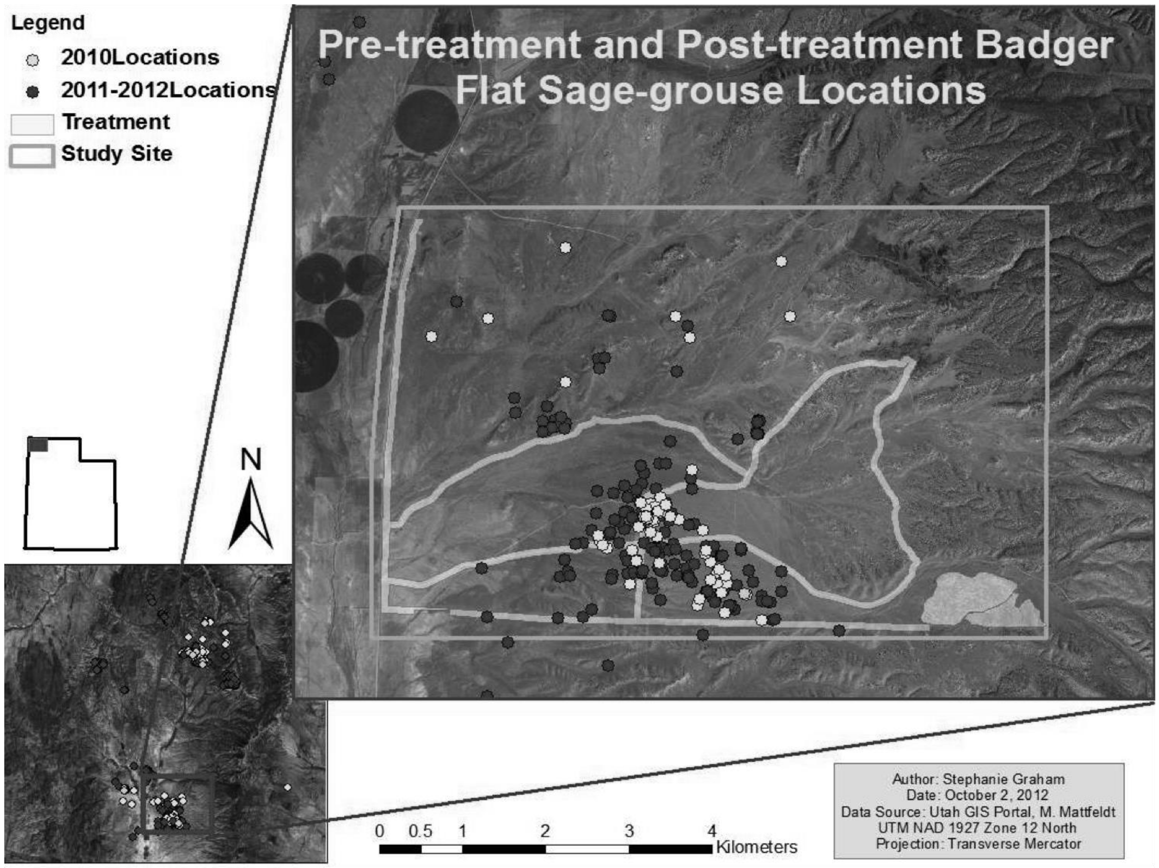

Figure 3-1. Greater sage-grouse locations across the Badger Flat study site, northwestern Box Elder County, Utah. Greenstrip treatments encompassed 286 ha and were 91.4 m wide.

Figure 3-2. Part of the greenstrip in November 2010, northwestern Box Elder County, Utah.

Figure 3-3. Juniper mastication with the use of a bullhog. Completed on Badger Flat, 1-15 August 2010, northwestern Box Elder County, Utah.

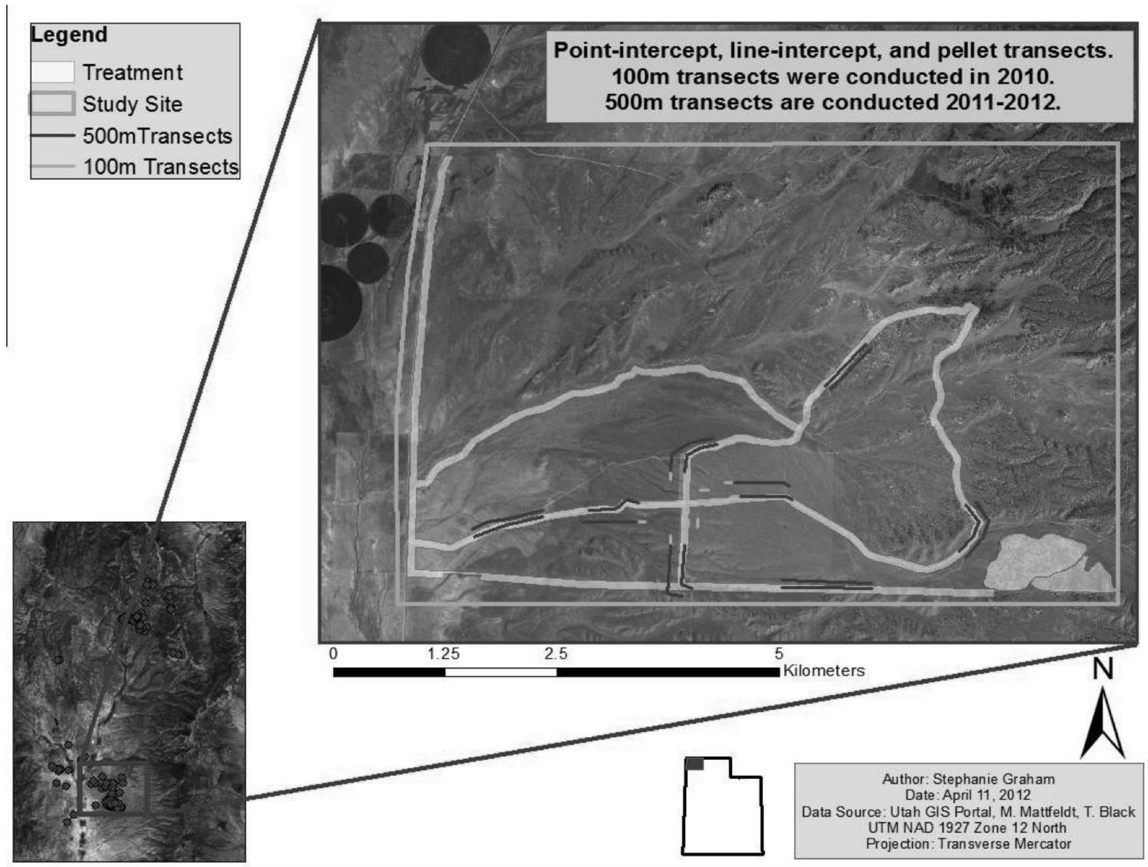

Figure 3-4. Transects that were 100 m were used in 2010 for point-intercept and line-intercept analysis of vegetation. Transects that were 500 m were used in 2011 and 2012 for point-intercept and line-intercept analysis of vegetation. 100 m transects were used for distance sampling of fecal pellets.

Figure 3-5. Sage-grouse used the greenstrip treatment as extended lekking grounds in 2011 and 2012.

Ground Cover Composition

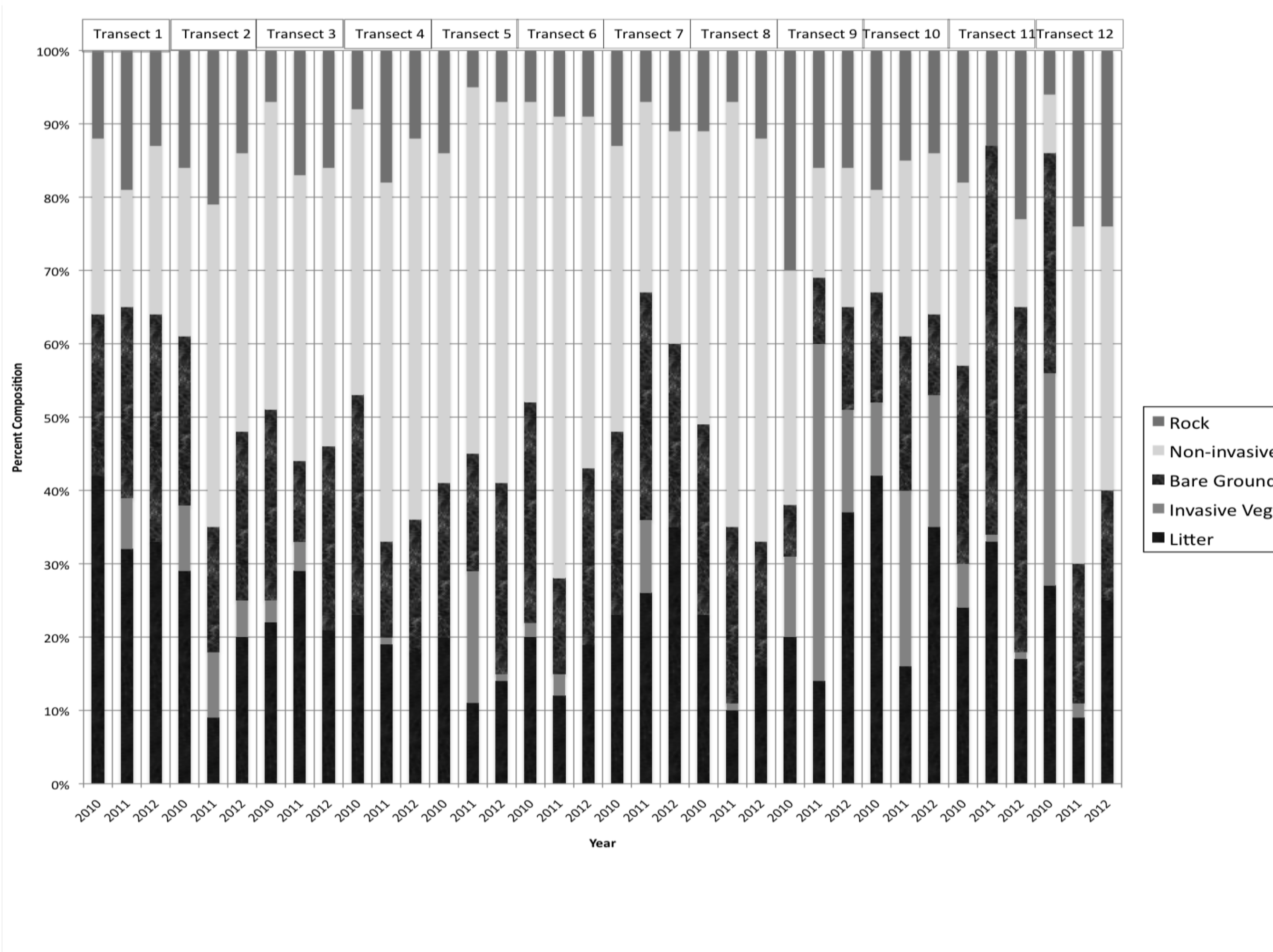

Figure 3-6. Overall ground cover composition based on point-intercept transects. Transects 1, 3, 5, 7, 9, 11 were located in treatment plots. Transects 2, 4, 6, 8, 10, 12 were located in untreated plots. There was not a substantial difference in the amount of invasive vegetation across treatments or years.

CHAPTER 4

FORAGE KOCHIA AS A DIETARY SOURCE FOR GREATER SAGE-GROUSE IN UTAH

ABSTRACT

Forage kochia (*Bassia prostrata*) is a non-native plant selected for use in greenstrips to mitigate the impact of wildfires on sagebrush (*Artemisia* spp.) ecosystems in the western US. In addition to a high moisture content, which contributes to its fire retardancy, the protein content of this semi-shrub approximates that of native black sagebrush (*A. nova*). Greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) may prefer black sagebrush to other sagebrush as winter forage because of its high protein and low terpene composition. No information has been published regarding the surrogate potential of forage kochia as a sage-grouse forage or cover plant. To determine sage-grouse dietary use of forage kochia relative to sagebrush, I collected forage kochia plants and sage-grouse fecal pellets from two sites in northcentral (Tabby Wildlife Management Area; WMA) and northwestern Utah (Badger Flat) where it was planted in 2004 and 2010, respectively. I used chromatography and microhistological techniques to identify the relative presence of forage kochia and sagebrush in sage-grouse fecal pellets. Because forage kochia exhibited non-unique markers and low plant secondary metabolite (i.e. terpene) content, gas chromatography failed to detect forage kochia in fecal pellets. Although liquid chromatography identified possible markers in forage kochia, these markers were not detected in the fecal pellets. Using micro-histological techniques, I detected forage kochia in less than 3% of the fecal pellets examined. (n = 30 pellets, 150

samples). Pellets from Tabby WMA contained a larger percentage of forage kochia (2.7%) than pellets from Badger Flat (0.7%). This difference could be an artifact of stand longevity and sage-grouse densities. Sagebrush constituted the dominant plant material in all pellets sampled. My results confirmed that although forage kochia was incidentally ingested by sage-grouse, it was not the primary content of sage-grouse diets. The limited availability of the plants in the study areas relative to sagebrush may have affected sage-grouse consumption of forage kochia. Managers should view these results with caution. On sites where native sagebrush has been eliminated by wildfires, managers should seek to include sagebrush plantings as part of a holistic recovery program.

INTRODUCTION

Greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) are a popular upland game bird and sagebrush (*Artemisia* spp.) obligate species that occupy sagebrush ecosystems in western North America. Currently, sage-grouse occupy <56% of their historical range across western North America (Schroeder et al. 2004). Historically, sage-grouse occupied approximately 33% of the land in Utah; however, they now occupy an estimated 13% of the state (Beck et al. 2003). These declines are a concern to land and wildlife managers throughout the species' range because of implications regarding the ecological condition and status of sagebrush ecosystems upon which sage-grouse and other sagebrush-obligate species depend (Schroeder et al. 1999).

The loss and fragmentation of sagebrush ecosystems has been implicated as the major factor in range-wide sage-grouse population declines (Vander Haegan et al. 2000, U. S. Department of the Interior 2010, Connelly et al. 2011). Habitat degradation has facilitated an increase in woodlands and invasive grasses, which have exacerbated historical habitat losses caused by land use changes and changes in wildfire regime (Lacey et al. 1989, Miller and Rose 1999, Bradley and Mustard 2006, Pyke 2011).

To reduce the threat of wildfires eradicating vast expanses of important sagebrush habitats, wildlife managers have advocated the use of greenstriping. Greenstrips generally consist of long, narrow strips of land that have been planted with fire retardant plants to minimize wildfire threats associated with at-risk habitats (Pellant 1994). These strips are strategically placed in at-risk habitats to impede and/or extinguish wildfires by removing the fuel sources (Pellant 1994).

Forage kochia (*Bassia prostrata*) is a semi-shrub from Kazakstan and Uzbekistan that has been planted on rangelands in the western US to compete with invasive plants (Tilley et al. 2006). Because forage kochia is considered to be a fire retardant plant species, it is also used in greenstrips (Harrison et al. 2002). On rangelands the plant provides an alternative food source for cattle (Stevens et al. 1985). Forage kochia has a large, deep taproot and grows readily in basic soils. It establishes well across a variety of shrublands because it is highly salt and drought tolerant, and can endure extreme temperatures. Pellant (1994) noted that forage kochia can compete with invasive annuals and has a 10-fold higher moisture content than cheatgrass (*Bromus tectorum*) and crested wheatgrass (*Agropyron cristatum*) in late August. Because forage kochia is considered to be a fire retardant plant species, it is recommended for use in greenstrips (Harrison et al. 2002). Once established, forage kochia produces a yearly seedcrop and has a high protein content (Stevens et al. 1985).

Wildlife managers have expressed concerns that forage kochia may also become invasive or the use of the plant may impede sagebrush recovery (J. Connelly, Idaho Department of Fish and Game, personal communication). Most research has indicated that forage kochia is not invasive (Harrison et al. 2002). Because sage-grouse may select for black sagebrush (*A. nova*) which contains 11-14% crude protein and has a low plant secondary metabolite (PSM, i.e. terpene) content than other sagebrush species (Thacker 2010, Frye et al. 2013), I was interested in determining if forage kochia, which exhibits similar properties, would be a surrogate dietary source for sage-grouse.

Sage-grouse diet selection was previously studied by analyzing crops and fecal matter (Klebenow and Gray 1968, Drut et al. 1994, Thacker 2010). Sage-grouse annual diets consist of a variety of forbs, arthropods, grasses, and shrubs, with sagebrush constituting the primary source of winter nutrition (Drut et al. 1994, Thacker 2010, Frye et al. 2013). Sage-grouse consumption of shrubs has also been documented through observational studies (Remington and Braun 1985, Frye et al. 2013). However, based on population size, physiological characteristics of plants, and size of study site, direct observation of herbivory may not be feasible. Therefore, the most non-invasive technique to study sage-grouse diets is through the dissection of fecal matter.

Sage-grouse consume plant and insect matter that travels from the esophagus through the crop, gizzard, intestines, ceca, and cloaca. Unlike other gallinaceous species, sage-grouse have gizzards that lack grinding abilities, and therefore cannot digest hard forage items, such as seeds (Remington and Braun 1985). Due to their unique digestive tract, sage-grouse consume primarily leaves and insects (Klebenow and Gray 1968, Remington and Braun 1985). Sage-grouse excrete waste material in cecal and roost piles. Hard fecal pellets contain identifiable plant fragments (Eastman and Jenkins1970).

A number of methods have been utilized to dissect sage-grouse crops and fecal pellets (Drut et al. 1994, Thacker 2010, Frye et al. 2013). Chemical and microhistological analysis can be completed to determine composition of fecal matter in various animal species (Dearden et al. 1975, Zeinsteger et al. 2009, Thacker 2010). Chromatography has been used to quantify sage-grouse consumption of sagebrush. Sagebrush contains terpenes that can be used as identifying markers of individual species (Thacker 2010, Frye et al. 2013). Chemical analysis of forage kochia had not been published in the U.S. prior to this study. Therefore, I hypothesized that terpenes or other lightweight and heavy molecules could be distinguished as markers of forage kochia, and these markers could be used to potentially identify forage kochia within the fecal pellets.

Microhistological techniques require looking at slides through a microscope in order to identify cell structure (Holechek 1982, Alipayo et al. 1992). Several different versions of microhistological methods have been utilized to analyze cell structures of plant and fecal matter (Sparks and Malechek 1968, Holechek 1982, Alipayo et al. 1992, Zeinsteger et al. 2009). Digestibility of plant material can affect microhistological feasibility.

No information confirming sage-grouse consumption of forage kochia relative to sagebrush in sagebrush ecosystems has been published. Such information is important to assist managers in making decisions regarding the role of forage kochia in a holistic, post-fire recovery program for sage-grouse habitats. Given forage kochia's ability to outcompete invasive species (McArthur et al. 1989), and increasing use in the restoration of sagebrush ecosystems after wildfires, more information is needed regarding its potential role as sage-grouse food and cover.

My objectives were to identify a method that could accurately detect forage kochia in fecal pellets and determine the relative frequency of forage kochia in the pellets. I also wanted to compare dietary quality of forage kochia with previously published studies of forage kochia and sagebrush. Based on previous chromatography studies, I hypothesized that I could determine forage kochia identifying markers based on terpenes or other molecules. Based on success of the chromatography methods, I predicted that I would be able to identify forage kochia through microhistological methods.

STUDY SITE

The fecal pellets used to conduct this study were collected from two different sites in Utah (Fig. 4-1). One study site consisted of a winter 2010 planting of forage kochia completed on an area known as Badger Flat, located in western Box Elder County in northwestern Utah. The study site encompassed a region of approximately 4,800 ha within the Grouse Creek Watershed. Badger Flat was managed by the Bureau of Land Management (BLM). Forage kochia (1445.2 kg of seed) was broadcast across 91.4 m wide greenstrips (286 ha). The primary land use was open range winter grazing by cattle.

The study site was categorized as a sagebrush ecosystem with surrounding woodlands and interspersed meadows. Elevations ranged from 1500-1800 m. Average daily summer temperatures ranged from 21˚C to 27˚C. Average daily winter temperatures ranged from -7˚C to 2˚C. Average precipitation was 29 cm per year.

Primary shrub species included Wyoming big sagebrush (*A. tridentata* ssp. *wyomingensis*), black sagebrush (*A. nova*), shadscale (*Atriplex confertifolia*), rabbitbrush (*Chrysothamnus* spp., *Ericameria* spp.), snowberry (*Symphoricarpos albus*), and juniper (*Juniperus osteoperma*). Common grasses included sandberg bluegrass (*Poa secunda*), Kentucky bluegrass (*Poa pratensis*), cheatgrass (*Bromus tectorum*), and wheatgrasses (*Agropyron* spp., *Elymus* spp., *Pseudoroegneria* spp.). Common forbs included blue-eyed mary (*Collinsia* parviflora), wild onion (*Allium acuminatum*), phlox (*Phlox* spp.), astragalus (*Astragalus* spp.), arrowleaf balsamroot (*Balsamorhiza sagittata*), tansymustard (*Descurainia pinnata)*, bur buttercup (*Ceratocephala testiculata)*, halogeton (*Halogeton glomeratus)*, and blue mustard (*Chorispora tenella*).

The second study site was Tabby Wildlife Management Area (WMA) located in Duchesne County, northeast of Fruitland, UT. In 2004, 710 ha were block seeded with 362 kg of forage kochia. Elevations ranged from 2000-2100 m. Tabby WMA was owned by the Utah Division of Wildlife Resources (UDWR). The primary land use was habitat for wildlife and minimal spring grazing by livestock. The study site was categorized by a shrub-steppe ecosystem with surrounding woodlands and interspersed meadows. Average daily/nightly summer temperatures ranged from to 5˚C to 32˚C. Average daily/nightly winter temperatures ranged from -17˚C to 2˚C. Average yearly precipitation was 39 cm, with a majority of precipitation occurring in winter and spring. Primary shrub species included Wyoming big sagebrush, shadscale, black greasewood (*Sarcobatus vermiculatus*), and gray horsebrush (*Tetradymia canescens*). Nearby ridge tops were covered with juniper (*Juniperus* spp.), pinyon pine (*Pinus edulis*), and mountain mahogany (*Cercocarpus* spp.). Common grasses included galleta (*Pleuraphis* *jamesii*), Needle-and-Thread (*Hesperostipa comata*), and wheatgrasses. Common forbs included carpet phlox (*Phlox hoodii*), Douglas' knotweed (*Polygonum douglasii*), astragalus spp., and scarlet gilia (*Ipomopsis aggregata*).

METHODS

Pellet Collection

Fecal pellets collected from Badger Flat were retrieved from sage-grouse that were radio-collared and relocated via radio-telemetry. These sage-grouse were radio-collared as part of another study (see Chapter 2). Pellets were collected during March and April 2012. After a bird was flushed, fresh fecal pellets were picked up, placed in plastic bags, and stored in freezers.

Fecal pellets from the Tabby WMA were collected during April 2012. A flock of 30-40 sage-grouse wintered in the Tabby WMA and migrated away from the area by March 2012 (B. Maxfield, UDWR, personal communication). Therefore, pellets from the Tabby WMA region were estimated at ≥1 month of age.

Pellets from both locations were stored in freezers until further processing was completed. At each roost pellet pile, 2 pellets were randomly collected. I assumed that each roost pile was excreted by one bird (Thacker 2010). I collected 160 pellets from Tabby WMA and 120 pellets from Badger Flat. Forage kochia plants were collected from both study sites and used in chromatography and microhistological analysis.

Sage-grouse pellets were also collected from a third site located near Bear Lake in northern Rich County in northeastern Utah as a control area for comparison. Forage kochia was not observed in the area where pellets were collected in Rich County and is not known to be present within >10km of the Rich County site (C. Cardinal, Utah State University, personal communication).

Chromatography

Pellets were analyzed at the U.S. Department of Agriculture-Agricultural Research Service (USDA-ARS) Poisonous Plant Lab in Logan, Utah. Terpene analysis was conducted using gas chromatography (Thacker 2010, Thacker et al. 2011). Terpene profiles from pellets and forage kochia were compared by visual pattern recognition to identify if forage kochia terpene profiles matched pellet cluster profiles.

High temperature gas chromatography was conducted to determine high molecular weight volatile components of pellets and forage kochia. Plant samples (0.24 g) were extracted with 10 mL of methylene chloride. Fecal pellets (0.4-1.0 g) were extracted with the 10 mL of methylene chloride. Samples were extracted for greater than 16 hours. A 1.0 mL aliquot was taken and evaporated to dryness and then derivatized by the addition of 0.2 mL pyridine and 0.05 mL of BSTFA reagent. Samples were then diluted to 1.0 mL with methylene chloride. Samples were analyzed by gas chromatography mass spectrometry using the following oven program: 70°C (1 min.); 70-200°C@10°C/min; 200-320°C@5°C/min; 320°C (4 min.).

Liquid chromatography-mass spectrometry (LC-MS) and chemical profile of non-volatile polar compounds were assessed. Forage kochia and pellet samples (1 g) were extracted with 10 mL of methanol. A 0.50 mL aliquot was added to 1.0 mL of 50% acetonitrile and analyzed by LC-MS: column (Betasil C18), Solvents (20mM ammonium acetate/acetonitrile), Flow (0.300 mL/min), Gradient (10% Acetonitrile (0-1min), 10% - 100% (1-20 min); detector (esi- 100-1000 m/z).

Microhisotology

Microhistological techniques were used to identify plant and fecal pellet cell structure. I analyzed 150 samples that originated from 15 pellets at each study site. Forage kochia leaves were dried and ground through a Wiley Mill (Arthur H. Thomas Company, Philadelphia, PA). Fecal pellets were ground through a coffee grinder. Replicated treatments were completed for all forage kochia and fecal pellet samples. Samples were rinsed for 5 minutes with deionized water on a 2 mm sieve. Samples were then placed in a vial and submerged with sodium hypochlorite (bleach) for 24 hours. Vials were unscrewed and recapped once every 6 hours to minimize gas buildup. Once removed, samples were rinsed with deionized water for 5-10 minutes through a 2 mm sieve until bleach odor had evaporated. Samples were air dried for 2-5 days. Razor blades were used to slice plant and fecal matter. Individual slides were mounted with forage kochia and fecal pellets. Other common shrubs, forbs, and grasses were mounted in the same fashion for comparison of cell structure. Images from literature were also utilized for visual recognition. Each slide was mounted on a 31-33-69 compound microscope (Bausch and Lomb Incorporated, Rochester, NY) and viewed at 40x. Photos of slides were taken with a Jenoptik camera coupled to a © Leica Mz7.5 dissecting microscope (Jenoptik AG, Jena, Germany; Leica Microsystems, Wetzlar, Germany). ProgRes® Image Capture Software was used to create the computer image (Jenoptik AG, Jena, Germany). All samples were evaluated for identifiable prickle hairs and epidermal layer.

Protein and Nutrient Analysis

Six forage kochia plants were collected from the Badger Flat site. The plants were dried and remained in a freezer until transported to the Utah State University Analytical Laboratory for analysis. The leaves from each of these plants were ground and protein content was analyzed. Total nitrogen was obtained using the Dumas method (Dumas 1831). To determine the nitrogen content 0.1 g +/- 0.0005 g was used and combusted at 950°C. Percentage nitrogen was recorded and crude protein was calculated based upon percent nitrogen.

RESULTS

Forage Kochia Availability

Based on calculations from transects at Grouse Creek in 2012, there were 5,827 forage kochia plants/ha (S. Graham, USU, unpublished data). Forage kochia occurred on 6% of the study site. Sagebrush and shadscale were the dominant vegetation types surrounding the forage kochia greenstrips at the Badger Flat site (S. Graham, unpublished data). On Tabby WMA, 3,594 forage kochia plants/ha were recorded in 2010 (Cox et al. 2010). Sagebrush and greasewood were the dominant vegetation types in 2012 (B. Maxfield, personal communication).

Chromatography

The initial gas chromatography confirmed that forage kochia did not contain a high enough terpene content to provide maker compounds that could be used to detect the presence of the plant in fecal pellets. The high temperature gas chromatography also revealed that no unique forage kochia compounds could be identified. Analysis indicated typical general plant compounds that included long and short fatty acid chains, polyhydroxy acids, phenolic acids, and steroidal compounds. Some of these compounds were also found in the sage-grouse fecal pellets. However, these compounds are common to an array of flora and could be from a variety of plant sources (Harborne et al. 1999).

Liquid chromatography-mass spectrometry revealed that some possible marker compounds were present in the analysis of the forage kochia. These compounds eluted around 10 minutes and were characterized by base ions of 944,974 and 812 m/z. Sage-grouse fecal pellets (n=15) were analyzed specifically for the three marker compounds in forage kochia and all were found to be negative for these compounds.

Microhistology

Prickle hairs and the epidermal layer were used to identify forage kochia (Fig. 4-2). Pellets at the Badger Flat site were composed of 96% sagebrush. Pellets at the Tabby WMA site were composed of 93% sagebrush. Other species that were observed at low rates included lupines (*Lupinus* spp.), asters (*Aster* spp.), and bitterbrush (*Purshia tridentata*). Forage kochia was detected in 1 sample from the Badger Flat study site

(0.7% composition) and 4 samples from the Tabby WMA site (2.7% composition) (Fig. 4-3, 4-4, 4-5). As expected, forage kochia was not detected in any Rich County samples.

Protein Content

Crude protein values of forage kochia leaves from the six plant samples were 11.9%, 11.8%, 10.3%, 10.3%, 10.4%, and 8.2%. Average crude protein for these forage kochia plants was 10.5% (±1.34).

DISCUSSION

Gas chromatography can be a useful technique for determining the presence of plants with high terpene contents in sage-grouse pellets (Thacker 2010). This method has less utility when identifying plants with little or no terpene content. Because forage kochia does not have a high terpene content, gas chromatography cannot be used for determining markers in pellets. Although liquid chromatography-mass spectrometry identified several possible forage kochia markers, these markers were not detected in the fecal pellets. Detection of sage-grouse bite marks (Remington and Braun 1985) on forage kochia were not possible based on leaf structure.

Microhistological analysis was a practical technique for determining the presence of forage kochia based on prickle hairs and epidermis. This method was modified from other microhistological applications (Alipayo et al. 1992) by increasing the bleaching time. Using this modified technique, I confirmed for the first time that sage-grouse ingested forage kochia. I tested bleaching forage kochia plants for 4 hours, 10 hours, 16 hours, 24 hours, 48 hours, and 72 hours. Bleaching times of less than 24 hours were unsuitable because too much pigment remained in the plant, and therefore cell structure was opaque. Bleaching times of greater than 24 hours degraded the plant cell and therefore prickle hairs and epidermal layer could not be adequately identified. Bleaching times of 24 hours were the most functional and efficient for viewing forage kochia prickle hairs and epidermis. It took several 2-5 days to prepare and read a sample. Repeat microhistological applications can be used to detect forage kochia leaves in sage-grouse fecal pellets. Microhistological techniques could also be applied to other plant species as well to determine sage-grouse diet composition.

Although forage kochia comprised a small proportion of the plant material contained in the pellets I studied, it could provide an alternative food source for wildlife and a natural firebreak based on its high protein and low terpene levels in winter. Sagebrush was the primary shrub species at both study sites. Sage-grouse diets shift from a forb, insect, and shrub composition in summer to mostly sagebrush composition during the winter months (Braun et al. 1977). Pellet contents may vary based on season and location. Food sources may vary based on age of sage-grouse and availability of forage material at respective sites (Drut et al. 1994, Wallestad and Eng 1975). Stages of plant succession may also influence the composition of wildlife diets. At the Badger Flat site, forage kochia emerged in late summer 2011. At the Tabby WMA site, forage kochia was planted in 2004. This varying stage in plant growth and acclimation of sage-grouse to forage kochia may explain the differences in diet composition. Both microhistological analysis and chromatography indicated that sage-grouse consume a majority of sagebrush during the winter and spring, which is consistent with other studies (Thacker et al. 2011, Frye et al. 2013).

Crude protein values of forage kochia plants studied were within those recorded from previous studies (Davis 1979, Schauer et al. 2004). Other studies have noted that sage-grouse prefer high protein diets with minimal secondary metabolites (Thacker et al. 2011, Frye et al. 2013). Black sagebrush was selected by sage-grouse as a primary forage material (Thacker et al. 2011). Thacker et al. (2011) hypothesized sage-grouse preference for black sagebrush could be due to high protein contents and low terpene content within the plant. Forage kochia crude protein content (8.2-11.9%) overlaps the range of crude protein content that exists in black sagebrush (11.0-12.25%) (Frye et al. 2013).

My research confirmed that forage kochia does not contain high PSM concentrations. Although forage kochia has many of the qualities associated with a desired winter forage for sage-grouse, it did not replace sagebrush as a winter staple. My study was limited to 2 and 7 years post-forage kochia emergence. A larger sample size could have resulted in different rates of forage kochia consumption. Long-term monitoring of older stage successional forage kochia plant communities may reveal higher amounts of consumption by sage-grouse.

Restoration activities may only be needed if invasive plants are dominant and diverse functional plant communities do not exist (Pyke 2011). Crested wheatgrass was planted throughout the western U.S. because it competes well with cheatgrass and has a high fire tolerance (Pellant 1994). However, crested wheatgrass can monopolize an area, impeding native plant restoration efforts (Hansen and Wilson 2006, Newhall et al. 2011). The same concern exists for planting forage kochia as a part of wide scale restoration project in sagebrush ecosystems (J. Connelly, Idaho Department of Fish and Game, personal communication).

In my study forage kochia had not encroached beyond its original seedbed. At the Tabby WMA site, forage kochia remained interspersed with sagebrush and other shrubs (Cox et al. 2010). If planted in conjunction with sagebrush, forage kochia could help increase fire resistance and provide an ecological bridge to impacted sagebrush ecosystems because it is largely non-invasive, outcompetes invasive plant species, and has a high moisture content year-round. Seeding of diverse native plants as part of a holistic recovery plan in at-risk ecosystems could further mitigate the potential for monoculture landscapes.

MANAGEMENT IMPLICATIONS

Based on the threat of wildfires and increasing fragmentation of landscapes, planting of vegetation species that minimize spread of invasive species and disturbance on critical habitat must be considered as part of a holistic recovery program. Forage kochia has been recommended as a first step in returning sage-grouse habitat to a healthier, more diverse plant community by reducing negative impacts associated with wildfires. Managers should consider each site on an individual basis. Habitat patchiness, climate factors, and invasive plants should be examined before treatment is implemented.

Dietary analysis is an important tool for devising proper management protocols. Chromatography and microhistology techniques can be utilized to identify components of sage-grouse diets. Each technique has advantages and limitations. Analysis of fecal pellets is a relatively cost-efficient, non-invasive operation, which can provide land managers with insight about wildlife diets. In landscapes where dietary components are minimal, alternative sources of nutrition may be beneficial to sage-grouse populations. Managers should consider all habitat features ranging from landscape continuity to nutritional condition when creating conservation plans.

LITERATURE CITED

Alipayo, D., R. Valdez, J. L. Holechek, and M. Cardenas. 1992. Evaluation of microhistological analysis for determining ruminant diet botanical composition. Journal of Range Management 45:148-152.

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.

Bradley, B., and J. F. Mustard. 2006. Characterizing the landscape dynamics of an invasive plant and risk of invasion using remote sensing. Ecological Applications 16:1132-1147.

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

Connelly, J. W., S. T. Knick, C. E. Braun, W. L. Baker, E. A. Beever, T. Christiansen, K. E. Doherty, E. O. Garton, S. E. Hanser, D. H. Johnson, M. Leu, R. F. Miller, D. E. Naugle, S. J. Oyler-McCance, D. A. Pyke, K. P. Reese, M. A. Schroeder, S. J. Stiver, B. L. Walker, and M. J. Wisdom. 2011. Pages 549-563 *in* S. T. Knick and J. W. Connelly, editors. Conservation of Greater Sage-Grouse: a synthesis of current trends and future management. Greater Sage-Grouse: ecology and conservation of a landscape species and habitats. University of California Press, Berkeley, USA.

Cox, J., D. Summers, J. Whitaker, and K. Gunnell. 2010. 2010 Watershed restoration initiative vegetation monitoring report. Performance Report for Federal Aid Project W-82-R-55. Publication No. 11-19. State of Utah Department of Natural Resources, Salt Lake City, Utah, USA.

Davis, A. M. 1979. Forage quality of prostrate kochia compared with three browse species. Agronomy Journal 71: 822-824.

Dearden, B. L., P. E. Pegau, and R. M. Hansen. 1975. Precision of microhistological estimates of ruminant food habits. Journal of Wildlife Management 39:402-407.

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.

Dumas, J. B. A. 1831. Procedes de l'analyse organique. Annales de chimie et de physique 247:198–213.

Eastman, D. S., and D. Jenkins. 1970 Comparative food habits of red grouse in northeast Scotland, using fecal analysis. Journal of Wildlife Management 34:612-620.

Frye, G. G., J. W. Connelly, D. D. Musil, and J. S Forbey. 2013. Phytochemistry predicts habitat selection by an avian herbivore at multiple scales. Ecology 94:308-314.

Hansen, M. J., and S. D. Wilson. 2006. Is management of an invasive grass *Agropyron cristatum* contingent on environmental variation? Journal of Applied Ecology 43:269-280.

Harborne, J. B., H. Baxter, and G. P. Moss. 1999. Phytochemical dictionary: a handbook of bioactive compounds from plants. Second edition. Taylor & Francis, Philadelphia, Pennsylvania, USA.

Harrison, R. D., B. L. Waldron, K. B. Jensen, R. Page, T. A. Monaco, W. H. Horton, and A. J. Palazzo. 2002. Forage kochia helps fight range fires. Rangelands 24:3-7.

Holechek, J. L. 1982. Sample preparation technique for microhistological analysis. Journal of Range Management 35:267-268.

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

Lacey, J. R., C. B. Marlow, and J. R. Lane. 1989. Influence of spotted knapweed (Cent*aurea maculosa*) on surface runoff and sediment yield. Weed Technology 3:627-631.

McArthur, E. D., A. C. Blauer, and R. Stevens. 1989. Forage kochia competition with cheatgrass in central Utah. Symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management, Las Vegas, Nevada, USA.

Miller, R. F., and J. A. Rose. 1999. Fire history and Western juniper encroachment in sagebrush steppe. Journal of Range Management 52:550-559.

Newhall, R. L., V. P. Rasmussen, and B. M. Kitchen. 2011. Introducing big sagebrush into a crested wheatgrass monoculture. Natural Resources and Environmental Issues 17, Utah State University, Uintah County Extension, Vernal, UT. *In* Proceedings – Threats to Shrubland Ecosystem Integrity; 2010 May 18-20; Logan, UT. Natural Resources and Environmental Issues, Volume XVII. S.J. and Jessie E. Quinney Natural Resources Research Library, Logan, Utah, USA.

Pellant, M. 1994. History and applications of the intermountain greenstripping program. Pages 63-68 *in* S. B. Monsen and S. G. Kitchen, comps. Proceedings-symposium on ecology and management of annual rangelands. 18-21 May 1992. Boise, ID. General Technical Report INT-GTR-313. USDA Forest Service, Intermountain Research Station, Ogden, Utah, USA.

Pyke, D. A. 2011. Restoring and rehabilitating sagebrush habitats. Studies in Avian Biology 38:531–548.

Remington, T. E., and C. E. Braun. 1985. Sage grouse food selection in winter, North Park, Colorado. Journal of Wildlife Management 49:1055-1061.

Schauer, C. S., D. W. Bohnert, M. F. Carpinelli, and S. J. Falck. 2004. Nutritional and seed responses of forage kochia to ruminal incubation. Rangelands 26: 8-11.

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

Schroeder, M. A., J. R. Young, and C. E. Braun. 1999. Sage grouse (*Centrocercus urophasianus*). Pages 1-28 *in* A. Poole and F. Gill, editors. The birds of North America, No. 425. The Birds of North America, Inc., Philadelphia, Pennsylvania, USA.

Sparks, D. R., and J. C. Malechek. 1968. Estimating percentage dry weight in diets using a microscope technique. Journal of Range Management 21:264-265.

Stevens, R., K. R. Jorgensen, E. D. McArthur, and J. N. Davis. 1985. 'Immigrant' Forage Kochia. Rangelands 7:22-23.

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

Thacker, E. T., D. R. Gardner, T. A. Messmer, M. R. Guttery, and D. K. Dahlgren. 2011. Using gas chromatography to determine winter diets of greater sage-grouse in Utah. Journal of Wildlife Management 76:588-592.

Tilley, D. J., D. Ogle, L. St John, B. L. Waldron, and R. D. Harrison. 2006. Plant guide: forage kochia. USDA-Natural Resources Conservation Service – Plant Materials Program, Boise, Idaho, USA.

U.S. Department of the Interior. 2010. Federal Register Notice. U.S. Fish and Wildlife Service, Washington, D. C., USA.

Vander Haegen, M. W., F. C. Dobler, and D. J. Pierce. 2000. Shrubsteppe bird response to habitat and landscape variables in Eastern Washington, U.S.A. Conservation Biology 14:1145-1160.

Wallestad, R., and R. L. Eng. 1975. Foods of adult sage grouse in central Montana. Journal of Wildlife Management 39:628-630.

Zeinsteger, P., A. Palacios, P. Leaden, and A. Gurni. 2009. Microhistological characteristics and in vitro ruminal digestion of a poisonous plant (*Nerium oleander*) versus another non-toxic (*Eucalyptus camaldulensis*). Revista veterimaria 20:3-9.

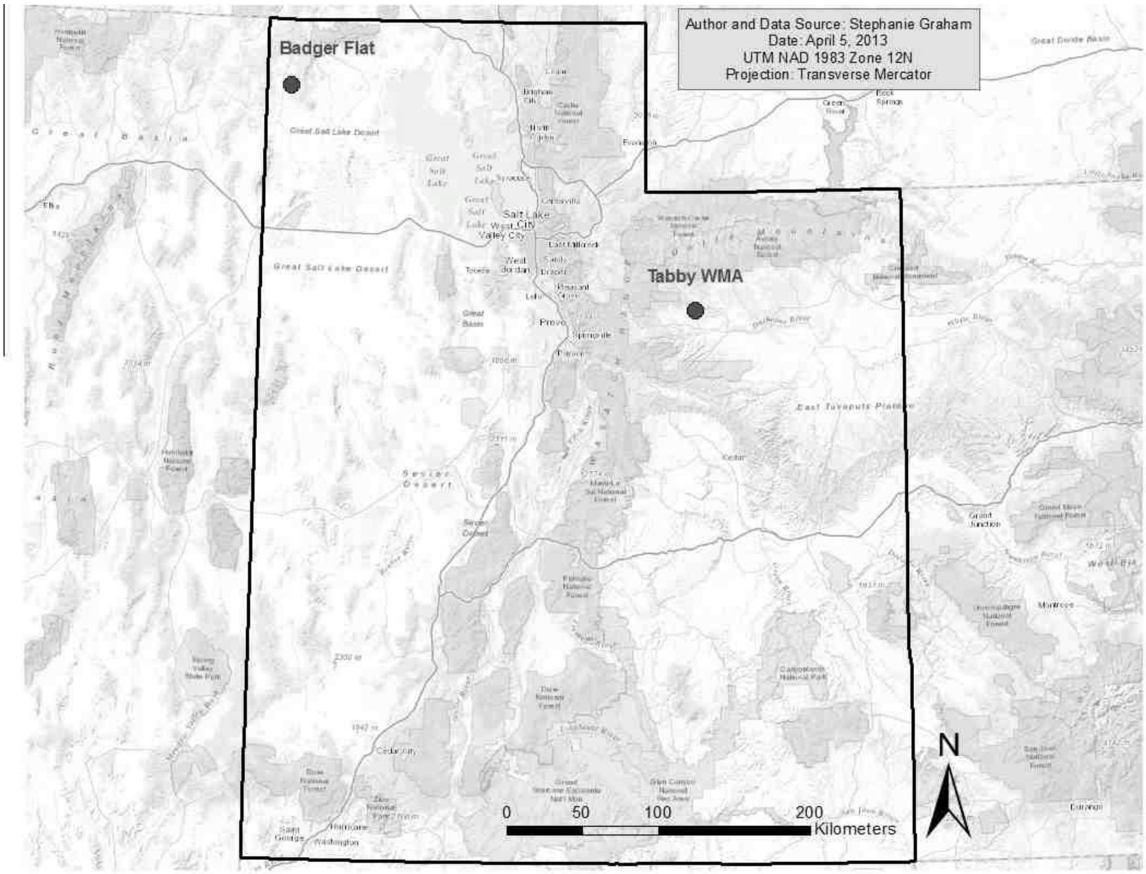

Figure 4-1. Pellets were collected for sage-grouse dietary analysis from Badger Flat and Tabby Wildlife Management Area (WMA), Utah in 2012.

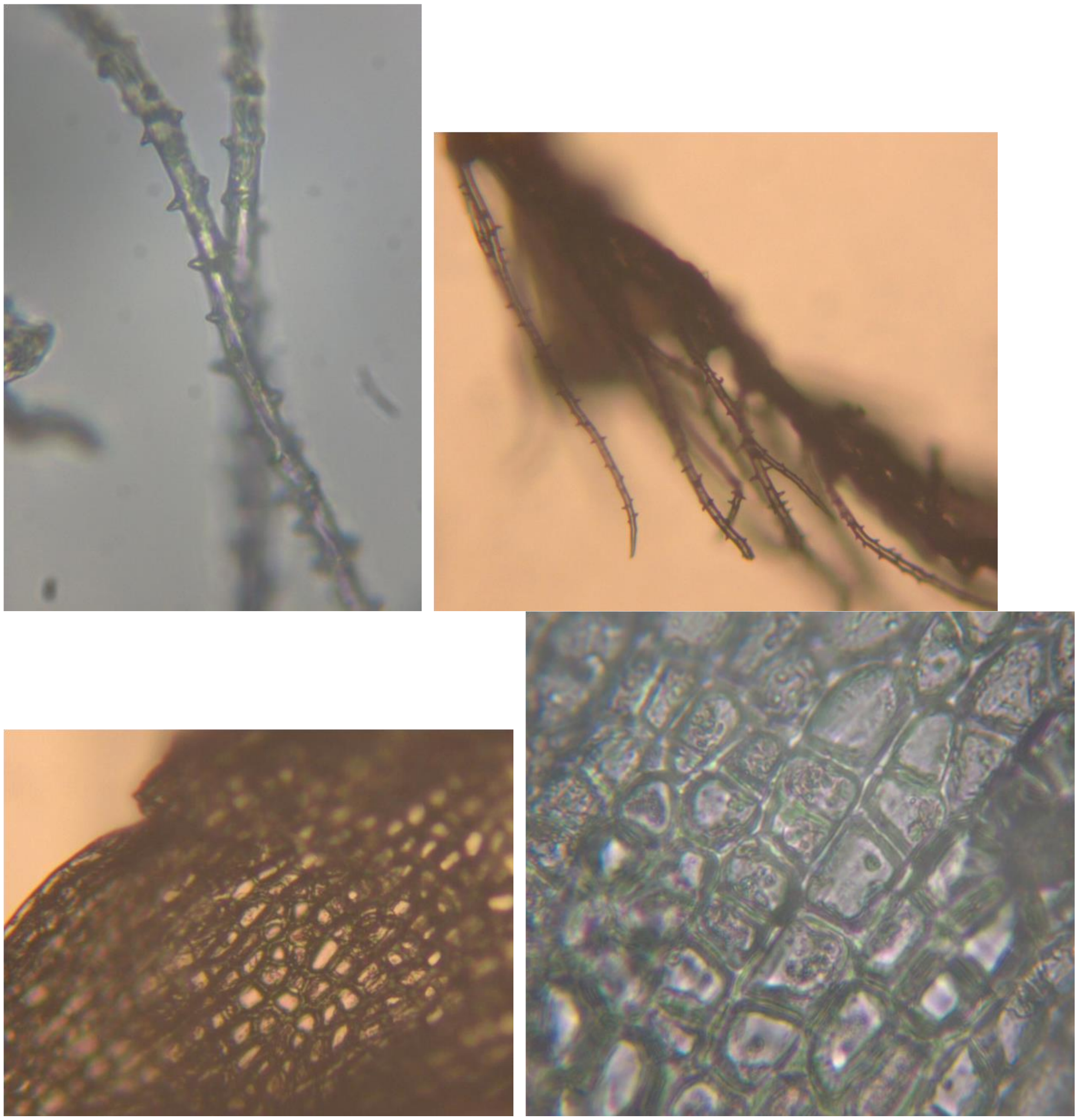

Figure 4-2. Top left, top right: forage kochia prickly hairs. Bottom left, bottom right: forage kochia epidermis.

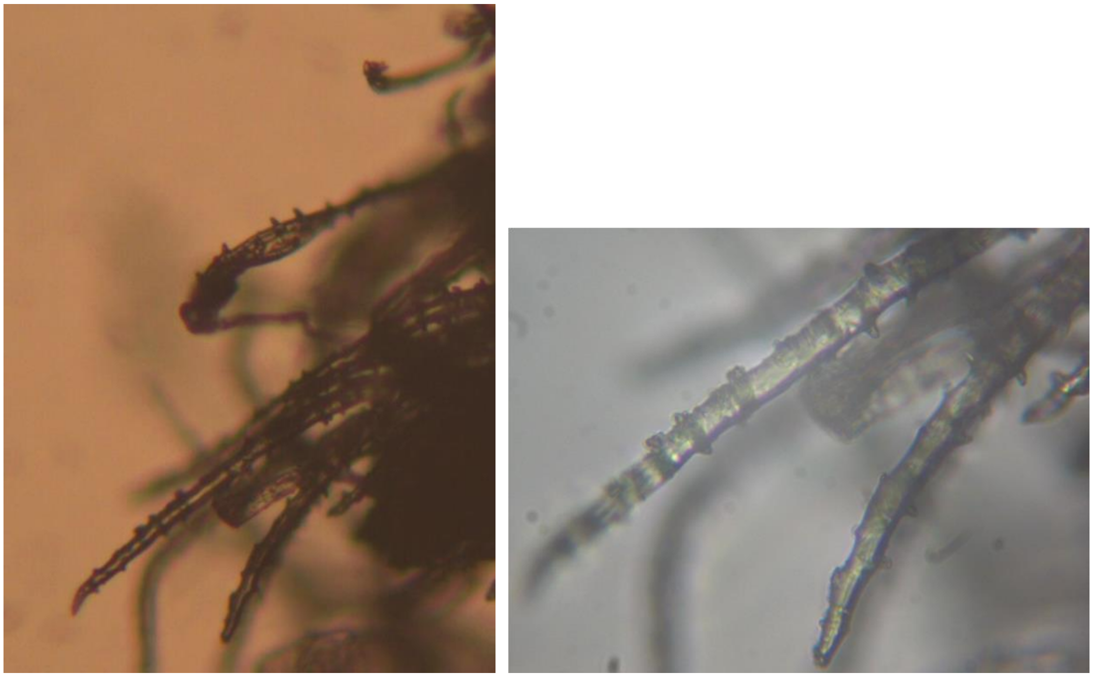

Figure 4-3. Forage kochia in sage-grouse fecal pellets.

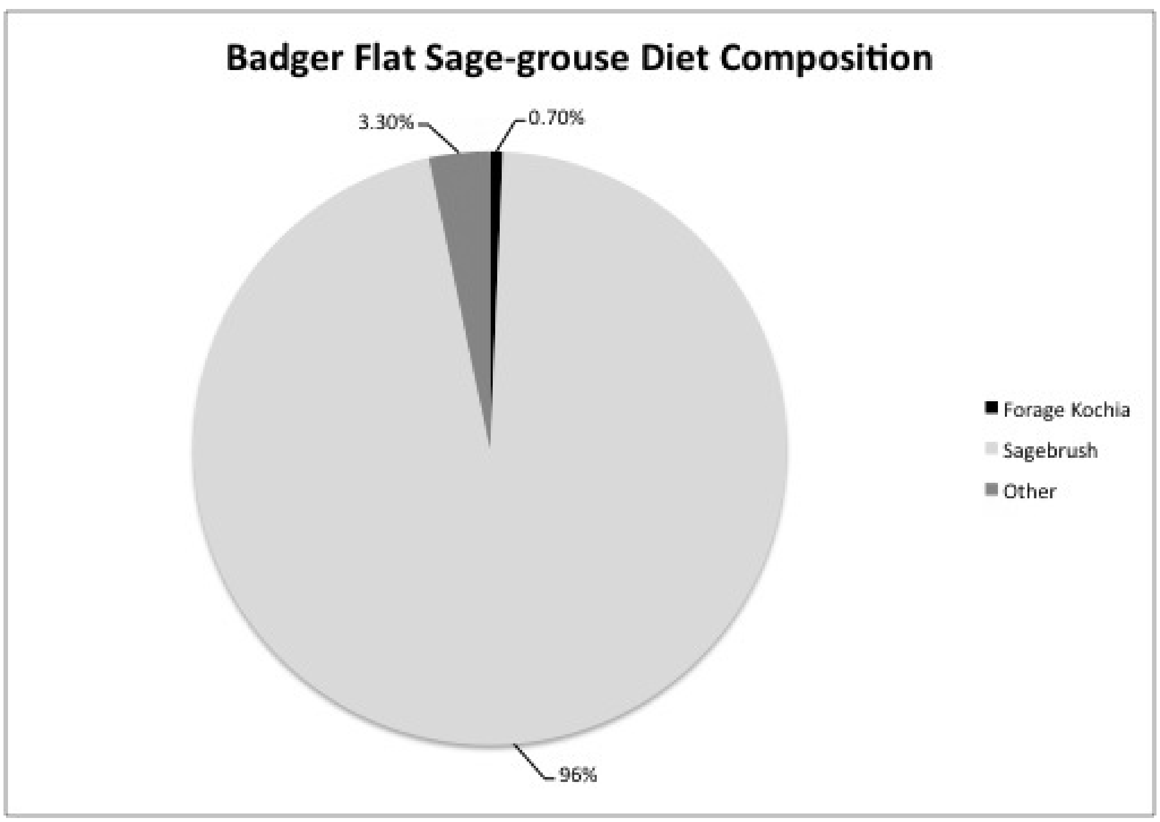

Figure 4-4. Sage-grouse pellets at Badger Flat were comprised of 0.7% forage kochia.

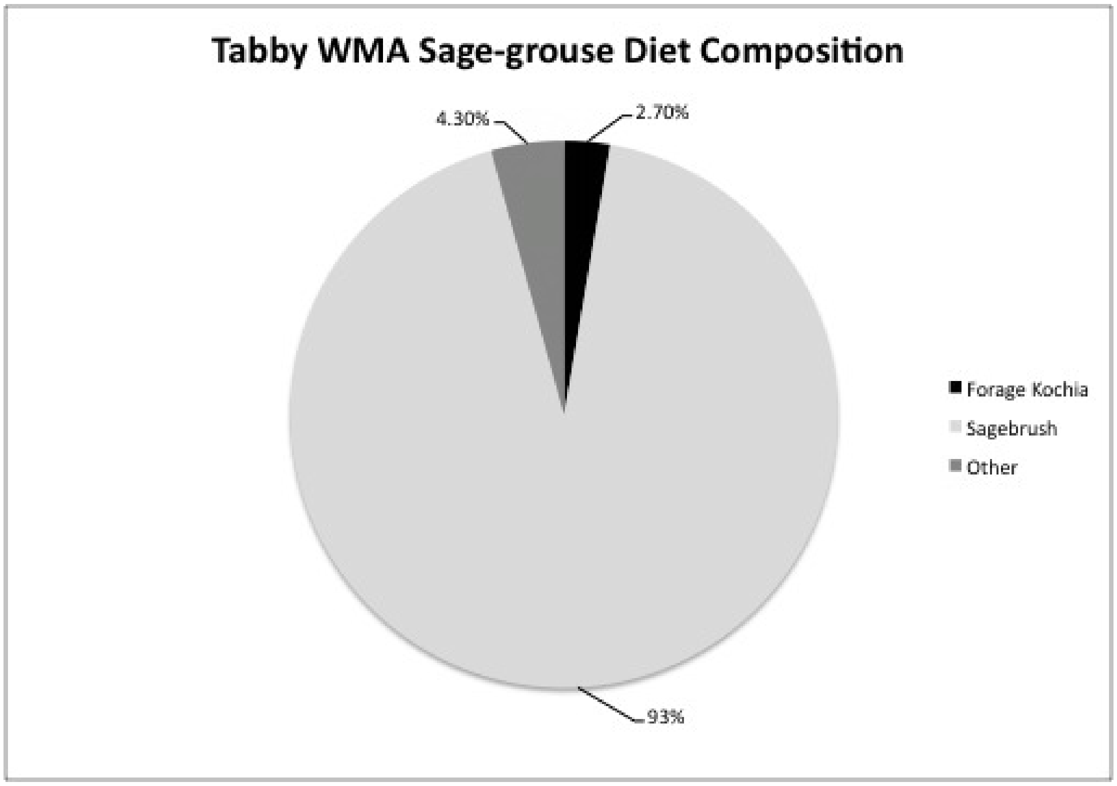

Figure 4-5. Sage-grouse pellets at Tabby WMA were comprised of 2.7% forage kochia.

CHAPTER 5

CONCLUSIONS

Greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse) populations occupy <56% of their historical range across western North America (Schroeder et al. 2004) and 39% of their historical range across the state of Utah (Beck et al. 2003). Degradation of sagebrush and fragmentation across landscapes have been identified as the primary factors in the decline of sage-grouse populations (Vander Haegan et al. 2000, U.S. Department of the Interior 2010, Wisdom et al. 2011). Sage-grouse carrying capacity is declining, which could lead to smaller isolated populations, and possible extinction (Garton et al. 2011). Sage-grouse depend on sagebrush communities throughout their life cycle and are an indicator of the effects of sagebrush habitat quality on other sagebrush obligate species (Stiver et al. 2006).

Wildfire, spread of invasive species, anthropogenic disturbances, weather, and predation have been identified as threats to sage-grouse populations (U.S. Department of the Interior 2010, Knick and Connelly 2011). Wildfires can convert native sagebrush habitats into invasive grasslands, reducing sagebrush obligate species and permanently altering community composition (Knick et al. 2005, Earnst et al. 2009). Fragmentation from anthropogenic activities can also change ecosystem processes (Lensing and Wise 2006). Climate can alter sagebrush steppe plant demographics (Dalgleish et al. 2011), which can affect sage-grouse behavior patterns. Predation by mammalian and avian species can also have a negative impact upon populations (Hagen 2011). Predators can take advantage of anthropogenic structures, such as roads and utility poles, to increase their capture rates and reduce energy expenditure (Crête and Larivière 2003, Aspbury and Gibson 2004).

Western Box Elder County is a diverse and fragmented landscape that hosts one of the four largest populations of sage-grouse in Utah (Utah Division of Wildlife Resources 2009). The impact of wildfire on sagebrush ecosystems is one of the main concerns that exists in the region (Thacker 2010). To combat this threat, BLM land managers implemented greenstrips through the use of an ely chain, bullhog, Plateau® (BASF Chemical Corporation, Research Triangle Park, NC) herbicide, and forage kochia (*Bassia prostrata*) seed. The objectives of my study were to: 1) document adult, nesting, and brood-rearing habitat use in a fragmented landscape, 2) determine the probable impacts of fragmentation, and seasonal effects of weather variables on sage-grouse vital rates, 3) determine effects of greenstripping on sage-grouse habitats and habitat-use, and 4) identify a method to detect forage kochia in fecal pellets and quantify dietary composition of forage kochia.

Most research studies focus on nesting and brood-rearing habitat (Connelly et al. 2000, Crawford et al. 2004); however, it is important to identify juvenile and adult habitat characteristics as well. Shrub cover, grass cover, and forb cover (11.5-15.2%, 9.4-15.3%, 1.9-4.8%, respectively) across Badger Flat adult and juvenile sites were all lower than recommended guidelines suggest for late spring and summer habitat (Connelly et al. 2000). Shrub cover (11.5-15.5%) in winter across Badger Flat was also in the lower range of suggested levels (Connelly et al. 2000). Shrub cover, forb cover, and grass cover (22.6-29.9%, 9.7-18.2%, 7.9-13.2%, respectively) throughout the rest of the Grouse Creek Watershed were within the guideline ranges for sage-grouse habitat (Connelly et al. 2000, Knerr 2007). Due to grazing by domestic cattle (*Bos tarus*) and grass structure, I used a method to measure effective grass height, which incorporates low, grazed or basal culms and tall or ungrazed culms. This method is more precise for measuring grass height within grazed regions. Adult and juvenile sage-grouse preferred slightly shorter grass compared to random sites.

Hens preferred wider shrubs for nesting. Larger diameter shrubs have more vertical cover and can reduce pressures by avian predators. Broods preferred areas with less rock, and therefore a higher percentage of vegetation, bare ground, and litter. Broods select for high protein content from insects and other sources (Fischer et al. 1996). One brood was found in a cheatgrass field immediately following the hatch. I speculated that this occurred because a large quantity of stink bugs (*Acrosternum hilare*) was also present in this region. Two broods moved onto alfalfa (*Medicago sativa*) fields, which exhibited greener vegetation and abundant insects. Other studies have found that sage-grouse will congregate in and consume alfalfa in late summer and early autumn (Wallestad and Eng 1975, Knerr 2007, Thacker 2010). Hens nested earlier in drier years and later in wetter years, which was similar to sage-grouse patterns in other regions of Utah (Robinson 2007). Sage-grouse in the study exhibited adaptations to the fragmentation and weather. Drier years could indicate a reduction in available insects or green vegetation, which is required for early brood-rearing (Drut et al. 1994). If fragmentation and climate change become more dramatic, the adaptation of single birds may not be enough to mitigate the long-term effects of climate change on seasonal vital rates.

Sage-grouse nest and brood success and survival rates are influenced by natural and anthropogenic fragmentation (Beck et al. 2006, Dahlgren et al. 2010). Fragmentation can also increase predation rates (Hagen 2011). Nest success rates were within the lower range (15.1-19.1%) of rates reported by other studies (Trueblood 1954, Gregg 1991, Schroeder et al. 1999, Knerr 2007). Nests were predated by both avian and mammalian species. Low nest survival rates could be due to the fragmentation and limited quality habitat that exists in the Grouse Creek Watershed. Six out of 10 broods survived to 50 days post-hatching; however, I was unable to calculate total brood survival since I did not place transmitters on chicks. Male survival was lower (22-39%) than previously reported range-wide, but female survival (73-84%) was comparable to results documented by other studies (Musil et al. 1993, Connelly et al. 1994, Zablan et al. 2003, Musil and Connelly 2005). The dichotomy in survival rates between males and females can possibly be attributed to physiological demands and breeding behavior. Male sage-grouse daily energy expenditure is four times higher than basal metabolic rate when displaying on the lek (Vehrencamp et al. 1989). In addition, male sage-grouse are more visible to avian and mammalian predators when present on the lek, which is where some of the predation events occurred.

Anthropogenic structures and invasive species contribute to fragmentation, which leads to a reduction in native flora and fauna species (Crooks 2002, Aspbury and Gibson 2004, Frey and Conover 2006, Wisdom et al. 2011). Roads and other linear disturbances provide corridors for predators (Grinder and Krausman 2001, Apps et al. 2002). Tall structures, such as powerlines, have also been identified as threats to sage-grouse by increasing avian predation (Aspbury and Gibson 2004). Hens may nest farther from leks if road disturbance is present (Lyon and Anderson 2003). The Grouse Creek Watershed is a highly fragmented region with the smallest contiguous patch of land, excluding the town of Grouse Creek, being <1 ha. The largest contiguous patch of land with interspersed roads, but without dividing roads, was 6,555 ha. The median contiguous patch of land with interspersed roads was 130 ha. Most (86%) sage-grouse mortalities were within 450 m of a road. Predated nests were closer to roads, particularly 2-track roads, than successful nests. Most mortality sites and nest sites were visible from tops of utility poles. Effects of fragmentation should be considered when making decisions about where to place energy development structures.

Broodless hens and male sage-grouse movements from the southern region to the northern regions coincided with temperature changes. In warmer, drier years, sage-grouse migrated earlier, while in wetter, colder years, sage-grouse migrated later. These local adaptations to weather were similar to sage-grouse behaviors in other regions of the state (Robinson 2007). Climate factors can affect sagebrush steppe plant demographics (Dalgleish et al. 2011), which can alter wildlife migration patterns and foraging behavior (Beck 1977).

My research is the first study to address the effects of greenstripping on sage-grouse populations and habitat. The risk of wildfire to permanently transform the sagebrush community on Badger Flat to an annual grassland was identified as a threat (BARM 2007, Thacker 2010). This research prompted the U.S. Bureau of Land Management to plant forage kochia greenstrips. Although sage-grouse were present on both treated and untreated sites, sage-grouse preferred untreated areas over treated areas. Sage-grouse expanded their lek to encompass more of the treated area. Chain harrowing reduced shrub cover and prepared the seedbed for forage kochia planting. Forage kochia germination rate (46%) was within the range reported by other studies (Kitchen and Monsen 2001, Creech 2012). Sagebrush had not fully regenerated after 2 years, but it is common for sagebrush to take >10 years to recover post-mechanical treatment (Boyd and Svejcar 2011). However, caution should be used when reducing sagebrush cover and creating a disturbance across sage-grouse habitats. There was no difference in the amount of invasive species between treated and untreated sites. However, without the use of Plateau® (BASF Chemical Corporation, Research Triangle Park, NC) herbicide, invasive plants may have been more prevalent (Eddington 2006).

Microhistological analysis revealed that forage kochia was present in sage-grouse pellets that had been collected from the Tabby Wildlife Management Area (WMA) and Badger Flat. Tabby WMA was seeded in 2004 and had a higher concentration of forage kochia in sage-grouse pellets than Badger Flat, which was seeded in 2010. Although forage kochia was consumed in small quantities, forage kochia may provide an alternative food source based on high protein content and low plant secondary metabolite levels.

In a fragmented landscape with areas that approximate climate change models and habitat characteristics do not meet sage-grouse habitat guidelines, it is important to research options for restoring or improving sagebrush habitats. Forage kochia has a high moisture content that may be beneficial to protecting sagebrush habitats from wildfire and can compete with invasive annuals (McArthur et al. 1989, Pellant 1994). Due to the amount of disturbance associated with chaining, treatments should be minimal in scope across sagebrush rangelands, and applications should be implemented to minimize the spread of invasive species. As well, long term monitoring should be completed to assess the impacts of greenstripping. My research documented low adult survival and nesting success rates. Nesting success rates can greatly influence overall population size (Holloran et al. 2005, Taylor et al. 2012). Therefore, efforts should be placed on maintaining or increasing available nesting habitat. My research also indicated that fragmentation might impact nest success rates and mortality rates. Mitigation techniques should be implemented that consider topography and landscape characteristics when new anthropogenic structures are being developed. Ecosystems should be assessed, and active or passive restoration should be applied based upon current habitat factors, threats, and potential changes in landscape.

LITERATURE CITED

Apps, C. D., N. J. Newhouse, and T. A. Kinley. 2002. Habitat associations of American badgers in southeastern British Columbia. Canadian Journal of Zoology 80:1228-1239.

Aspbury, A. S., and R. M. Gibson. 2004. Long-range visibility of greater sage grouse leks: a GIS-based analysis. Animal Behaviour 67:1127-1132.

BARM (West Box Elder Adaptive Resource Management Local Working Group). 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. Unpublished Report. Salt Lake City, Utah, USA.

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

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

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

Boyd, C. S., and T. J. Svejcar. 2011. The influence of plant removal on succession in Wyoming big sagebrush. Journal of Arid Environments 75:734-741.

Connelly, J. W., K. P. Reese, W. L. Wakkinen, M. D. Robertson, and R. A. Fisscher. 1994. Sage grouse ecology report. Idaho Department of Fish and Game, Job Completion Report W-160-R-19, Subproject 9, Boise, USA.

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

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

Creech, C. F. 2012. Effects of planting date, harvest date, and environmental conditions on germination of forage kochia accessions. Thesis, Utah State University, Logan, USA.

Crête, M., and S. Larivière. 2003. Estimating the costs of locomotion in snow for coyotes. Canadian Journal of Zoology 81:1808-1814.

Crooks, K. R. 2002. Relative sensitivities of mammalian carnivores to habitat fragmentation. Conservation Biology 16:488-502.

Dahlgren, D. K., T. A. Messmer, and D. N. Koons. 2010. Achieving better estimates of Greater sage-grouse chick survival in Utah. Journal of Wildlife Management 74:1286-1294.

Dalgleish, H., D. Koons, M. Hooten, C. Moffet, and P. B. Adler. 2011. Climate influences the demography of three dominant sagebrush steppe plants. Ecology 92:75-85.

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

Earnst, S., H. L. Newsome, W. L. LaFramboise, and N. LaFramboise. 2009. Avian response to wildfire in Interior Columbia Basin Shrubsteppe. The Condor 111:370-376.

Eddington, D. B. 2006. Effects of cheatgrass control on Wyoming big sagebrush in Southeastern Utah. Thesis, Department of Plant and Animal Science, Brigham Young University, Provo, Utah, USA.

Fischer, R. A., K. P. Reese, and J. W. Connelly. 1996. An investigation on fire effects within xeric sage grouse brood habitat. Journal of Range Management 49:194-198.

Frey, N., and M. R. Conover. 2006. Habitat use by meso-predators in a corridor environment. Journal of Wildlife Management 70:1111-1118.

Garton, E. O., J. W. Connelly, J. S. Horne, C. A. Hagen, A. Moser, and M. A. Schroeder. 2011. Greater sage-grouse population dynamics and probability of persistence. Pages 293-381 *in* S. T. Knick and J. W. Connelly, editors. Greater sage-grouse: ecology and conservation of a landscape species and its habitat. Studies in Avian Biology 38. University of California Press, Berkeley, CA.

Grinder, M. I., and P. R. Krausman. 2001. Home range, habitat use, and nocturnal activity of coyotes in an urban environment. Journal of Wildlife Management 65:887-898.

Gregg, M. A. 1991. Use and selection of nesting habitat by sage grouse in Oregon. Thesis, Oregon State University, Corvallis, USA.

Hagen, C. A. 2011. Predation on Greater Sage-Grouse: facts, process, and effects. Pp. 95-110 *in* S. T. Knick and J. W. Connelly, editors. Greater Sage-Grouse: ecology and conservation of a landscape species and its habitats. Studies in Avian Biology (vol. 38), University of California Press, Berkeley, USA.

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

Kitchen, S. G., and S. B. Monsen. 2001. Forage kochia seed germination response to storage time and temperature. Journal of Range Management 54:299-306.

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

Knick, S. T., and J. W. Connelly. 2011. Greater sage-grouse: ecology and conservation of a landscape species and its habitats. University of California Press, Berkeley, USA.

Knick, S. T., A. L. Holmes, and R. F. Miller. 2005. The role of fire in structuring sagebrush habitats and bird communities. Studies in Avian Biology 30:1-13.

Lensing, J. R., and D. H. Wise. 2006. Predicted climate change alters the indirect effect of predators on an ecosystem process. Proceedings of the National Academy of Sciences of the United States of America 103:15502-15505.

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.

McArthur, E. D., A. C. Blauer, and R. Stevens. 1989. Forage kochia competition with cheatgrass in central Utah. Symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management, Las Vegas, Nevada, USA.

Musil, D. D., and J. W. Connelly. 2005. Sage-grouse ecology report. Idaho Department of Fish and Game, Job Completion Report W-160-R-32, Subproject 53, Boise, USA.

Musil, D. D., J. W. Connelly, and K. P. Reese. 1993. Movements, survival, and reproduction of sage grouse translocated into Central Idaho. Journal of Wildlife Management 57:85-91.

Pellant, M. 1994. History and applications of the intermountain greenstripping program. Pages 63-68 *in* S. B. Monsen and S. G. Kitchen, comps. Proceedings-symposium on ecology and management of annual rangelands. 18-21 May 1992. Boise, ID.

General Technical Report INT-GTR-313. USDA Forest Service, Intermountain Research Station, Ogden, Utah, USA.

Robinson, J. D. 2007. Ecology of two geographically distinct greater sage-grouse populations inhabiting Utah’s west desert. Thesis, Utah State University, Logan, USA.

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

Schroeder, M. A., J. R. Young, and C. E. Braun. 1999. Sage grouse (*Centrocercus urophasianus*). Pages 1-28 *in* A. Poole and F. Gill, editors. The birds of North America, No. 425. The Birds of North America, Incorporated, Philadelphia, Pennsylvania, USA.

Stiver, S. J., A. D. Apa, J. R. Bohne, S. D. Bunnell, P. A. Deibert, S. C. Gardner, M. A. Hilliard, C. W. McCarthy, and M. A. Schroeder. 2006. Greater sage-grouse comprehensive conservation strategy. Western Association of Fish and Wildlife Agencies, Cheyenne, Wyoming, USA.

Taylor, R. L., B. L. Walker, D. E. Naugle, and L. S. Mills. 2012. Managing multiple vital rates to maximize greater sage-grouse population growth. Journal of Wildlife Management 76:336-347.

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

Trueblood, R. W. 1954. The effect of grass reseeding in sagebrush lands on sage grouse populations. Thesis, Utah State University, Logan, USA.

U.S. Department of the Interior. 2010. Federal Register Notice. U.S. Fish and Wildlife Service, Washington, D. C., USA.

Utah Division of Wildlife Resources (UDWR). 2009. Utah Greater Sage-grouse Management Plan. Utah Department of Natural Resources, Division of Wildlife Resources, Publication 09-17, Salt Lake City, USA.

Vander Haegen, M. W., F. C. Dobler, and D. J. Pierce. 2000. Shrubsteppe bird response to habitat and landscape variables in Eastern Washington, U.S.A. Conservation Biology 14:1145-1160.

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

Wallestad, R., and R. L. Eng. 1975. Foods of adult sage grouse in central Montana. Journal of Wildlife Management 39:628-630.

Wisdom, M. J., C. W. Meinke, S. T. Knick, and M. A. Schroeder. 2011. Factors associated with extirpation of sage-grouse. Pages 451-472 *in* S. T. Knick and J. W. Connelly, editors. Greater sage-grouse: ecology and conservation of a landscape species and its habitats. Studies in Avian Biology. Volume 38. University of California Press, Berkeley, USA.

Zablan, M. A., C. E. Braun, and G. C. White. 2003. Estimation of greater sage-grouse survival in North Park, Colorado. Journal of Wildlife Management 67:144-154.