5-2014

The Role of Vegetation Structure, Composition, and Nutrition in Greater Sage-Grouse Ecology in Northwestern Utah

Brian R. Wing
Utah State University

THE ROLE OF VEGETATION STRUCTURE, COMPOSITION, AND NUTRITION

IN GREATER SAGE-GROUSE ECOLOGY IN NORTHWESTERN UTAH

by

Brian R. Wing

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	John W. Connelly Committee Member
Michael R. Conover Committee Member	Mark R. McLellan Vice President for Research and Dean of the School of Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

2014

ABSTRACT

The Role of Vegetation Structure, Composition, and Nutrition

in Greater Sage-Grouse Ecology in Northwestern Utah

by

Brian R. Wing, Master of Science

Utah State University, 2014

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

The greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) is a sagebrush (*Artemisia* spp.) obligate species and a candidate for listing under the Endangered Species Act of 1973. The Box Elder Sage-Grouse Management Area (SGMA), located in northwestern Utah, encompasses one of the state's largest sage-grouse populations. Other than lek locations, little was previously known about the general ecology of the sage-grouse inhabiting the Raft River subunit of this SGMA. More information was needed regarding the status of this population and the effects of previous management actions.

From January 2012 through December 2013, I captured, radio-marked, and monitored 123 (68 female, 55 male) sage-grouse in the Raft River subunit. My objectives were to describe the effects of microhabitat use and breeding season foraging patterns on the seasonal movements, survival, and reproductive rates of this sage-grouse population.

Sage-grouse in the Raft River subunit have distinct winter and summer ranges, with the breeding areas overlapping the winter range. Some individuals travelled long distances between their winter and summer range, while others moved only a few kilometers. Annual survival rates were similar to Utah and range-wide averages, being slightly higher for females than males. Nest and brood success rates were above most Utah and range-wide averages.

I conducted vegetation surveys at sage-grouse use sites and random sites to determine if specific habitat preferences exist in this population of the species. Sage-grouse in the study area selected sites with specific vegetation characteristics to fit their seasonal needs. Sage-grouse use sites were greater overall in forb height, grass height, and shrub height and cover than random sites. Successful females selected nest sites with greater forb height and cover and grass and shrub height than unsuccessful nesting females. Brooding females selected sites greater in forb, grass, and shrub height than non-brood sites.

During March and April 2013, I monitored 41 (29 female, 12 male) radio-marked sage-grouse at flock browse sites. The sagebrush plants browsed at these sites did not differ from non-browsed and random plants in nutritional quality and chemical composition. Black sagebrush (*A. nova*) was lower in percent crude protein and higher in total monoterpene concentration than Wyoming big sagebrush (*A. tridentata wyomingensis*). Radio-marked females were frequently found in association with sites where black sagebrush was browsed, and an unidentified monoterpene was considerably more concentrated in browsed plants associated with females that nested successfully.

(126 pages)

PUBLIC ABSTRACT

The Role of Vegetation Structure, Composition, and Nutrition

in Greater Sage-Grouse Ecology in Northwestern Utah

by

Brian R. Wing, Master of Science

Utah State University, 2014

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

The greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) is the largest grouse species in North America and an indicator species for the condition of sagebrush (*Artemisia* spp.) ecosystems. The Box Elder Sage-Grouse Management Area (SGMA) in northwestern Utah encompasses one of the state's largest sage-grouse populations.

To fill knowledge gaps regarding the population inhabiting the Raft River subunit of the Box Elder SGMA, I captured, radio-marked, and monitored 123 (68 female, 55 male) sage-grouse from January 2012 through December 2013. My purpose was to describe how the seasonal movements, survival, and reproductive rates of this sage-grouse population are effected by small-scale habitat use and breeding season foraging patterns.

Sage-grouse in the Raft River subunit have distinct winter and summer ranges, and some travelled long distances annually. Survival rates were similar to other Utah populations and range-wide averages. Nest and brood success rates were above range-

wide averages and those reported in the adjacent Grouse Creek subunit of the same SGMA.

Sage-grouse in the study area selected habitats with specific vegetation characteristics to fit their seasonal needs. Sage-grouse use sites differed from random sites with greater forb height, grass height, and shrub height and cover. Nest success rates were directly related to selected vegetation, as successful nests were located more often under sagebrush and within greater forb height and cover and grass and shrub height than unsuccessful nests. Brood sites were also greater in forb, grass, and shrub height than other use sites.

In March and April of 2013, I located radio-marked sage-grouse at flock browse sites to observe their sagebrush diet selection patterns. Lab analyses showed no differences in nutritional quality or chemical composition between browsed sagebrush plants and non-browsed and random plants. However, browsed black sagebrush (*A. nova*) was lower in protein and higher in chemical content than browsed Wyoming big sagebrush (*A. tridentata wyomingensis*). Radio-marked females were frequently observed at sites where black sagebrush was browsed, and one individual chemical was considerably more concentrated in browsed plants associated with females that nested successfully.

My research provides useful information regarding the seasonal habitat use patterns and vegetation preferences of sage-grouse in the Box Elder SGMA. To conserve the sage-grouse population in northwestern Utah, management actions must protect the seasonal habitats and vegetation that the species depends on for its productivity and survival.

ACKNOWLEDGMENTS

I would like to thank my advisor and project manager, Dr. Terry A. Messmer, for the opportunity to conduct this research. His guidance and support have been outstanding, and his continuously optimistic attitude is admirable and greatly appreciated. I also thank my supervisory committee members, Dr. John W. Connelly and Dr. Michael R. Conover, for providing their time and expertise in helping me complete my research.

I appreciate the people that worked hard to conduct the field and lab work of this research. I thank Avery Cook for all of his help and cooperation as we studied different aspects of this sage-grouse population using the same sample of radio-collared birds. I thank Todd Black for providing his help and expertise in orienting us with the study area and capturing birds. I also thank Dr. Dale Gardner and Kermit Price of the U. S. Department of Agriculture Poisonous Plants Research Lab in Logan, Utah for their time and willingness in helping me complete my sagebrush nutrition and chemical analyses. I would also like to thank the field technicians who often endured less-than-ideal conditions to track birds and collect data; namely Kelly Heitkamp, Rebecca Jo Laymon, Nicholas Gent, Cody Griffin, Andrew Clawson, Kyrie Jensen, and Dyllan Frahm.

I am thankful for the many residents and landowners of west Box Elder County that have also made this research possible. A large portion of sage-grouse habitat occurs on private lands, and this work could not have been accomplished without the help and support of private landowners. Thanks to each of these individuals that have so willingly provided access to their lands and a wealth of knowledge regarding the geographic area.

These are conservation-minded people who work hard to protect and maintain the natural resources of the area.

I also thank those that provided the financial, technical, and professional support that made this research possible: the Ruby Pipeline and El Paso Corporation, Utah Watershed Restoration Initiative, Utah Division of Wildlife Resources, U.S. Bureau of Land Management, and the Box Elder County Coordinated Resources Management and local working group members.

I would like to thank my wife, Monica, for her patience and support during the course of this research. She was completely supportive while I was away from home, and she was always willing to review my writing and help in any other way she possibly could. She continues to be my greatest source of encouragement.

I also thank my parents, Ralph and Pam Wing, for encouraging me to attain a higher education and pursue a career in what interests me most. I thank my father for introducing me to the outdoors, initiating my interest in wildlife, and for being a great example of hard work and accomplishment. I thank my mother for motivating me to be my best, spurring my creativity, and supporting me in my aspirations with love and kindness.

Brian R. Wing

CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

SPECIES DESCRIPTION

Greater sage-grouse (*Centrocercus urophasianus*; sage-grouse), are the largest native grouse species in North America and a key indicator species for the condition of sagebrush (*Artemisia* spp.) ecosystems. Sage-grouse are sexually dimorphic with males being about twice the size of females (Patterson 1952, Dalke et al. 1963). Males are typically 1.7–2.9 kg in weight and 65–75 cm long. Females are 1.0–1.8 kg in weight and are 50–60 cm long (Schroeder et al. 1999). Sexes also differ in coloration when males don their breeding plumage in late winter. During the breeding (lekking) season, males have stiff white feathers on the breast and neck, fleshy yellow combs above the eyes, long filoplume feathers on the neck, and dark patches on the chin and throat (Dalke et al. 1963, Schroeder et al. 1999). During their courtship displays, males fan their long pointed tail feathers, brush their wings across their stiff breast feathers, and inflate two yellow balloon-like esophageal pouches on their breast which are used to make a popping sound (Schroeder et al. 1999). Otherwise, both sexes are cryptically colored in drab brown, gray, black, and white, though females are even more cryptic in appearance than males. Females keep the same color pattern year-round and have long pointed tail feathers similar to males. Sage-grouse belong to the family *Phasianidae*, within the order *Galliformes.*

In 2010, the U.S. Fish and Wildlife Service (USFWS) designated the species as a candidate for protection under the Endangered Species Act of 1973 (ESA), citing long-term habitat loss and fragmentation as major factors in observed population declines (USFWS 2010). Sage-grouse currently occupy about 56% of their historic range in 11 U.S. states and 2 Canadian provinces, whereas they once occupied 12 U.S. states and 3 Canadian provinces (Connelly et al. 2004, Schroeder et al. 2004, USFWS 2010). The USFWS will decide in late 2015 if the species will receive full protection under the ESA (USFWS 2010). Because of the wide spread distribution of the species and large expanses of suitable sagebrush habitats, biologists agree that long term species conservation is still possible (Connelly et al. 2011*b*). However, more information is needed regarding meta-population vital rates, habitat use, and seasonal movements for application to management.

ECOLOGY AND GENERAL HABITAT REQUIREMENTS

Breeding

Sage-grouse engage in communal breeding behavior; they are a polygynous species where one male may breed with multiple females. In the spring of each year, typically during the months of March and April but with some variation due to weather conditions (Robinson and Messmer 2013), multiple male sage-grouse gather in the early morning hours on breeding sites known as leks to perform their breeding display and attract female attention (Patterson 1952). A dominant male generally occurs at the center of each lek and will often breed a majority of the females. Female sage-grouse may attend a lek on multiple mornings and will choose a suitable male to breed with based on his breeding display. Sage-grouse typically use the same lek locations year after year, which are most often patches of low or sparse vegetation to allow greater visibility of the displaying males (Patterson 1952, Dalke et al. 1963). Sage-grouse may even use disturbed sites for lekking, if these provide adequate visibility (Connelly et al. 1981, Duvuvuei 2013).

Nesting

Following breeding on the lek, female sage-grouse choose a nest location. Nesting sites are often within 3 km of the nearest lek, but may be located 10 km or more from the nearest lek (Wakkinen et al. 1992, Hanf et al. 1994, Fedy et al. 2012). Sage-grouse nests are typically located under sagebrush (Patterson 1952, Wallestad and Pyrah 1974). It is not uncommon for another similar shrub species to be chosen as a nest site (Klebenow 1969, Gregg et al. 1994, Gruber 2012, Duvuvuei 2013), but nests are typically more successful when located under sagebrush (Connelly et al. 2011*c*). Gregg et al. (1994), Holloran et al. (2005), and Knerr (2007) reported that sage-grouse nest sites are typically taller and denser in shrub and grass canopy cover than random sites. Dahlgren (2006) and Guttery (2011) did not observe the same relationship for sage-grouse nesting in higher elevation sagebrush communities in Utah. Connelly et al. (2000) recommended maintaining mean sagebrush nesting canopy cover of 15–25% with mean height of nest bushes 30–72 cm, depending on site moisture conditions.

Several studies have reported that nests located within greater shrub canopy cover are typically more successful (Wallestad and Pyrah 1974, Gregg et al. 1994, Kolada et al. 2009). Nest success may vary as much as 15–86% from one population to another, depending on habitat quality, the female's age and experience, and the abundance of nest predators (Connelly et al. 2011*a*). If the first nest is unsuccessful, the female may re-nest, though the second clutch will likely be smaller than the first (Schroeder 1997). The typical clutch size of sage-grouse is 6–9 eggs but rarely may be as high as 12 eggs (Schroeder 1997, Connelly et al. 2011*a*). Incubation begins once the clutch is complete and typically lasts about 27 days (Patterson 1952, Connelly et al. 2011*a*).

Brood-rearing

Following hatching, sage-grouse chicks stay with the female until late summer or early fall. Due to the low mobility of young chicks, females will typically stay fairly close to the nest location for their first few weeks of age. However, this varies among broods (Knerr 2007), and some females have been observed moving their brood a relatively long distance within only a few days of hatching (Connelly et al. 2000). During their first few weeks of life, the chicks live on a diet consisting mainly of forbs and insects (Patterson 1952, Drut et al. 1994, Gregg and Crawford 2009). Sage-grouse chicks are able to fly short distances at about 2 weeks of age (Patterson 1952).

As the chicks become more competent fliers and the brooding season advances, the female normally moves her brood greater distances to find habitat with sufficient moisture and vegetation to maintain their diet (Klebenow 1969). Sage-grouse brooding areas are generally less dense in canopy cover than nesting sites (Thacker 2010). Martin (1970), Wallestad (1971), and Sveum et al. (1998) reported finding broods in areas of about 14% shrub canopy cover on average. Forb cover is typically greater at brood sites than at nest and random sites (Connelly et al. 2000, Bunnell et al. 2004, Knerr 2007), often at an average of 15% or more (Sveum et al. 1998). The survival of young sage-grouse is dependent on habitat quality, food availability, predator abundance, and weather. Just as with nest success rates, brood survival rates vary greatly among sage-grouse populations.

Summer

In the summer months, males and non-brooding females may also move long distances to find suitable forage. Past research has shown that seasonal movement distances vary greatly among populations and even among individuals of the same population (Connelly et al. 1988). The total distance a sage-grouse moves between its winter and summer habitats may be well under 10 km or as much as 60 km or more (Connelly et al. 1988, Reinhart et al. 2013). The distance moved likely depends on fidelity to seasonal ranges and the amount of precipitation received (Connelly et al. 1988). Sage-grouse will typically avoid exceedingly dry areas during the summer months due to the lack of adequate forage (Fischer et al. 1996). Sage-grouse have a specialized digestive system without a muscular gizzard containing stones (Patterson 1952); therefore, they are only able to digest soft plant tissues and insects. If suitable forage cannot be found near their winter and spring habitat, sage-grouse will likely move to higher elevations or areas of regularly irrigated agricultural crops (Patterson 1952). Sage-grouse may be found independently or in small flocks during this time.

Fall and Winter

In the fall, sage-grouse will typically form larger flocks of all age groups and both sexes (Patterson 1952, Thacker 2010). Fall sage-grouse habitat is often located between their summer and winter ranges (Connelly et al. 2000). In the winter months, sage-grouse typically flock together, though they may be segregated by sex (Patterson 1952).

Sage-grouse may winter near or at the lek location. The winter diet of sage-grouse consists almost entirely of sagebrush leaves (Patterson 1952, Dalke et al. 1963). Beck and Braun (1978) reported that it is not unusual for sage-grouse to gain weight during the winter months. Big sagebrush (*A. tridentata* ssp.) is commonly the major component of many sage-grouse diets in winter (Remington and Braun 1985, Connelly et al. 2000). However, Thacker et al. (2012) and Frye et al. (2013) reported that some sage-grouse populations prefer black sagebrush (*A. nova*) over big sagebrush for winter forage. Sage-grouse typically fair well in winter, despite the harsh temperatures, and they are unaffected by snow unless it accumulates high enough to cover their sagebrush food source (Hupp and Braun 1989). Because of snow depth, sage-grouse will likely be found at relatively low elevations during the winter. Past studies have shown that sagebrush at winter sage-grouse sites typically ranges 24–56 cm in mean height and approximately 15–40% in mean canopy coverage (Connelly et al. 2000).

CONSERVATION THREATS AND HABITAT MANAGEMENT

Loss of suitable habitat is likely the greatest factor in the recent decline of sage-grouse populations (Braun et al. 1977, USFWS 2010). Sage-grouse are sagebrush obligates, meaning they depend on sagebrush for their survival; it is used as both a primary forage and preferred cover. Sagebrush habitat has been lost to several sources which most often include human development for agriculture and urbanization or energy sources, fire, invasive plants, and pinyon-juniper (*Pinus* spp., *Juniperus* spp.) encroachment (Connelly and Braun 1997, Crawford et al. 2004, Baruch-Mordo et al. 2013).

Habitat loss may affect sage-grouse in multiple ways; an obvious effect is the loss of forage and cover. Other negative effects include a total loss or fragmentation of breeding locations and seasonal ranges (Braun et al. 1977), lost nesting and brood-rearing locations (Connelly and Braun 1997), interrupted or altered seasonal movements, population isolations and reduced genetic flow, and the possibility of an increase in predation (Coates and Delehanty 2010).

Many animal species prey upon sage-grouse at all stages of their life cycle (Schroeder and Baydack 2001, Hagen 2011). Common nest predators include but are not limited to common raven (*Corvus corax*), American crow (*Corvus brachyrhynchos*), black-billed magpie (*Pica hudsonia*), American badger (*Taxidea taxus*), striped skunk (*Mephitis mephitis*), red fox (*Vulpes vulpes*), and coyote (*Canis latrans*). Once hatched, sage-grouse chicks are preyed on by many of the same predators, but will also become susceptible to raptors including golden eagle (*Aguila chrysaetos*), *Buteo* hawks, and larger falcons (*Falco* spp.). Adult sage-grouse are most commonly preyed upon by golden eagles and larger mammalian carnivores, such as coyote, fox, and bobcat (*Lynx rufus*).

Although direct control of the predator community may improve the vital rates of a sage-grouse population (Baxter et al. 2008), proper habitat management techniques can be potentially more effective in mitigating the effects of predators (Connelly et al. 2000, Schroeder and Baydack 2001). In managing for better sage-grouse habitat, the objective should be to increase suitability for sage-grouse and reduce suitability for predator species. For example, larger patches of nesting habitat with a lower proportion of edges can decrease the likelihood of nests being discovered by predators travelling the perimeter of habitat patches (Angelstam 1986, Jimenez and Conover 2001).

The structure and composition of nesting habitat can also mitigate predation. Conover et al. (2010) reported that sage-grouse in southwest Wyoming and south-central Utah selected nest sites that provided greater visual obstruction than at random sites. Past studies have shown that sage-grouse nests are typically most successful when located within greater sagebrush canopy cover (Wallestad and Pyrah 1974, Connelly et al. 1991). The geographic location of nesting habitat is also important to avoid the highest concentrations of predators and reduce the risk of predation (Dinkins et al. 2012). Predation in general is likely to increase if predator movements through sage-grouse habitat are facilitated by roads, ditches, fence lines, trees, and structures. Fragmentation of sage-grouse habitat can also lead to increased predation, as the birds must move greater distances and thus increase their risk of being exposed to predators (Beck et al. 2006). To further discourage predation in sage-grouse habitat, it may also be effective to remove trees or structures that act as perches or nest sites for avian predators.

The first step in managing sage-grouse habitat is to identify which geographical areas are important to the species at each season of the year. Because the desirable components vary among habitat types, consideration should be given to the particular season that the habitat is used and for what it is used (Crawford et al. 2004). For example, sage-grouse select nesting sites which typically exhibit greater vegetation cover, while brood-rearing sites often occur in areas of lower and more mesic vegetation (Connelly et al. 2011*b*). Further, a variety of edible forbs found in mesic areas are important in sage-grouse spring and summer ranges. Preferred winter ranges exhibit heterogeneous stands of sagebrush that provide the birds forage and cover above the typical snowline. Once occupied sage-grouse habitats are identified, species conservation in these areas can be achieved by protecting these habitats and/or restoring degraded habitats.

Conservation of sagebrush habitats commonly includes eliminating encroaching plant species which displace native sagebrush, forbs, and grasses and increase the risk of wildfire. Undesirable plants may be native (i.e., pinyon-juniper) or invasive (i.e., cheatgrass [*Bromus tectorum*]). Important native vegetation may be restored if needed, but this will likely require several years and is only moderately effective (Pyke 2011), so it is much better to protect these critical habitat components before they are lost.

Over the years, many different methods of habitat treatment have been used in sagebrush ecosystems. Some of the most common methods include fire, grazing, chemical, and mechanical treatments. Some studies have reported negative impacts on sage-grouse ecology due to such habitat treatments (Braun et al. 1977, Connelly et al. 2000, Beck et al. 2012). In many areas, land managers now use experimental habitat treatments to determine the best options for increasing the productivity of a landscape. This often includes strategic manipulations or treatments and/or establishment of specific vegetation. Disturbance processes may encourage diversity in the age and species of vegetation; however, this often facilitates the spread of invasive species and should only be conducted in careful moderation (Pyke 2011). To be effective, it is crucial that habitat treatments are designed on a foundation of research-based knowledge relevant to the ecosystem of interest.

RESEARCH PURPOSE

Although much is known about sage-grouse biology range-wide, managers agree more information is needed regarding the effects of management actions on sage-grouse populations at the local level (Connelly et al. 2011*b*). For example: whether or not to employ treatments, the type of treatments, and the scale at which they should be conducted to optimize the benefits to habitat (Dahlgren et al. 2006, Graham 2013). This is the case for the sage-grouse population inhabiting northwestern Utah.

My research was conducted in Utah's sage-grouse management area (SGMA) in Box Elder County, northwestern Utah. To conserve this sage-grouse population, research is needed to describe its habitat use patterns, seasonal movements, vital rates, sources of mortality, and response to previous sage-grouse habitat management actions. My research provides data and information regarding the status of sage-grouse in northwestern Utah. With this information, a more-accurate assessment of population status and factors affecting its conservation can be made. This research provides managers with information to guide the design and implementation of management actions for the long-term conservation of the sage-grouse population in this area.

The relative importance of factors affecting sage-grouse vital rates and habitat use can be determined using a hierarchal approach (Johnson 1980, Stiver et al. 2010). This approach analyzes habitat at multiple levels ranging from a species' geographical range to the actual selection of forage at a particular feeding site. For sage-grouse, these hierarchal levels are first order: the entire geographical distribution of the species in North America; second order: the home range of a particular population or subpopulation of sage-grouse; third order: the habitat use and seasonal movements of individuals within the home range; and fourth order: the characteristics and components of the habitat being used by sage-grouse and their daily movements within a specific seasonal range (Stiver et al. 2010).

Chapter 2 of my thesis describes the third and fourth order of habitat use and general ecology of sage-grouse in northwestern Utah, especially those that inhabit the Raft River subunit of the SGMA in this region of the state. Using descriptive and statistical analyses, I characterize the structure and species composition of vegetation found at actual sage-grouse use sites and random sites. I assess the small-scale vegetative characteristics selected by nesting and brooding females and compare these values to other use and random sites.

In chapter 3, I describe a fifth order of hierarchal habitat use by comparing the nutritional and chemical quality of sagebrush browsed by sage-grouse to non-browsed and random plants of the same subspecies. This chapter includes descriptive and statistical analyses to describe the nutritional and chemical effects of browsed sagebrush on sage-grouse breeding season survival and reproductive success.

Chapter 4 is the conclusion of my thesis. In this chapter, I summarize the results of my research on the effects of vegetation structure, composition, and breeding season diet selection on sage-grouse ecology in northwestern Utah. This thesis is written in a multiple-paper format following the Journal of Wildlife Management 2011 guidelines (Block et al. 2011).

LITERATURE CITED

Angelstam, P. 1986. Predation on ground-nesting birds' nests in relation to predator densities and habitat edge. Oikos 47:365–373.

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

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

Beck, T. D. I., and C. B. Braun. 1978. Weights of Colorado sage-grouse. Condor 80:241–243.

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

Beck, 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.

Block, W. M., F. R. Thompson, D. Hanseder, A. Cox, and A. Knipps. 2011. Journal of Wildlife Management guidelines. The Wildlife Society, Bethesda, Maryland, USA.

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

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

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

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

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

Connelly, J. W., C. A. Hagen, and M. A. Schroeder. 2011*a*. Characteristics and dynamics of greater sage-grouse populations. Pages 53–67 *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 38. University of California Press, Berkeley, USA.

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*b*. Conservation of greater sage-grouse: a synthesis of current trends and future management. Pages 549–563 *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 38. University of California Press, Berkeley, 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., E. T. Rinkes, and C. E. Braun. 2011*c*. Characteristics of greater sage-grouse habitats: a landscape species at micro- and macro-scales. Pages 69–83 *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 38. University of California Press, Berkeley, USA.

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

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

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

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

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

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

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.

Dinkins, J. B., M. R. Conover, C. P. Kirol, and J. L. Beck. 2012. Greater sage-grouse select nest sites and brood sites away from avian predators. Auk 129:600–610.

Drut, M. S., W. H. Pyle, and J. A. Crawford. 1994. Diets and food selection of sage-grouse chicks in Oregon. Journal of Range Management 47:90–93.

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

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

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

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

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

Gregg, M. A., 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.

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.

Gruber, N. W. 2012. Population dynamics and movements of translocated and resident greater sage-grouse on Anthro Mountain, Utah. Thesis, Utah State University, Logan, USA.

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. Pages 95–100 *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 38. University of California Press, Berkeley, USA.

Hanf, J. M., P. A. Schmidt, and E. B. Groshend. 1994. Sage-grouse in the high desert of central Oregon: results of a study 1988–1993. U. S. Department of the Interior, Bureau of Land Management Series P-SG-01, Prineville, Oregon, USA.

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

Hupp, J. W., and C. E. Braun. 1989. Topographic distribution of sage-grouse foraging in winter. Journal of Wildlife Management 53:823–829.

Jimenez, J. E., and M. R. Conover. 2001. Ecological approaches to reduce predation on ground-nesting game birds and their nests. Wildlife Society Bulletin 29:62–69.

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

Klebenow, D. A. 1969. Sage-grouse nesting and brood habitat in Idaho. Journal of Wildlife Management 33:649–661.

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

Kolada, E.J., M.L. Casazza, and J.S. Sedinger. 2009. Ecological factors influencing nest survival of greater sage-grouse in Mono County, California. Journal of Wildlife Management 73:1341–1347.

Martin, N. S. 1970. Sagebrush control related to habitat and sage-grouse occurrence. Journal of Wildlife Management 34:313–320.

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

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 38. University of California Press, Berkeley, USA.

Reinhart, J. S., T. A. Messmer, and T. Black. 2013. Interseasonal movements in tri-state greater sage-grouse: implications for state-centric conservation plans. Human-Wildlife Interactions 7:172–181.

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

Robinson, J. D., and T. A. Messmer. 2013. Vital rates and seasonal movements of two isolated greater sage-grouse populations in Utah's West Desert. Human-Wildlife Interactions 7:182–194.

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

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

Schroeder, M. A., and R. K. Baydack. 2001. Predation and the management of prairie grouse. Wildlife Society Bulletin 29:24–32.

Schroeder, M. A., J. R. Young, and C. E. Braun. 1999. Greater sage-grouse. Pages 1–28 *in* A. Poole and F. Gill, editors. Birds of North America 425. Academy of Natural Sciences, Philadelphia, Pennsylvania, and American Ornithologists' Union, Washington, D.C., USA.

Stiver, S. J., E. T Rinkes, and D. E. Naugle. 2010. Sage-grouse habitat assessment framework. U.S. Bureau of Land Management, Boise, Idaho, 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.

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. 2012. Using gas chromatography to determine winter diets of greater sage-grouse in Utah. Journal of Wildlife Management 76:588–592.

U.S. Fish and Wildlife Service. 2010. Endangered and threatened wildlife and plants; 12-month findings for petitions to list the greater sage-grouse as threatened or endangered. Federal Register 75:13910–14014.

Wakkinen, W. L., K. P. Reeese, and J. W. Connelly. 1992. Sage-grouse nest locations in relation to leks. Journal of Wildlife Management 56:381–383.

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

Wallestad, R. O., and B. D. Pyrah. 1974. Movement and nesting of sage-grouse females in central Montana. Journal of Wildlife Management 38:630–633.

CHAPTER 2

THE ROLE OF VEGETATION STRUCTURE AND COMPOSITION IN GREATER SAGE-GROUSE ECOLOGY IN BOX ELDER COUNTY, NORTHWESTERN UTAH

ABSTRACT

The greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) is a key indicator species for the condition of sagebrush (*Artemisia* spp.) ecosystems. Because of continued population declines attributed to habitat loss and fragmentation, in 2010, the U.S. Fish and Wildlife Service (USFWS) identified the species as a candidate for protection under the Endangered Species Act of 1973. Federal and state agencies have developed regional and local plans to mitigate species conservation threats. As part of this effort, the state of Utah has identified 11 sage-grouse management areas (SGMAs) to prioritize conservation efforts. The Box Elder SGMA, located in northwestern Utah, encompasses one of the state's largest sage-grouse populations. Other than lek locations and counts, little was known about the general ecology of the sage-grouse inhabiting the Raft River subunit of this SGMA. During 2012 and 2013, I captured, radio-marked, and monitored 123 (68 female, 55 male) sage-grouse to determine habitat selection, seasonal movements, survival, and reproductive rates. I measured the structure and composition of vegetation at bird-use and random sites to determine if microhabitat characteristics differed between the sites and ultimately affected population vital rates. Sage-grouse vital rates in the study area exceeded range-wide reported averages with 63.6% nest success, 71.4% brood success, and a mean monthly survival probability of 0.95. Sage-

grouse use sites exhibited greater forb, grass, and shrub height and cover than random sites. Successful nests exhibited greater forb height and cover and grass and shrub height than unsuccessful nests. Brood sites exhibited more forb, grass, and shrub height than non-brood sites. To sustain sage-grouse populations in the Box Elder SGMA, managers should implement management projects and strategies that protect current habitats from wildfire and development. Managers should also consider projects that would increase the available habitat base by implementing projects which remove conifers in areas where they are encroaching on sagebrush communities.

INTRODUCTION

In 2010, the U.S. Fish and Wildlife Service (USFWS) designated the greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) as a candidate species for protection under the Endangered Species Act of 1973. Habitat loss and fragmentation were implicated as factors contributing to sage-grouse population declines (Connelly et al. 2004, USFWS 2010). Sagebrush (*Artemisia* spp.) habitat has been lost or degraded by human development for agriculture and urbanization or energy sources, fire, non-native invasive plants, and pinyon-juniper (*Pinus* spp., *Juniperus* spp.) encroachment (Connelly et al. 2004, Crawford et al. 2004, Baruch-Mordo et al. 2013). The possible negative effects of habitat loss include reduced forage, reduced nesting and escape cover, fragmentation of breeding and seasonal ranges (Braun et al. 1977), lost nesting and brood-rearing locations (Connelly and Braun 1997), interrupted or altered seasonal movements, population isolations and reduced genetic flow, and an increase in predation (Coates and Delehanty 2010).

Sage-grouse are sagebrush obligates that depend on sagebrush for their survival. The winter diet of sage-grouse consists almost entirely of sagebrush leaves (Patterson 1952, Dalke et al. 1963). Sage-grouse females prefer to nest under sagebrush plants, and these are typically more successful than those that select other shrub species as nesting substrate (Connelly et al. 2011*c*). Though the species and percent shrub cover may vary between seasonal ranges, sagebrush remains the one essential component of sage-grouse habitat (Connelly et al. 2011*c*).

In addition to sagebrush, other plant species are important to sage-grouse. Sage-grouse chicks depend on a diet of insects and forbs for their first few weeks of life (Patterson 1952, Gregg and Crawford 2009), and sagebrush is not regularly consumed until about 12 weeks of age (Drut et al. 1994). Brood sites typically exhibit greater forb cover than nest and random sites (Connelly et al. 2011*c*). Adult sage-grouse will also consume forbs when available, and they may travel great distances to seek out areas of sufficient moisture such as higher elevations, riparian zones, and irrigated alfalfa (*Medicago sativa*) fields (Patterson 1952, Reinhart et al. 2013).

Because of the wide-spread distribution of sage-grouse and large expanses of suitable sagebrush habitats, many biologists believe that long term conservation of the species is still possible (Connelly et al. 2011*b*). Although much is known about sage-grouse biology range-wide, more information is needed regarding population vital rates, seasonal movements, and habitat use relative to the effects of past habitat treatments and management actions (Connelly et al. 2004). This is the case for the sage-grouse population inhabiting the Raft River subunit of Utah's sage-grouse management area (SGMA) in Box Elder County, northwestern Utah.

My research was conducted as part of an in-depth study of sage-grouse in the Raft River subunit of the Box Elder SGMA. My research describes the status and general ecology of sage-grouse in this geographical area. More specifically, I described the small-scale or microhabitat characteristics of the habitats selected by sage-grouse and their relationship to reproduction and survival. My research provides managers with information to guide future management in the Box Elder SGMA to conserve its sage-grouse populations.

STUDY AREA

My research was conducted in the Raft River subunit within Utah's Box Elder SGMA (Utah Division of Wildlife Resources [UDWR] 2009). However, because sage-grouse in northwestern Utah may move long distances (Thacker 2010, Reinhart et al. 2013), the study area also included the Grouse Creek and Pilot Mountain subunits (Fig. 2-1). The Raft River subunit encompasses approximately 440,750 ha. The entire study area encompasses approximately 691,550 ha and is in the northwest corner of Utah in Box Elder County. The study area extends from the Utah-Idaho border on the north to the Great Salt Lake and salt flats at the south, and from the Utah-Nevada border on the west to the Hansel Mountains near Snowville, Utah and the Great Salt Lake at the east. The elevation of the study area ranges from 1,300–2,900 m above sea level. Land ownership in the study area was approximately 50% private, 45% federal, and 5% state lands. Common land uses included grazing by domestic livestock, hay production, and rock quarrying.

The climate of the study area is typical of the Great Basin with cold winters and hot summers (West 1983). Average temperatures in this area range from a low of -10 °C in January to a high of 29 °C in July. Average annual precipitation is 34 cm. Average annual snowfall is 92 cm (Western Regional Climate Center 2014). Annual precipitation and snowfall was below average in 2012; the winter had relatively mild temperatures and very little snow accumulated in the valley. In 2013, winter temperatures were often below -20 °C, the snow level persisted in the valley, and spring precipitation was greater than in 2012.

Vegetation composition in the area is related to soil type, moisture, and elevation. Several species of sagebrush were found throughout the area including big (*A. tridentata* ssp.), black (*A. nova*), low (*A. arbuscula*), fringed (*A. frigida*), bud (*A. spinescens*), and pygmy (*A. pygmaea*). Other shrub and tree species present included rabbitbrush (*Chrysothamnus* spp.), greasewood (*Sarcobatus vermiculatus*), horsebrush (*Tetradymia* spp.), antelope bitterbrush (*Purshia tridentata*), serviceberry (*Amelanchier utahensis*), snowberry (*Symphoricarpos* spp.), chokecherry (*Prunus virginiana*), juniper, pinyon pine, Douglas fir (*Pseudotsuga menziesii*), and aspen (*Populus tremuloides*). Common forb species included milkvetch (*Astragalus* spp.), phlox (*Phlox* spp.), hawksbeard (*Crepis* spp.), western yarrow (*Achillea millefolium*), and lupine (*Lupinus* spp.). Native and introduced grasses included Indian ricegrass (*Achnatherum hymenoides*), bluebunch wheatgrass (*Pseudoroegneria spicata*), bluegrasses (*Poa* spp.), Great Basin wildrye (*Elymus cinereus*), crested wheatgrass (*Agropyron cristatum*), and cheatgrass (*Bromus tectorum*).

The sage-grouse population in northwestern Utah has been monitored by the UDWR through lek counts since the 1950s. The conservation of the species has become more of a focus in the area since the formation of the West Box Elder Adaptive Resource Management (WBARM) Local Working Group in 2003, following the UDWR's statewide Strategic Management Plan for Sage-Grouse in 2002 (WBARM 2007). Since that time, landowners and state and federal agencies have been proactive in completing sage-grouse habitat improvement projects. Major threats to species conservation in the Box Elder SGMA include wildfires and conifer encroachment (WBARM 2007). Conservation projects in the area have focused on removing invasive pinyon-juniper from seasonal sagebrush habitats.

METHODS

Data Collection

Capture, Marking, and Tracking

Beginning in January of 2012, both female and male sage-grouse were captured and radio-marked following protocols described by Connelly et al. (2003). Birds were captured at night in 2-person teams using an all-terrain vehicle (ATV), spotlight, and long-handled net. Each captured bird was fitted with a numbered leg band and a 20 g necklace-type Advanced Telemetry Systems™ (ATS) (Advanced Telemetry Systems, Insanti, MN, USA) radio transmitter (150.000−151.000 MHz) equipped with a mortality sensor. Captured birds were sexed, aged (Eng 1955), and weighed using a Pesola™ (Pesola, Baar, Switzerland) 2,500 g spring scale. Large males, weighing beyond the limit of the spring scale, were weighed using an electronic fishing scale. A covert feather from the bird's back was removed to be sent to the UDWR for DNA analysis, and the capture location was recorded using a handheld global positioning system (GPS) unit (UTM, 12N, NAD 83). Birds were handled with care and released on site according to protocol approved by the Utah State University Institutional Animal Care and Use Committee (IACUC #1194) and UDWR Certificate of Registration (COR #2BAND8743).

Following capture, radio-marked sage-grouse were located to determine seasonal movements, survival rates, nesting and brood success, and habitat use patterns. Telemetry equipment used consisted of Communications Specialists™ (Communications Specialists, Orange, CA, USA) and Telonics™ (Telonics, Mesa, AZ, USA) receivers, handheld 3-element Yagi antennas, and vehicle-mounted omni-directional antennas. A handheld GPS unit was used to mark the geographic location each time a marked bird was visually located and observed. Marked females were located 2–3 times each week during nesting. After hatching, females with broods were located 1–2 times each week. Marked males were located weekly from spring to late summer. From fall to early spring, all marked sage-grouse were located monthly.

Due to the differing land uses of the study area and the elevational differences in weather and moisture levels, I anticipated that at least some of the sage-grouse in the study area would travel farther than others to meet seasonal habitat requirements. This meant some sage-grouse would move into the nearby mountains or into the lower valley irrigated fields and pastures. Because some birds moved rapidly across the landscape or into less-accessible locations, I used a small fixed-wing aircraft fitted with ATS™ radio telemetry equipment to locate them. Aircraft services were contracted through Airmotive Service of Brigham City, Utah.

Juvenile and Adult Mortality

Marked birds were visually located as quickly as possible when a transmitter gave a mortality signal. The geographic location was marked using a handheld GPS unit, and the cause of death was determined if possible. In most cases, carcasses were quickly consumed or scavenged and very little remained of the carcass to determine the cause of death. If a carcass was found within 1 or 2 days after death, then there was a much greater chance of making an accurate assessment. If a relatively fresh carcass was found, the remains and radio transmitter were inspected for teeth and claw marks, broken bones, and any noticeable kill or feeding pattern. If a carcass was relatively intact with few broken bones, and the transmitter did not appear to have been chewed, then an avian predator was determined to be responsible. If a carcass was less intact, had considerable bone breakage, or the transmitter was noticeably chewed, then it was determined that a mammalian predator was responsible. However, because of the possibility of scavenging, mammalian predation was only determined if the carcass was fresh within 2 days.

Nest and Brood Monitoring

Nesting was determined when a female sage-grouse was found in the same location on 2 consecutive visits during the breeding season. Nesting females were located using handheld telemetry equipment and binoculars. To mitigate nest abandonment, care was taken to not disturb nesting females. Nest locations were marked by GPS and an inconspicuous physical marker to aid researchers in returning to the nest and to mitigate predation. Actively nesting females were carefully observed 2–3 times each week until the nest hatched or failed. A successful hatch was determined when egg halves were found intact in or near the nest bowl or the inner membrane of the egg was separated from the shell (Klebenow 1969, Wallestad and Pyrah 1974).

After hatching, females with broods were located at least weekly. The number and relative size of chicks observed at each location was recorded to monitor the status and condition of the brood. The brood was flushed and counted 50 days after hatching to determine brood success (Schroeder 1997). During daylight hours, radio telemetry was used to locate the adult female, and the area of her flush was thoroughly searched in a 40 m radius using an outward spiral pattern until all chicks had flushed. If the number of chicks counted did not seem accurate judging from recent observations, another brood flush count was performed within a week. In 2012, 3 broods were counted at night by spotlight, but were recounted within a week using the described daylight method.

Vegetation Surveys

Once a nest had either hatched or failed, the vegetation characteristics at the nesting site were recorded to include vegetation height, percent cover, and species composition. The characteristics of the nest shrub were recorded and measured by species, height, diameter, and a Robel pole (Robel et al. 1970) was placed in the center of the nest bowl to determine the visual obstruction (VOR) of the nest provided by the shrub. Robel measurements were made by recording the lowest visible point on the pole as viewed from a distance of 4 m from the nest on each of the following transects. Four

15 m transects were examined from the nest bowl out. The first transect was directed toward a random bearing which was chosen by blindly turning a compass bezel. The remaining transects were directed outward at 90 degree increments from the bearing of the first transect. Along each transect, the line-intercept method was used to evaluate the height and canopy cover of shrub species (Canfield 1941). The height and species composition of forbs and grasses were evaluated along each transect using the Daubenmire frame technique (Daubenmire 1959). Five frames were examined on each transect at 3 m intervals. Proportions were recorded for each forb and grass species occurring within the frame as well as other types of non-vegetation ground cover or the lack thereof.

Vegetation surveys were also conducted at sites where a female sage-grouse and brood were located. These surveys were conducted in the same manner as the nest surveys described above, however, each transect was a length of 10 m and 4 Daubenmire frames were placed at 2.5 m intervals. The same line-intercept process was used to evaluate shrub species, and Daubenmire frames were used to evaluate the species composition of grasses and forbs in the same manner.

In addition to nest and brood surveys, vegetation surveys were also conducted at locations of radio-marked male sage-grouse and non-nesting, non-brooding female sage-grouse. These surveys consisted of the same line-intercept and Daubenmire frame methods described for brood site vegetation surveys. Line transects were 10 m in length, and 4 Daubenmire frames were placed at 2.5 m intervals on each transect.

Vegetation was also surveyed at random sites and compared to sage-grouse use sites. Random locations (UTM, 12N, NAD 83) for these surveys were generated by computer using a generalized random-tessellation stratified design (Stevens and Olsen 2004). This method of random sample selection was used to produce a spatially-balanced sample set and reduce clumping. The surveys at these random sites were conducted in the same manner as surveys at actual habitat use sites, consisting of 4, 10 m transects and including the same line-intercept and Daubenmire frame techniques.

Data Analysis

Seasonal Movements

Distances were calculated for each marked sage-grouse relative to sex, age, and reproductive success. Maximum distances between winter and summer seasonal habitats were calculated for all marked sage-grouse. The distance from lek of capture to all attempted nest sites was calculated for all females that made an attempt to nest. The maximum distance travelled by broods from their nest to summer range was also calculated. Descriptive statistics were calculated for each movement type. In addition to descriptive statistics, 2-sample 2-tailed *t*-tests were calculated using R statistical software (R Version 2.15.1, www.r-project.org, accessed 8 Mar 2013) to evaluate differences in movement between successful and unsuccessful nests. Differences were considered significant at $P < 0.05$. Movement distances from summer to winter range were also included as a covariate in a Program MARK (MARK Version 7.1, http://warnercnr. colostate.edu/~gwhite/mark/mark.htm, accessed 27 Aug 2013) known fate survival analysis to determine if migration effort contributed to survival rates. A 95% confidence interval (CI) was used to determine significance. A confidence interval including 0 indicated that an effect was not significant.

Survival

Monthly survival of marked sage-grouse was calculated using Program MARK software. A known fate analysis with logit link function was used to calculate monthly survival probabilities by sex and age class. All sage-grouse included in survival estimates had survived at least 1 week after capture to ensure that mortalities were not related to capture trauma. All types of mortalities past 1 week of survival were included in the calculation, and proportions were calculated for each cause of mortality. A 95% confidence interval was used to determine the significance of sex and age effects on survival. A confidence interval including 0 indicated that an effect was not significant.

Nest and Brood Success

Nesting effort and nest and brood success were calculated to determine the reproductive rate of the sage-grouse population in the study area. Nest initiation was calculated as the proportion of accessible live females at the beginning of the nesting period which made at least 1 attempt to nest. Re-nesting effort was calculated as the proportion of females that survived the failure of an initial nest and made a second attempt to nest. Nest success was calculated as the proportion of nests with at least 1 hatched egg (Fischer et al. 1993). Hatching success was calculated as the proportion of all eggs that hatched in successful nests. Clutch size was estimated and proportioned by counting the number of hatched and un-hatched eggs in a nest once the female had left after a success or failure. Predated nests were not included in the clutch size estimation because egg shells were often missing or crushed. Egg fertility was calculated as the proportion of eggs laid in a nest that had either hatched or contained a partially-developed embryo. Descriptive statistics and 2-sample 2-tailed *t*-tests were calculated in R statistical software to determine if any differences of distance, initiation or hatch date, age of female, or habitat characteristics existed between successful and unsuccessful nests and broods. Differences were considered significant at $P < 0.05$.

Vegetation Structure and Composition

Because the sample size of females was low in 2012, vegetation data by nest and brood sites could not be compared to 2013. Therefore, vegetation data from both years were combined for analysis. Survey site descriptions included nest sites, brood sites, other use sites, and random sites. Vegetation characteristics were analyzed by calculating means for vegetation height, percent ground cover, and species composition with regard to the description of the survey site. To determine the most common forb, grass, and shrub species, weighted means were calculated by multiplying the mean percent cover of each species by its frequency or the number of survey plots in which it occurred. Vegetation species with the highest weighted means were considered to be the most common. Within the appropriate site descriptions, surveys were compared by success rate, sex, and also to random surveys to determine if sage-grouse selected habitats for particular microhabitat characteristics and if certain characteristics contribute to better reproductive success.

Statistical analyses of vegetation data were performed using R statistical software. These analyses included descriptive statistics and 2-sample 2-tailed *t*-tests to evaluate differences in data due to sex, reproductive success, and in comparison to random sites. Differences were considered significant at $P < 0.05$.

RESULTS

Capture, Marking, and Tracking

I initiated sage-grouse captures in January 2012 when sage-grouse were found wintering on or in close proximity to their breeding grounds. In the first season, sage-grouse were captured on or near 10 different leks, 3 of which were previously unknown and found while conducting 2012 lek searches. By the end of April 2012, I had radio-marked 14 females and 46 males. Females proved to be more challenging to capture than males in this first season because few of them were found roosting on or near leks. The females I did capture were found relatively close to leks.

To mitigate this challenge, I began capturing sage-grouse again in summer 2012, when flocks of birds were observed roosting together on the summer range. Previously radio-marked females were located at night in hopes of capturing other females roosting with them. I located small flocks of females, but due to the steep and rugged terrain, usually had to approach them on foot with a battery backpack to power the spotlight and a stereo blaring static noise to cover the sound of researchers' footsteps. In August, large flocks were observed congregating in alfalfa fields near Park Valley. We radio-collared 3 males at this location, and after 2 or 3 nights, we determined that there were very few, if any, females in this flock. In September, we had finally developed a suitable method for catching birds on foot and we captured and radio-collared 3 females in their summer range. Shortly after this, the birds began migrating back to their winter range, and we were able to use an ATV again in our capture efforts.

From November 2012 through April 2013, despite greater snow accumulation and colder temperatures, we had much better success finding females on or near leks than we had the previous year. We captured and radio-marked 51 more females and 6 more males. We found sage-grouse in the same winter and breeding areas as the previous season. Overall, we captured and radio-marked 68 females and 55 males (Table 2-1). Of these 123 birds, 75 were adults and 48 were juveniles or yearlings. Female weights ranged 0.90−1.75 kg ($\bar{x}$ = 1.28, SE = 0.04). Male weights ranged 1.87−2.75 kg ($\bar{x}$ = 2.45, SE = 0.05). In 2012, 2 males died within a week of capture, which could possibly have been related to capture trauma.

Seasonal Movements

Maximum distances travelled by birds from winter to summer range varied 2.3−58.0 km (Table 2-2). The mean movements of the 66 monitored females was 18.3 km (SE = 1.4, range = 3.1–58.0 km). The mean distance of the 45 monitored males was 18.0 km (SE = 2.7, range = 2.3−35.1 km). Of these birds, 67 were adults with a mean of 18.5 km (SE = 1.4, range = 2.3–58.0 km). The 44 monitored yearlings travelled a mean distance of 17.6 km (SE = 1.4, range = 3.1−38.7 km).

The sage-grouse I studied wintered at lower elevations in mixed sagebrush of the valleys, while summer ranges were typically higher in elevation. Males typically left their winter range as soon as the breeding season had ended and had generally settled into their summer range by the end of May. Due to nesting and brood-rearing activities, females were typically later in moving to their summer range, and they were usually settled into a general area by mid to late June. From spring to summer, 88% of radio-marked birds moved north, and 65% used summer areas of higher elevation such as the summit of the Raft River and Grouse Creek Mountains. Sixteen percent of radio-marked birds used low elevation, agricultural areas of irrigated pastures or alfalfa fields. The most exceptional summer ranges were selected by 2 females that moved about 20–30 km northeast of Park Valley, where 1 raised a successful brood in a section dominated by crested wheatgrass and the other was found in a very dry area of low-elevation salt desert shrubs and grasses. The longest distance movements were made in 2013 by 5 females which 15 km north of the Utah-Idaho border, with maximum distances ranging 38–58 km. As a covariate in the known fate analysis, maximum distance from winter to summer range did not affect survival rates (β = 0.01, CI = -0.02–0.03).

I also calculated distances for each nest from the female's lek of capture and a maximum distance of brood range from the nest. Successful nests ranged 1.0–18.6 km ($\bar{x}$ = 8.0, SE = 1.1) from lek of capture. Unsuccessful nests ranged 0.3–27.9 km ($\bar{x}$ = 6.8, SE = 2.1) from lek of capture. There was no difference between distances of successful and unsuccessful nests (t = 0.42, P = 0.678). Broods ranged 0.3–25.9 km ($\bar{x}$ = 4.2, SE = 1.4) from their nest of hatch, and these distances did not affect success rates (t = 2.11, P = 0.053).

Survival

Monthly survival probabilities for radio-marked sage-grouse in the study area ranged 0.74−1.00 with an overall mean of 0.95 (SE = 0.01). Monthly survival for females ranged 0.86−1.00 ($\bar{x}$ = 0.96, SE = 0.01), while males ranged 0.75−1.00 ($\bar{x}$ = 0.94, SE = 0.01). Monthly survival rates for adults ranged 0.86−1.00 ($\bar{x}$ = 0.95, SE =

0.01), whereas juveniles and yearlings ranged 0.74−1.00 ($\bar{x}$ = 0.94, SE = 0.01). In general, monthly survival rates did not differ between years by sex or age class. For females, survival in 2012 was at its lowest from August to October, while in 2013 it was lowest from April to August. For males, survival in 2012 was lowest in April and July to September, and in 2013 it was lowest in April and May. For adults, survival in 2012 was lowest in July and August, while in 2013 it was lowest in April and May. For juveniles and yearlings, survival was lowest in 2012 in June, October, and November; in 2013 it was lowest in February and April to August. Overall, survival was highest in the winter months of December and January with probabilities ranging 0.96−1.00 ($\bar{x}$ = 0.99, SE = 0.01). The known fate analysis did not show an effect of sex (β = 0.41, CI = -0.10–0.93) or age (β = 0.12, CI = -0.43–0.65) on survival.

Predation was the most common cause of mortality, but because of mammalian scavengers, it was often difficult to determine if an avian or mammalian predator was responsible. Of 61 mortalities, 4 (7%) were determined to have been caused by an avian predator, 6 (10%) were determined to have been caused by a mammalian predator, 3 (5%) were legally harvested by hunters, and the remaining 48 (78%) were of unknown causes.

Nest and Brood Success

Nest initiation and success rates were relatively consistent between study years (Table 2-3). In 2012, 10 of 12 (83.3%) monitored females initiated nests, and in 2013, 34 of 37 (91.9%) monitored females initiated nests. The nest initiation rate of both years combined was 89.8%. In 2013, 1 female initiated a second nest within a week of the first nest being predated; this nest was also predated and was the only re-nesting attempt that was observed over the course of my research.

In 2012, starting dates of nest incubation ranged from 15 April to 11 May. In 2013, start dates ranged from 6 April to 19 May. Dates of starting nest incubation did not differ for successful and unsuccessful nests (t = 0.25, P = 0.802). There was also no difference in nest success by age of nesting female (t = 0.46, P = 0.647).

In 2012 and 2013, 6 of 10 (60.0%) and 22 of 35 (64.7%) nests successfully hatched, respectively. Most unsuccessful nests were predated, with 4 of 4 (100%) in 2012 and 10 of 13 (76.9%) in 2013. One nest in 2013 failed because the female was killed nearby while off the nest; however the nest had not been predated and was still intact. Also in 2013, 2 nests were abandoned by the female, and to my knowledge, neither of these had been flushed by researchers.

Clutch sizes ranged 5−8 eggs in 2012 and 4−10 eggs in 2013. Overall, the mean clutch size was 6.8 eggs (SE = 0.36). Hatching success, or the number of eggs that hatched in successful nests, ranged 71−100% ($\bar{x}$ = 87.8, SE = 0.07) in 2012 and 63−100% ($\bar{x}$ = 95.6, SE = 0.03) in 2013. Egg fertility ranged 71−100% ($\bar{x}$ = 90.3, SE = 0.09) in 2012 and 88−100% ($\bar{x}$ = 94.3, SE = 0.03) in 2013.

Brood success varied by more than 25% between study years, but this is likely due to the much smaller sample size in 2012. In 2012, 3 of 6 (50.0%) broods survived to 50 days of age, and in 2013, 17 of 22 (77.3%) broods survived to 50 days of age. Over both years, brood success was 71.4%. Overall, final brood counts ranged 1−8 chicks with a mean of 3.7 chicks (SE = 0.4). Successful and unsuccessful broods did not differ by hatch date (t = 1.81, P = 0.101) or by age of brooding female (t = 0.56, P = 0.586).

Vegetation Structure and Composition

I completed 492 vegetation surveys during my study. These surveys included 36 nest sites, 105 brood sites, 171 (86 non-brooding female, 85 male) other sage-grouse use sites, and 180 random sites. On average, 30–40 surveys were conducted each month at both use sites and random sites. Surveys were completed from 4 May to 30 July in 2012 and from 7 May to 23 July in 2013. Nest sites were surveyed soon after hatching or failing, and other use sites were completed within a week of observing a bird at the site.

Nest success was directly related to some of the vegetation characteristics at sites selected by females. The species of the shrub which a female selected affected the probability of nest success (t = 2.68, P = 0.014). Of successful nests, 18 of 19 (94.7%) were located under a species of sagebrush. One of these nests was placed under black sagebrush, 17 were placed under a subspecies of big sagebrush, and 1 was placed under a juniper which had been toppled by a recent chaining treatment but not uprooted. For unsuccessful nests, 10 of 17 (58.8%) were placed under sagebrush species. One of the nests was placed under black sagebrush, 9 under big sagebrush subspecies, and the remaining 7 nests were located under rabbitbrush, horsebrush, and both chained and unchained junipers. There was no difference in the height (t = 0.67, P = 0.509), diameter (t = 0.73, P = 0.475), or VOR (t = 1.85, P = 0.073) of nest shrubs for successful and unsuccessful nests.

Successful nests exhibited greater forb height (t = 9.40, $P \leq$ 0.001), forb cover (t = 4.48, $P \leq$ 0.001), grass height (t = 8.87, $P \leq$ 0.001), total shrub height (t = 4.15, $P \leq$ 0.001), and sagebrush height (t = 8.75, $P \leq$ 0.001) than unsuccessful nests (Table 2-4). Successful nest sites averaged 11.7 cm (SE = 0.4) forb height, 9.4% (SE = 0.3) forb cover, 23.4 cm (SE = 0.6) grass height, 44.6 cm (SE = 0.8) total shrub height, and 47.0 cm (SE = 1.0) sagebrush height (Table 2-5). Unsuccessful nests averaged 7.0 cm (SE = 0.3) forb height, 7.4% (SE = 0.3) forb cover, 16.6 cm (SE = 0.5) grass height, 38.9 cm (SE = 1.1) total shrub height, and 34.8 cm (SE = 0.9) sagebrush height. As a whole, nest sites exhibited greater forb height (t = 4.57, $P \leq$ 0.001), forb cover (t = 3.42, $P \leq$ 0.001), grass height (t = 7.44, $P \leq$ 0.001), grass cover (t = 3.16, P = 0.002), total shrub height (t = 6.23, $P \leq$ 0.001), total shrub cover (t = 5.55, $P \leq$ 0.001), sagebrush height (t = 10.99, $P \leq$ 0.001), and sagebrush cover (t = 3.12, P = 0.003) than random sites (Figs. 2-2 and 2-3). Successful nest sites exhibited less bare ground than unsuccessful nest sites (t = 2.61, P = 0.009). Nest sites exhibited less bare ground (t = 13.28, $P \leq$ 0.001) than random sites.

Because unsuccessful broods typically failed early in the season, I was unable to obtain a sufficient sample size of vegetation surveys at these sites to be compared statistically with that of successful broods. As a whole, brood sites were greater in forb height (t = 10.81, $P \leq$ 0.001), grass height (t = 6.41, $P \leq$ 0.001), total shrub height (t = 6.74, $P \leq$ 0.001), and sagebrush height (t = 8.85, $P \leq$ 0.001) than non-brooding female sites (Table 2-6). Brood sites averaged 14.6 cm (SE = 0.3) forb height, 26.9 cm (SE = 0.4) grass height, 41.0 cm (SE = 0.6) total shrub height, and 41.6 cm (SE = 0.6) sagebrush height (Table 2-7). Non-brooding female sites averaged 10.2 cm (SE = 0.2) forb height, 23.3 cm (SE = 0.4) grass height, 35.7 cm (SE = 0.6) total shrub height, and 34.1 cm (SE = 0.06) sagebrush height. Brood sites exhibited greater forb height (t = 16.03, $P \leq$ 0.001), grass height (t = 20.90, $P \leq$ 0.001), total shrub height (t = 5.73, $P \leq$ 0.001), total shrub cover (t = 4.85, $P \leq$ 0.001), sagebrush height (t = 13.41, $P \leq$ 0.001), and sagebrush cover (t = 2.33, P = 0.021) than random sites (Table 2-8). Brood sites exhibited more bare ground than non-brooding female sites (t = 3.20, $P \leq 0.001$) but less than random sites (t = 13.15, $P \leq 0.001$).

Male use sites exhibited lower grass height (t = 4.19, $P \leq 0.001$) and greater sagebrush height (t = 4.01, $P \leq 0.001$) than non-brooding female use sites (Table 2-9). Mean grass height was 21 cm (SE = 0.4) and sagebrush height was 37.5 cm (SE = 0.6) at male use sites. Collectively, male and non-brooding female use sites exhibited greater forb height (t = 6.82, $P \leq 0.001$), grass height (t = 13.88, $P \leq 0.001$), total shrub cover (t = 4.22, $P \leq 0.001$), sagebrush height (t = 6.78, $P \leq 0.001$), and sagebrush cover (t = 3.17, P = 0.002) than random sites. Male use sites exhibited more bare ground (t = 6.01, $P \leq 0.001$) than non-brooding female sites. Collectively, these use sites exhibited less bare ground (t = 15.43, $P \leq 0.001$) than random sites.

The species composition of vegetation was similar among site descriptions but with a few differences between use and random sites. Among all habitat use sites and random sites, lupine, phlox, and hawksbeard were among the 5 most commonly observed forb species (Tables 2-10, 2-11, 2-12, and 2-13). At random sites, other common forb species also included halogeton (*Halogeton glomeratus*) and cryptantha (*Cryptantha* spp.), which were present but not nearly as common at use sites. Cheatgrass and Sandberg bluegrass were the 2 most common grass species observed in all vegetation surveys. Bluebunch wheatgrass and Great Basin wildrye also ranked in the 5 most common grass species of all use sites; other common species varied between site descriptions. The most common shrub species at use sites were Wyoming big sagebrush (*A. t. wyomingensis*), mountain big sagebrush (*A. t. vaseyana*), black sagebrush, snowberry, and rabbitbrush. The most common shrub species at random sites also included black sagebrush, Wyoming big sagebrush, and rabbitbrush, but juniper and basin big sagebrush (*A. t. tridentata*) were also common, unlike use sites.

DISCUSSION

Seasonal Movements

The seasonal movements of the radio-marked sage-grouse were similar to those reported by Reinhart et al. (2013). The maximum distances travelled by birds in the study area were similar to those monitored by Reinhart et al. (2013) from 2005 to 2006 in the Grouse Creek subunit, which is within the same SGMA and adjacent to the study area. However, Reinhart et al. (2013) reported greater extremes in distance from 0.2–69.3 km, whereas the birds I monitored ranged from 2.3–58 km. Reinhart et al. (2013) reported an overall mean seasonal movement of 13.1 km; in my research, the mean distance travelled was about 18 km for each sex and age class. Like Reinhart et al. (2013), some of the birds I monitored moved into Idaho during the summer months, showing evidence of at least some population connection between states. Reasons for variation in mean movement distances from Reinhart et al. (2013) may be due to the differences of the Raft River and Grouse Creek subunits in topography, land use, and precipitation.

Seasonal ranges and movements of sage-grouse in the Raft River subunit were similar to the population in southeastern Idaho described by Connelly et al. (1988), whose winter and breeding ranges were essentially the same. Sage-grouse in my study area were often found wintering in very close proximity to their lek sites. The birds had typically arrived in their winter and breeding range by mid November and stayed until they had either nested or stopped visiting leks in mid April or early May. In most cases, summer ranges were located in areas with adequate moisture to provide suitable forage during the dry season.

Survival

Compared to range-wide averages of 30–78% (Connelly et al. 2011*a*), survival rates of sage-grouse in the study area were relatively high. Survival in the study area was also higher than many studies in Utah, which have reported annual survival ranging 37–88% (Dahlgren 2006, Knerr 2007, Duvuvuei 2013, Graham 2013). Annual survival in the study area ranged 60–90% for females and 50–70% for males. For females, this inconsistency may be due to the difference in sample sizes between years, as the number of females ranged from 14 birds in 2012 to 67 in 2013. However, the number of males ranged from 46 birds in 2012 to 41 in 2013, and I suspect that the differences in precipitation between 2012 and 2013 may explain some of this variation (Robinson and Messmer 2013). Because birds were captured at various times throughout the study, a monthly survival estimate provides more accuracy in my work with this population. Similar to other sage-grouse populations (Knerr 2007, Duvuvuei 2013), survival was highest during the winter months.

Nest and Brood Success

The observed 89.8% overall nest initiation rate for this population was consistent with the 76–95% reported by other similar Utah studies (Dahlgren 2006, Knerr 2007, Duvuvuei 2013). Nest success rates were high at 63.6% overall, while the average is

46% for other telemetry studies range-wide (Connelly et al. 2011*a*). In the adjacent Grouse Creek subunit, Knerr (2007) and Graham (2013) reported overall nest success rates of 45% from 2005 to 2006 and 36% from 2010 to 2012. The observed 71.4% brood success rate in the study area was greater than those of other similar studies in Utah, which range 44–66% (Dahlgren 2006, Knerr 2007, Duvuvuei 2013).

My final brood counts consisted mostly of daytime flush counts. Dahlgren et al. (2010) reported nighttime spotlight counts to be more effective than daylight counts. This particular study was conducted in an area dominated by black sagebrush, a species of low height, which provided good visibility of ground-roosting birds in the nighttime hours. In my study area, sage-grouse broods were occasionally found in areas of low vegetation; however, they were just as likely to be found within areas of taller big sagebrush subspecies such as basin, Wyoming, and mountain (Knerr 2007, Thacker 2010). Nighttime spotlight counts proved to be less effective in these areas of obstructed ground visibility. Further, in my study area, broods often flushed well before observers were within an effective range for spotlight counting, which would likely result in a less accurate count than if they had been viewed in daylight.

Vegetation Structure and Composition

Vegetation selected by sage-grouse as nest sites in the study area were similar to that observed in other populations. Connelly et al. (2011*c*) reported that most sage-grouse range-wide nest under sagebrush. Overall, 77.7% of nests were under some species of sagebrush; this is a lower proportion than in many study areas, which are often

90% or more (Connelly et al. 2011*c*), but higher than the 55% reported by Knerr (2007) in the adjacent Grouse Creek subunit.

Similar to the observations of Duvuvuei (2013), a portion of nest surveys contained pinyon-juniper cover. In the study area, 7 of 45 (15.5%) nest sites were located in association with pinyon-juniper cover, whereas Duvuvuei (2013) reported 30.4%. Four (8.9%; 3 adult, 1 yearling) radio-marked females in the study area selected junipers as nest shrubs; this is considerably less than the 24% reported by Knerr (2007). Only 1 of these nests located under junipers was successful, which suggests that junipers may not be as effective as sagebrush nesting cover. The fact that a portion of the radio-marked females chose to nest under junipers suggests that juniper encroachment has advanced into historic nesting areas.

Duvuvuei (2013) reported that 24% of nests on Anthro Mountain in northeastern Utah were located under pinyon or juniper. Most (84%) of these nests were initiated by females which had been translocated from Parker Mountain in south-central Utah. Duvuvuei (2013) stated that this may be evidence that nesting habitat was limited on Anthro Mountain, as there were no reports of sage-grouse nesting under pinyon-juniper on Parker Mountain (Chi 2004, Dahlgren 2006). Similar to northeastern Utah, nesting habitat may also be limited in the study area, and removing invasive junipers may increase nesting success by promoting shrub species which provide better nest cover.

I observed 4 radio-marked females nesting in areas that had been treated for junipers within 5 years, and 1 of these was in an area that had been treated within 6 months. Two of the females successfully hatched their nest, and 1 produced a successful brood of at least 3 chicks by remaining in the treatment area for the entire summer. Frey et al. (2013) reported similar observations in southern Utah with radio-marked sage-grouse using an area of pinyon-juniper encroachment immediately after treatment. Juniper was the third most common species measured in my random line-intercept surveys, the sixth most common at nest sites, and the seventh most common at brood sites and other use sites. This suggests that sage-grouse in the study area were most likely to select habitats away from juniper forests. Pinyon was much less common than juniper in the study area and was only recorded in 1 of 492 (0.2%) surveys.

Mean total shrub canopy cover at nest sites was 37.6%, which is much greater than the 13.2–23.8% reported by Dahlgren (2006), Knerr (2007), and Duvuvuei (2013). Mean sagebrush cover was 20.4%; within the 15–25% recommended by Connelly et al. (2000). Grass height and cover at nest sites was not unlike that reported in other studies, as it was greater than at random sites. The observed 7.4–9.4% forb cover at nest sites was lower than the 18.5% reported by Knerr (2007) and 14.5% by Duvuvuei (2013) but higher than the 1.0% reported by Dahlgren (2006).

Similar to other studies (Connelly et al. 2011*c*), vegetation at brood sites differed from nest sites and random sites in structure of grasses and shrubs. Surprisingly, forb cover was not much different from nest and random sites; although, forb height was considerably greater. Similar to nest sites, the forb cover at brood sites in the study area was relatively low at 10.1% when compared with the 21.4% reported by Knerr (2007) and 18.4% by Duvuvuei (2013). Total shrub cover at brood sites was higher than average at a mean of 34.1%, when other Utah studies have reported 20.1–27.1% (Dahlgren 2006, Knerr 2007, Duvuvuei 2013). Mean sagebrush cover was 17.5%; within the 10–25% recommended by Connelly et al. (2000).

During the summer months, some sage-grouse were observed regularly feeding in agricultural areas of the study area; typically irrigated pastures or fields containing alfalfa. Use of cultivated alfalfa fields was also reported by Knerr (2007), Thacker (2010), and Graham (2013) in the adjacent Grouse Creek subunit. During the course of my research, 16% of the radio-marked birds used alfalfa fields. This suggests that these areas are beneficial to sage-grouse. Of the birds observed using these irrigated areas as summer range, one-third (20% of the birds captured at this location) were captured in a winter/spring habitat within about 3 km. The remaining two-thirds using these agricultural areas were captured during the winter or spring in a particularly dry location approximately 20 km south of the irrigated fields and pastures of Park Valley and Rosette. Feeding in this low-elevation summer range may be of particular benefit to these birds, allowing them to remain productive while wintering and breeding so far south. My vegetation data includes some use and random surveys in irrigated pastures containing alfalfa, but more research is necessary to describe the possible benefits that cultivated alfalfa fields may have on the vital rates of specific parts of this sage-grouse population.

Although invasive plant species pose a conservation threat for sage-grouse habitat in northwestern Utah, the sagebrush was in relatively good condition. There are still many areas that have not been impacted by juniper encroachment, and a good portion of the affected areas have been treated and appear to be recovering. Total shrub canopy cover in the study area is considerably greater than what has been reported by other Utah studies. However, the reproductive rates and survival of this sage-grouse population are also higher than most Utah populations. Forb cover in the study area is lower than many

Utah populations, except Parker Mountain which is reported to exhibit only 1–3% (Dahlgren 2006). Despite its lack of forb cover, Parker Mountain remains as one of the most productive sage-grouse habitats in Utah. It is my opinion that there is currently no need to manage shrub or forb cover in the Raft River subunit to meet recommended guidelines. I feel that the condition of the observed sage-grouse population is a good indication of a healthy sagebrush ecosystem, and any planned treatments should focus exclusively on conserving this habitat by controlling invasive plant encroachment and mitigating the risks of wildfire.

MANAGEMENT IMPLICATIONS

My research demonstrated that sage-grouse in this area selected habitats where the vegetation structure provided increased cover and forage and improved their productivity. Thus, if wildlife managers desire to sustain and increase this population, management actions should be designed to protect the current sage-grouse habitat and increase the overall habitat base.

Pinyon-juniper encroachment constitutes a major threat to sage-grouse habitat in northwestern Utah, as it displaces the sagebrush that sage-grouse depend on for forage and cover. Juniper encroachment in the study area was readily apparent in nesting and brood-rearing habitats. My data suggests that juniper removal in the Raft River subunit can restore impacted nesting and brood-rearing habitat within just a few years. If pinyon-juniper treatments are performed within seasonal sage-grouse habitats, care should be taken to avoid damaging the sagebrush understory. Further, treatments should be done in areas where sagebrush is still present and can therefore be effectively restored to its ideal level of coverage. If sagebrush is removed or has been replaced by junipers, it will likely take several years to grow and become reestablished.

Other invasive plants are also a threat to sage-grouse habitat in northwestern Utah. The most obvious of these was the non-native cheatgrass, which has become common throughout much of western North America. Cheatgrass was recorded in all types of my vegetation surveys, and it was the most common grass observed at nest sites and brood sites. Further, cheatgrass was also the most common grass observed at random sites. Cheatgrass is a threat to sage-grouse habitat because it out-competes native vegetation and increases the risk of wildfire.

My research suggests that this population of sage-grouse has great potential for conservation. In the midst of pinyon-juniper encroachment, cheatgrass invasion, and other forms of habitat loss, these birds still exhibited above-average reproductive rates and relatively high survival rates. My research provides valuable information regarding some of the microhabitat characteristics that are beneficial to sage-grouse in this area. This information can guide future management actions in conserving the sage-grouse of northwestern Utah by conserving the sagebrush habitats they depend on.

LITERATURE CITED

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

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

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

Chi, R. Y. 2004. Greater sage-grouse reproductive ecology and tebuthiuron manipulation of dense big sagebrush on Parker Mountain. Thesis, Utah State University, Logan, USA.

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

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

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

Connelly, J. W., C. A. Hagen, and M. A. Schroeder. 2011*a*. Characteristics and dynamics of greater sage-grouse populations. Pages 53–67 *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 38. University of California Press, Berkeley, USA.

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*b*. Conservation of greater sage-grouse: a synthesis of current trends and future management. Pages 549–563 *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 38. University of California Press, Berkeley, 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. University of Idaho, College of Natural Resources Experiment Station Bulletin 80, Moscow, USA.

Connelly, J. W., E. T. Rinkes, and C. E. Braun. 2011*c*. Characteristics of greater sage-grouse habitats: a landscape species at micro- and macro-scales. Pages 69–83 *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 38. University of California Press, Berkeley, 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. Moseley, M. A. Schroeder, T. D. Whitson, R. F. Miller, M. A. Gregg, and C. S. Boyd. 2004. Ecology and management of sage-grouse and sage-grouse habitat. Journal of Range Management 57:2–19.

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

Dahlgren, D. K., T. A. Messmer, E. T. Thacker, and M. R. Guttery. 2010. Evaluation of brood detection techniques: recommendations for estimating greater sage-grouse productivity. Western North American Naturalist 70:233–237.

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.

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

Drut, M. S., W. H. Pyle, and J. A. Crawford. 1994. Diets and food selection of sage-grouse chicks in Oregon. Journal of Range Management 47:90–93.

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

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

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

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

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

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.

Klebenow, D. A. 1969. Sage-grouse nesting and brood habitat in Idaho. Journal of Wildlife Management 33:649–661.

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

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

Reinhart, J. S., T. A. Messmer, and T. Black. 2013. Interseasonal movements in tri-state greater sage-grouse: implications for state-centric conservation plans. Human-Wildlife Interactions 7:172–181.

Robel, R. J., J. N. Briggs, A. D. Dayton, and L. C. Hulbert. 1970. Relationships between visual obstruction measurements and weight of grassland vegetation. Journal of Range Management 23:295–297.

Robinson, J. D., and T. A. Messmer. 2013. Vital rates and seasonal movements of two isolated greater sage-grouse populations in Utah's West Desert. Human-Wildlife Interactions 7:182–194.

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

Stevens, D.L. Jr., and A.R. Olsen. 2004. Spatially balanced sampling of natural resources. Journal of the American Statistical Association 99:262–278.

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

U. S. Fish and Wildlife Service. 2010. Endangered and threatened wildlife and plants; 12-month findings for petitions to list the greater sage-grouse as threatened or endangered. Federal Register 75:13910–14014.

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

Wallestad, R. O., and B. D. Pyrah. 1974. Movement and nesting of sage-grouse females in central Montana. Journal of Wildlife Management 38:630–633.

West Box Elder Adaptive Resource Management. 2007. West Box Elder greater sage-grouse local conservation plan. Utah State University Extension and Jack H. Berryman Institute, Logan, and Utah Division of Wildlife Resources, Salt Lake City, USA.

West, N. E. 1983. Great Basin-Colorado Plateau sagebrush semi-desert. Pages 331–349 *in* N. E. West, editor. Temperate deserts and semi-deserts. Elsevier Scientific Publishing Company, Amsterdam, Netherlands.

Western Regional Climate Center. 2014. Monthly climate summary 1981–2010: Park Valley, Utah (426658). <http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?ut6658>. Accessed 30 Jun 2014.

Table 2-1. Demographics and mortality of greater sage-grouse (*Centrocercus urophasianus*) monitored in northwestern Utah, 2012–2013.

	2012	**2013**	**Years Combined**
	***n* (%)**	***n* (%)**	***n* (%)**
Total monitored	60	108	123
Female	14 (23.3)	67 (62.0)	68 (55.3)
Male	46 (76.7)	41 (38.0)	55 (44.7)
Yearling[a]	17 (28.3)	46 (42.6)	48 (39.0)
Adult	43 (71.7)	62 (57.4)	75 (61.0)
Total mortality	15 (25.0)	46 (42.3)	61 (49.6)
Female	1 (7.1)	25 (37.3)	26 (38.2)
Male	14 (30.4)	21 (51.2)	35 (63.6)
Yearling[a]	2 (11.8)	17 (37.0)	19 (39.6)
Adult	13 (30.2)	29 (46.8)	42 (56.0)

[a]Includes juveniles

Table 2-2. Seasonal movements of greater sage-grouse (*Centrocercus urophasianus*) monitored in northwestern Utah, 2012–2013.

		Distance (km)	
	n	**$\bar{x}$ (SE)**	**Range**
Nest from lek of capture			
Successful	19	8.0 (1.1)	1.0–18.6
Unsuccessful	17	6.8 (2.1)	0.3–27.9
Brood from nest of hatch			
Successful	13	5.7 (2.0)	0.6–25.9
Unsuccessful	7	1.4 (0.6)	0.3–4.8
Winter to summer			
Female	66	18.3 (1.4)	3.1– 58.0
Male	45	18.0 (2.7)	2.3–35.1
Yearling	44	17.6 (1.4)	3.1–38.7
Adult	67	18.5 (1.4)	2.3–58.0

Table 2-3. Productivity of greater sage-grouse (*Centrocercus urophasianus*) monitored in northwestern Utah, 2012–2013.

	2012	**2013**	**Years Combined**
	***n* (%)**	***n* (%)**	***n* (%)**
Females monitored	12	37	49
Nest initiation	10 (83.3)	34 (91.9)	44 (89.8)
Nests monitored	10	35	45
Successful nests	6 (60.0)	22 (64.7)	28 (63.6)
Predated nests	4 (40.0)	11 (31.4)	15 (33.3)
Abandoned nests	0	2 (5.7)	2 (4.4)
Re-nest attempts	0	1 (2.9)	1 (2.2)
Mean clutch size (range)	6.6 (5–8)	6.9 (4–10)	6.8 (4–10)
Mean % eggs hatched (range)	87.8 (71–100)	95.6 (63–100)	94.0 (63–100)
Mean % egg fertility (range)	90.3 (71–100)	94.3 (88–100)	95.6 (71–100)
Successful broods	3 (50.0)	17 (77.3)	20 (71.4)
Mean final brood size (range)	2.3 (2–3)	3.8 (1–8)	3.7 (1–8)

Table 2-4. Statistical comparison of the vegetation structure and ground cover at greater sage-grouse (*Centrocercus urophasianus*) nest sites and random sites in northwestern Utah, 2012–2013.

Parameter	**Sample 1**	**Sample 2**	***t***	***P***	**95% CI**
Forb height	Successful	Unsuccessful	9.40	≤ 0.001*	3.65–5.58
Forb height	All nests	Random	4.57	≤ 0.001*	0.94–2.34
Forb cover	Successful	Unsuccessful	4.48	≤ 0.001*	1.15–2.94
Forb cover	All nests	Random	3.42	≤ 0.001*	0.59–2.17
Grass height	Successful	Unsuccessful	8.87	≤ 0.001*	5.33–8.36
Grass height	All nests	Random	7.44	≤ 0.001*	2.82–4.83
Grass cover	Successful	Unsuccessful	0.05	0.958	-1.68–1.77
Grass cover	All nests	Random	3.16	0.002*	0.70–2.97
Total shrub height	Successful	Unsuccessful	4.15	≤ 0.001*	3.02–8.42
Total shrub height	All nests	Random	6.23	≤ 0.001*	4.98–9.54
Total shrub cover	Successful	Unsuccessful	0.64	0.526	-0.06–0.12
Total shrub cover	All nests	Random	5.55	≤ 0.001*	0.09–0.20
Sagebrush height	Successful	Unsuccessful	8.75	≤ 0.001*	9.48–14.96
Sagebrush height	All nests	Random	10.99	≤ 0.001*	7.51–10.77
Sagebrush cover	Successful	Unsuccessful	0.51	0.616	-0.06–0.10
Sagebrush cover	All nests	Random	3.12	0.003*	0.02–0.10

*Significant *P*-value at < 0.05

Table 2-5. Vegetation structure and ground cover at greater sage-grouse (*Centrocercus urophasianus*) nest sites in northwestern Utah, 2012–2013.

	Successful		**Unsuccessful**	
	$\bar{x}$ (SE)	**Range**	**$\bar{x}$ (SE)**	**Range**
Nest shrub				
Height[a] (cm)	77.8 (3.7)	52.0–107.0	88.0 (15.0)	38.0–300.0
Diameter[a] (cm)	145.6 (7.5)	89.0–203.0	158.1 (15.5)	65.0–313.0
VOR[b] (cm)	59.2 (1.6)	10.0–110.0	50.4 (1.8)	0–200.0
Total shrub height[a] (cm)	44.6 (0.8)	7.0–270.0	38.9 (1.1)	2.0–450.0
Total shrub cover[a] (%)	39.0 (4.6)	12.6–66.0	36.1 (4.9)	16.5–52.0
Sagebrush height (cm)	47.0 (1.0)	7.0–151.0	34.8 (0.9)	4.0–152.0
Sagebrush cover (%)	21.3 (2.3)	5.7–39.7	19.4 (2.9)	1.1–40.9
Forb height (cm)	11.7 (0.4)	1.0–66.0	7.0 (0.3)	1.0–52.0
Forb cover (%)	9.4 (0.3)	1.0–60.0	7.4 (0.3)	1.0–30.0
Grass height (cm)	23.4 (0.6)	3.0–81.0	16.6 (0.5)	2.0–62.0
Grass cover (%)	18.0 (0.6)	1.0–85.0	18.0 (0.6)	1.0–75.0
Litter cover (%)	40.2 (1.2)	5.0–100.0	38.9 (1.3)	5.0–100.0
Bare ground (%)	27.6 (1.3)	5.0–98.0	32.5 (1.4)	2.0–100.0

[a]Includes measurements of trees and zero shrub canopy cover

[b]Visual obstruction reading measured with a Robel pole

Table 2-6. Statistical comparison of the vegetation structure and ground cover at greater sage-grouse (*Centrocercus urophasianus*) brood sites, non-brooding female sites, and random sites in northwestern Utah, 2012–2013.

Parameter	**Sample 1**	**Sample 2**	***t***	***P***	**95% CI**
Forb height	Brood	Non-brood	10.81	≤ 0.001*	3.59–5.18
Forb height	Brood	Random	16.03	≤ 0.001*	5.53–7.08
Forb cover	Brood	Non-brood	0.11	0.913	-0.65–0.73
Forb cover	Brood	Random	0.14	0.891	-0.74–0.85
Grass height	Brood	Non-brood	6.41	≤ 0.001*	2.47–4.65
Grass height	Brood	Random	20.90	≤ 0.001*	9.44–11.40
Grass cover	Brood	Non-brood	1.01	0.316	-1.53–0.49
Grass cover	Brood	Random	0.94	0.347	-0.52–1.47
Total shrub height	Brood	Non-brood	6.74	≤ 0.001*	4.01–7.31
Total shrub height	Brood	Random	5.73	≤ 0.001*	4.23–8.62
Total shrub cover	Brood	Non-brood	1.54	0.126	-0.01–0.10
Total shrub cover	Brood	Random	4.85	≤ 0.001*	0.07–0.15
Sagebrush height	Brood	Non-brood	8.85	≤ 0.001*	5.85–9.17
Sagebrush height	Brood	Random	13.41	≤ 0.001*	8.43–11.32
Sagebrush cover	Brood	Non-brood	0.96	0.340	-0.06–0.02
Sagebrush cover	Brood	Random	2.33	0.021*	0.01–0.06

*Significant *P*-value at < 0.05

Table 2-7. Vegetation structure and ground cover at greater sage-grouse (*Centrocercus urophasianus*) brood sites and non-brooding female sites in northwestern Utah, 2012–2013.

	Brood sites		**Non-brooding female sites**	
	$\bar{x}$ **(SE)**	**Range**	$\bar{x}$ **(SE)**	**Range**
Total shrub height[a] (cm)	41.0 (0.6)	4.0–950.0	35.7 (0.6)	0–480.0
Total shrub cover[a] (%)	34.1 (2.0)	2.0–90.0	30.0 (2.2)	0–74.5
Sagebrush height (cm)	41.6 (0.6)	2.0–168.0	34.1 (0.6)	3.0–130.0
Sagebrush cover (%)	17.5 (1.2)	0.3–44.4	19.5 (1.6)	0.6–71.8
Forb height (cm)	14.6 (0.3)	1.0–126.0	10.2 (0.2)	1.0–76.0
Forb cover (%)	10.1 (0.2)	1.0–100.0	10.0 (0.3)	1.0–100.0
Grass height (cm)	26.9 (0.4)	1.0–111.0	23.3 (0.4)	1.0–111.0
Grass cover (%)	16.6 (0.4)	1.0–95.0	17.2 (0.4)	1.0–95.0
Litter cover (%)	44.3 (0.7)	1.0–100.0	43.1 (0.7)	1.0–100.0
Bare ground (%)	32.4 (0.8)	2.0–100.0	29.0 (0.8)	5.0–100.0

[a]Includes measurements of trees and zero shrub canopy cover

Table 2-8. Vegetation structure and ground cover at greater sage-grouse (*Centrocercus urophasianus*) brood sites and random sites in northwestern Utah, 2012–2013.

	Brood sites		**Random sites**	
	$\bar{x}$ **(SE)**	**Range**	$\bar{x}$ **(SE)**	**Range**
Shrub height[a] (cm)	41.0 (0.6)	4.0–950.0	34.6 (0.9)	0–1000.0
Shrub cover[a] (%)	34.1 (2.0)	2.0–90.0	23.1 (1.5)	0–90.0
Sagebrush height (cm)	41.6 (0.6)	2.0–168.0	31.8 (0.4)	2.0–146.0
Sagebrush cover (%)	17.5 (1.2)	0.3–44.4	14.1 (0.8)	0.3–37.3
Forb height (cm)	14.6 (0.3)	1.0–126.0	8.3 (0.2)	1.0–83.0
Forb cover (%)	10.1 (0.2)	1.0–100.0	10.0 (0.3)	1.0–90.0
Grass height (cm)	26.9 (0.4)	1.0–111.0	16.5 (0.3)	1.0–121.0
Grass cover (%)	16.6 (0.4)	1.0–95.0	16.2 (0.4)	1.0–90.0
Litter cover (%)	44.3 (0.7)	1.0–100.0	41.2 (0.6)	1.0–100.0
Bare ground (%)	32.4 (0.8)	2.0–100.0	45.0 (0.6)	2.0–100.0

[a]Includes measurements of trees and zero shrub canopy cover

Table 2-9. Statistical comparison of the vegetation structure and ground cover at other greater sage-grouse (*Centrocercus urophasianus*) use sites and random sites in northwestern Utah, 2012–2013.

Parameter	**Sample 1**	**Sample 2**	***t***	***P***	**95% CI**
Forb height	Female	Male	0.66	0.508	-1.02–0.50
Forb height	All other	Random	6.82	≤ 0.001*	1.45–2.62
Forb cover	Female	Male	1.49	0.136	-1.40–0.19
Forb cover	All other	Random	0.76	0.445	-0.46–1.04
Grass height	Female	Male	4.19	≤ 0.001*	1.22–3.36
Grass height	All other	Random	13.88	≤ 0.001*	4.96–6.60
Grass cover	Female	Male	0.79	0.431	-0.64–1.50
Grass cover	All other	Random	1.69	0.090	-0.12–1.70
Total shrub height	Female	Male	0.82	0.411	-2.08–0.85
Total shrub height	All other	Random	1.07	0.285	-0.91–3.08
Total shrub cover	Female	Male	0.64	0.522	-0.07–0.04
Total shrub cover	All other	Random	4.22	≤ 0.001*	0.04–0.11
Sagebrush height	Female	Male	4.01	≤ 0.001*	1.73–5.03
Sagebrush height	All other	Random	6.78	≤ 0.001*	2.84–5.15
Sagebrush cover	Female	Male	1.14	0.258	-0.02–0.06
Sagebrush cover	All other	Random	3.17	0.002*	0.02–0.07

*Significant *P*-value at < 0.05

Table 2-10. Most common species of vegetation at greater sage-grouse (*Centrocercus urophasianus*) nest sites in northwestern Utah, 2012–2013.

Type	**Common name**	**Genus species**	$\bar{x}$ **(SE)**[a]	**Freq.**[b]	**Wt.**[c]
Forb	Phlox	*Phlox* spp.	8.3 (0.5)	32	265.6
	Lupine	*Lupinus* spp.	15.2 (1.4)	12	182.2
	Western stickseed	*Lappula occidentalis*	7.9 (0.4)	21	165.9
	Hawksbeard	*Crepis* spp.	7.1 (0.5)	18	127.8
	Balsamroot	*Balsamorhiza* spp.	13.2 (2.2)	7	92.4
Grass	Cheatgrass	*Bromus tectorum*	17.6 (0.8)	26	457.6
	Sandberg bluegrass	*Poa secunda*	15.5 (0.8)	25	387.5
	Bluebunch wheat	*Pseudoroegneria spicata*	19.7 (1.2)	14	275.8
	Crested wheat	*Agropyron cristatum*	23.6 (1.3)	11	259.6
	Great Basin wildrye	*Leymus cinereus*	19.4 (3.2)	8	155.2
Shrub	Wyoming big sage	*Artemisia t. wyomingensis*	14.5 (0.5)	21	304.5
	Mountain big sage	*Artemisia t. vaseyana*	20.7 (0.6)	12	248.4
	Snowberry	*Symphoricarpos* spp.	14.6 (1.0)	12	175.2
	Black sage	*Artemisia nova*	10.4 (0.4)	15	156.0
	Rabbitbrush	*Chrysothamnus* spp.	4.5 (0.2)	30	135.0

[a]Mean percent cover and associated standard error

[b]Frequency or number of survey plots that the species occurs in

[c]Weighted mean (mean percent cover multiplied by the frequency)

Table 2-11. Most common species of vegetation at greater sage-grouse (*Centrocercus urophasianus*) brood sites in northwestern Utah, 2012–2013.

Type	**Common name**	**Genus species**	$\bar{x}$ **(SE)**[a]	**Freq.**[b]	**Wt.**[c]
Forb	Lupine	*Lupinus* spp.	17.1 (0.9)	53	906.3
	Phlox	*Phlox* spp.	7.3 (0.3)	79	576.7
	Buckwheat	*Eriogonum* spp.	14.8 (1.7)	18	266.4
	Balsamroot	*Balsamorhiza* spp.	18.1 (3.9)	13	235.3
	Hawksbeard	*Crepis* spp.	7.8 (0.5)	27	210.6
Grass	Cheatgrass	*Bromus tectorum*	15.6 (0.8)	68	1060.8
	Sandberg bluegrass	*Poa secunda*	14.1 (0.5)	64	904.3
	Bluebunch wheat	*Pseudoroegneria spicata*	17.6 (0.8)	47	827.2
	Great Basin wildrye	*Leymus cinereus*	20.3 (1.5)	37	751.1
	Kentucky bluegrass	*Poa pratensis*	25.5 (2.7)	17	433.5
Shrub	Snowberry	*Symphoricarpos* spp.	14.0 (0.5)	46	644.0
	Wyoming big sage	*Artemisia t. wyomingensis*	12.2 (0.5)	52	634.4
	Mountain big sage	*Artemisia t. vaseyana*	18.3 (0.5)	34	622.2
	Rabbitbrush	*Chrysothamnus* spp.	4.8 (0.3)	85	408.0
	Black sage	*Artemisia nova*	9.9 (0.4)	37	366.3

[a]Mean percent cover and associated standard error

[b]Frequency or number of survey plots that the species occurs in

[c]Weighted mean (mean percent cover multiplied by the frequency)

Table 2-12. Most common species of vegetation at non-brooding female and male greater sage-grouse (*Centrocercus urophasianus*) use sites in northwestern Utah, 2012–2013.

Type	**Common name**	**Genus species**	**$\bar{x}$ (SE)[a]**	**Freq.[b]**	**Wt.[c]**
Forb	Phlox	*Phlox* spp.	7.7 (0.2)	141	1078.7
	Lupine	*Lupinus* spp.	13.4 (0.7)	69	924.6
	Milkvetch	*Astragalus* spp.	9.0 (0.6)	51	459.0
	Western yarrow	*Achillea millefolium*	12.6 (0.8)	29	365.4
	Hawksbeard	*Crepis* spp.	8.7 (0.5)	37	321.9
Grass	Sandberg bluegrass	*Poa secunda*	15.8 (0.5)	101	1595.8
	Cheatgrass	*Bromus tectorum*	14.3 (0.7)	82	1168.5
	Great Basin wildrye	*Leymus cinereus*	22.2 (1.4)	49	1087.8
	Bluebunch wheat	*Pseudoroegneria spicata*	16.1 (0.7)	59	949.9
	Western wheatgrass	*Pascopyrum smithii*	22.2 (0.8)	34	754.8
Shrub	Mountain big sage	*Artemisia t. vaseyana*	18.0 (0.5)	64	1152.0
	Wyoming big sage	*Artemisia t. wyomingensis*	13.0 (0.4)	75	975.0
	Black sage	*Artemisia nova*	10.6 (0.3)	58	614.8
	Snowberry	*Symphoricarpos* spp.	10.9 (0.5)	45	490.5
	Rabbitbrush	*Chrysothamnus* spp.	3.0 (0.1)	130	390.0

[a]Mean percent cover and associated standard error

[b]Frequency or number of survey plots that the species occurs in

[c]Weighted mean (mean percent cover multiplied by the frequency)

Table 2-13. Most common species of vegetation at random sites in northwestern Utah, 2012 –2013.

Type	**Common name**	**Genus species**	$\bar{x}$ **(SE)**[a]	**Freq.**[b]	**Wt.**[c]
Forb	Phlox	*Phlox* spp.	8.5 (0.4)	66	561.0
	Halogeton	*Halogeton glomeratus*	11.1 (1.0)	21	233.1
	Hawksbeard	*Crepis* spp.	7.2 (0.8)	19	136.8
	Cryptantha	*Cryptantha* spp.	6.3 (1.4)	18	113.4
	Lupine	*Lupinus* spp.	7.8 (0.9)	13	101.4
Grass	Cheatgrass	*Bromus tectorum*	15.9 (0.8)	59	938.1
	Sandberg bluegrass	*Poa secunda*	11.4 (0.5)	66	752.4
	Crested wheat	*Agropyron cristatum*	18.4 (1.1)	29	533.6
	Squirreltail	*Elymus elymoides*	16.3 (1.5)	30	489.0
	Indian ricegrass	*Achnatherum hymenoides*	18.4 (1.1)	23	423.2
Shrub	Black sage	*Artemisia nova*	12.1 (0.3)	70	847.0
	Wyoming big sage	*Artemisia t. wyomingensis*	8.9 (0.3)	63	560.7
	Juniper	*Juniperus* spp.	12.1 (0.7)	34	411.4
	Basin big sage	*Artemisia t. tridentata*	9.7 (0.5)	33	320.1
	Rabbitbrush	*Chrysothamnus* spp.	3.0 (0.2)	94	282.0

[a]Mean percent cover and associated standard error

[b]Frequency or number of survey plots that the species occurs in

[c]Weighted mean (mean percent cover multiplied by the frequency)

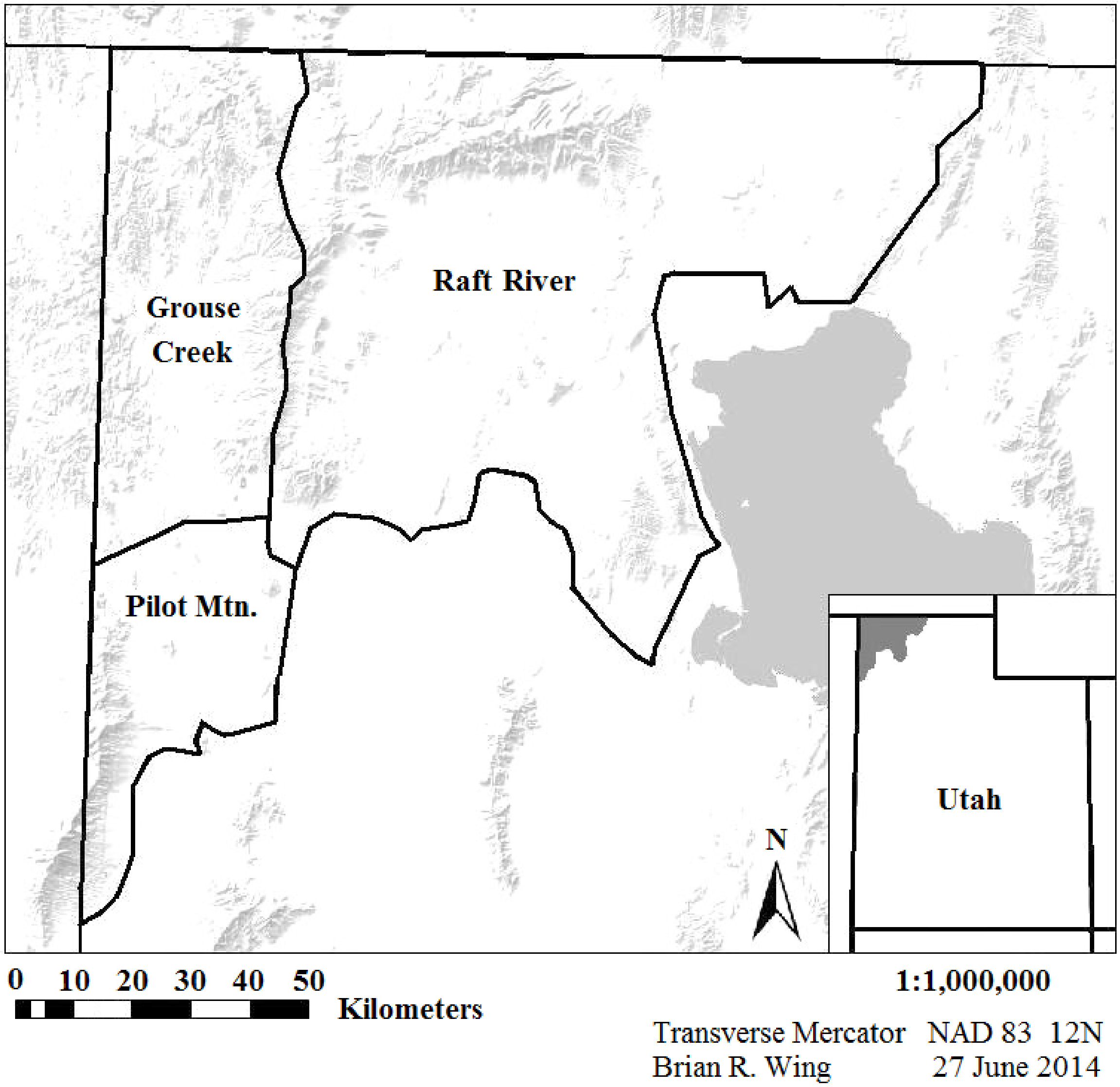

Figure 2-1. Greater sage-grouse (*Centrocercus urophasianus*) study area in the Box Elder Sage-Grouse Management Area, northwestern Utah, 2012–2013.

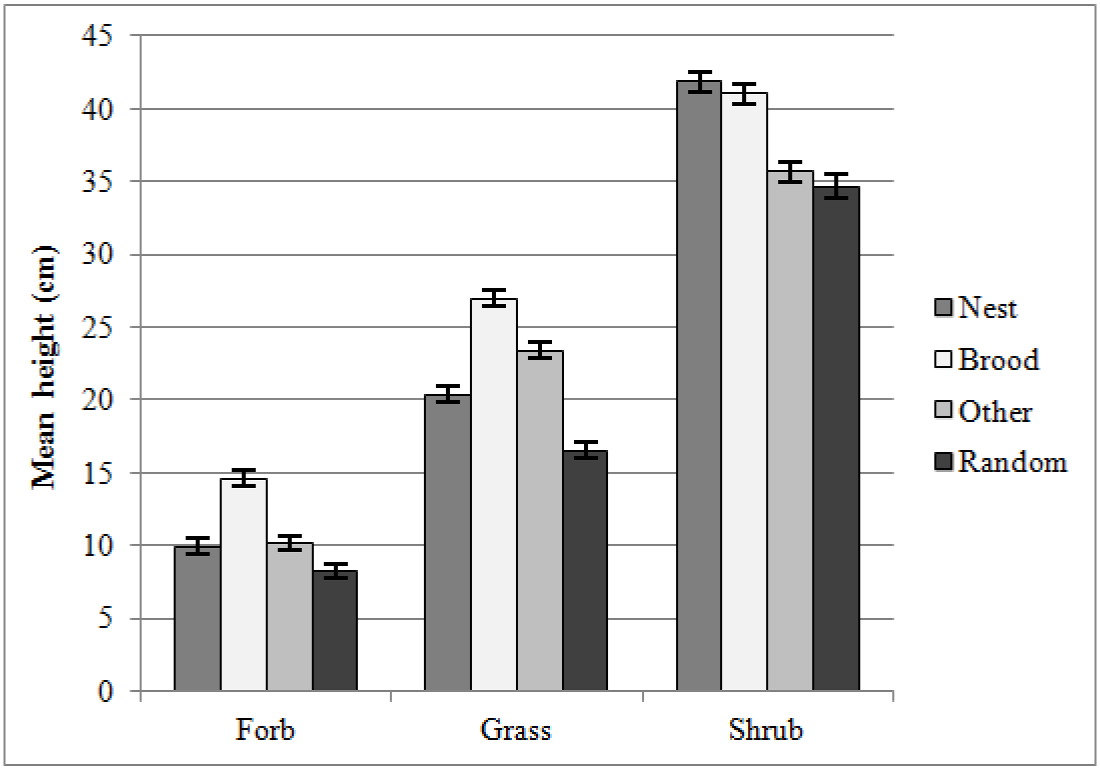

Figure 2-2. Mean height (± standard error) of vegetation at greater sage-grouse (*Centrocercus urophasianus*) use sites and random sites in northwestern Utah, 2012–2013.

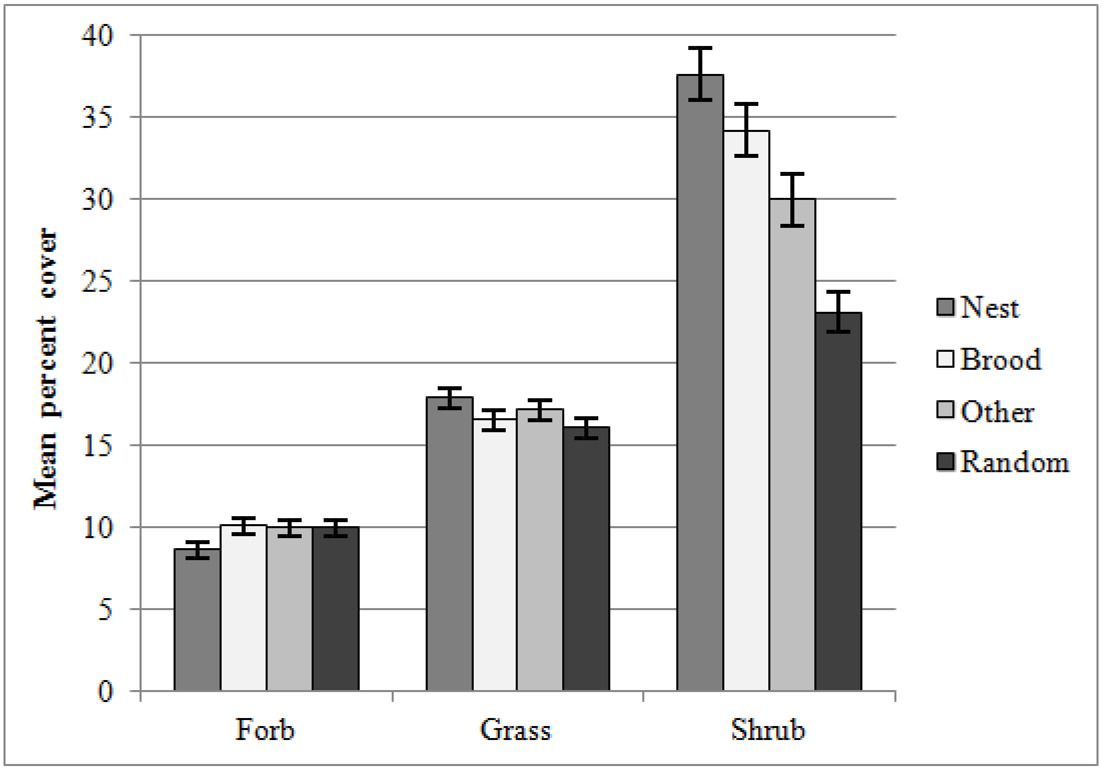

Figure 2-3. Mean percent cover (± standard error) of vegetation at greater sage-grouse (*Centrocercus urophasianus*) use sites and random sites in northwestern Utah, 2012–2013.

CHAPTER 3

FORAGE SELECTION OF BREEDING GREATER SAGE-GROUSE IN BOX ELDER COUNTY, NORTHWESTERN UTAH

ABSTRACT

The greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) is a sagebrush (*Artemisia* spp.) obligate species which may also serve as an indicator species for the condition of sagebrush ecosystems. Because of continued population declines attributed to habitat loss and fragmentation, the U.S. Fish and Wildlife Service (USFWS) determined in 2010 that sage-grouse warranted protection under the Endangered Species Act of 1973. To mitigate species conservation threats identified by the USFWS, the state of Utah has identified 11 sage-grouse management areas (SGMAs) to prioritize management efforts. The Box Elder SGMA, in northwestern Utah, encompasses one of the state's largest sage-grouse populations. From March to May 2013, I monitored 41 (29 female, 12 male) radio-marked sage-grouse in the Raft River subunit of the Box Elder SGMA to determine if a relationship existed between breeding season foraging patterns and population vital rates (i.e., nest initiation and success, egg fertility, clutch size, and adult survival). During this period, I sampled 100 sage-grouse use sites to determine which sagebrush species or subspecies were browsed and if browsed plants differed in nutritional quality (i.e., crude protein) and chemical composition (i.e., monoterpenes) from non-browsed and randomly selected plants. Radio-marked females were observed frequently in association with black sagebrush (*A. nova*) dominated sites, selecting the species at 72.9% of browse sites. Radio-marked males selected black

sagebrush at 43.3% of browse sites. Percent crude protein and total monoterpene concentration in black sagebrush and Wyoming big sagebrush (*A. tridentata wyomingensis*) plants did not differ between browsed, non-browsed, and random sites ($P > 0.05$). Browsed black sagebrush plants were lower in average percent crude protein ($P = 0.003$) and higher in total monoterpene concentration ($P \leq 0.001$) than browsed Wyoming big sagebrush. Nest success, age of nesting females, egg fertility, clutch size ($P > 0.05$), and female monthly survival rates (CI = -0.21–0.49), for the sage-grouse monitored, did not differ by crude protein and total monoterpene content of associated browsed black sagebrush. However, 1 individual unidentified monoterpene was more concentrated in browsed black sagebrush plants associated with successful nesting females than unsuccessful females ($P = 0.002$). Because of female preference for black sagebrush, I was not able to obtain a sufficient sample size of Wyoming big sagebrush to describe its nutritional and chemical effects on vital rates. My results supported previous published work regarding sage-grouse preference for black sagebrush as winter and spring forage and suggest a possible link to nest success for individual monoterpenes.

INTRODUCTION

In 2010, the U.S Fish and Wildlife Service (USFWS) designated the greater sage-grouse as a candidate species for protection under the Endangered Species Act of 1973, citing loss and fragmentation of sagebrush (*Artemisia* spp.) habitats as a major factor in observed population declines (USFWS 2010). Sage-grouse are sagebrush obligates and depend on sagebrush as both a primary forage and preferred cover (Connelly et al. 2011). The winter diet of sage-grouse generally consists almost entirely of sagebrush leaves

(Patterson 1952, Dalke et al. 1963). Despite the defensive chemistry of sagebrush (Striby et al. 1987, Rosentreter 2005), sage-grouse are well-adapted to a diet consisting largely of the plant and may even gain weight during the winter months (Beck and Braun 1978).

Plant secondary metabolites (PSMs) (e.g., monoterpenes, sesquiterpene lactones, and phenolics) are typically considered to be a toxic defense of plants which are often avoided by herbivores (Forbey et al. 2013*a*). Sagebrush is relatively high in PSMs (Kelsey et al. 1982), and the effect of these chemical compounds on sage-grouse digestion is not fully understood (Forbey et al. 2013*b*). Published information on the palatability of sagebrush is incomplete and consists mostly of observations on other wildlife species, especially mammals (Rosentreter 2005).

Previous studies have reported lower monoterpene concentrations in the sagebrush species selected as forage by sage-grouse. Frye et al. (2013) reported that sage-grouse in south-central Idaho preferred black sagebrush (*A. nova*) to Wyoming big sagebrush (*A. t. wyomingensis*), despite the higher level of crude protein found in the latter. Presumably, black sagebrush was selected because of its lower concentration of PSMs. Frye et al. (2013) did not specify which type of black sagebrush they observed (Rosentreter 2005). Remington and Braun (1985) reported a similar relationship in Colorado, where Wyoming big sagebrush was preferred over mountain big sagebrush (*A. t. vaseyana*), apparently due to higher protein and lower monoterpene content.

Remington and Braun (1985) and Frye et al. (2013) also reported some variation of nutritional and chemical content within preferred species of sagebrush browsed by sage-grouse. Both of these studies reported higher levels of crude protein in browsed plants than non-browsed and random plants, but differences of monoterpene concentrations in browsed plants were reported only by Frye et al. (2013). Neither of these studies attempted to differentiate forage selection patterns by sex, age, or population vital rates.

Thacker et al. (2012) suggested that the nutritional quality and chemical composition of the sagebrush plants selected as forage by sage-grouse may affect their survival or reproductive success. It is possible that the diet of a female sage-grouse could even affect her egg production (e.g., clutch size, egg fertility, and hatching success), as some studies involving other bird species have demonstrated (Bauer 1985, Eldridge and Krapu 1988). If adult survival or female reproductive rates differ among individual sage-grouse relative to the amount of crude protein or monoterpenes in the plants they select for forage, managers may need to consider more than the availability of sagebrush cover when developing conservation plans. Further, this information may be particularly important if climate change causes an increase in plant chemical defenses and thus affects the availability and palatability of sagebrush (Forbey et al. 2013*b*). No research has been published to describe the effects of sage-grouse sagebrush selection patterns on population vital rates (i.e., nest initiation, nest success, and adult survival).

The purpose of my research was to describe the sagebrush foraging behavior of sage-grouse during the breeding season in northwestern Utah. Specifically, I wanted to determine if individual browsed plants in sage-grouse use areas differed from non-browsed and random plants in their nutritional quality and chemical composition and if the phytochemistry of browsed plants was related to individual sage-grouse nest initiation and success, egg fertility and clutch size, and monthly adult survival rates.

STUDY AREA

My research was conducted within the Raft River subunit of Utah's Box Elder Sage-Grouse Management Area (SGMA) (Utah Division of Wildlife Resources [UDWR] 2009). The Raft River subunit encompasses approximately 440,750 ha in the northwest corner of Utah in Box Elder County (Fig. 3-1). The Raft River subunit extends from the Utah-Idaho border on the north to the Great Salt Lake and salt flats at the south, and from the Grouse Creek Mountains on the west to the Hansel Mountains near Snowville, Utah and the Great Salt Lake at the east. The primary study area encompassed sage-grouse breeding ranges in this subunit, located in the valleys and foothills south of the Raft River Mountains, east of the Grouse Creek Mountains, and near the Matlin Mountains approximately 20 km south of Rosette, Utah. The primary study area encompassed approximately 39,540 ha and ranged from 1,500–2,500 m above sea level in elevation.

The climate of the study area is typical of the Great Basin with cold winters and hot summers (West 1983). Average temperatures in this area range from a low of -10 °C in January to a high of 29 °C in July. Average annual precipitation is 34 cm. Average annual snowfall is 92 cm (Western Regional Climate Center 2014). In 2013, winter temperatures were often below -20 °C, the snow level persisted in the valley, and spring precipitation was much greater than in 2012.

Land ownership in the Raft River subunit was approximately 50% private, 45% federal, and 5% state lands. Common land uses included grazing by domestic livestock, hay production, and rock quarrying. Vegetation composition in the area is related to soil type, moisture, and elevation.

The most common sagebrush species in the study area were black sagebrush and Wyoming, basin (*A. t. tridentata*), and mountain big sagebrush subspecies. Other sagebrush species present included low (*A. arbuscula*), bud (*A. spinescens*), and pygmy (*A. pygmaea*). Proportions of sagebrush cover in the primary study area were approximately 55% Wyoming and basin big sagebrush, 34% black sagebrush, and 11% mountain big sagebrush (U.S. Geological Survey [USGS] 2004).

Other shrub and tree species present included rabbitbrush (*Chrysothamnus* spp.), greasewood (*Sarcobatus vermiculatus*), horsebrush (*Tetradymia* spp.), antelope bitterbrush (*Purshia tridentata*), serviceberry (*Amelanchier utahensis*), snowberry (*Symphoricarpos* spp.), juniper (*Juniperus* spp.), and pinyon pine (*Pinus* spp.). Common forb species included milkvetch (*Astragalus* spp.), phlox (*Phlox* spp.), hawksbeard (*Crepis* spp.), western yarrow (*Achillea millefolium*), and lupine (*Lupinus* spp.). Native and introduced grasses included Indian ricegrass (*Achnatherum hymenoides*), bluebunch wheatgrass (*Pseudoroegneria spicata*), bluegrasses (*Poa* spp.), Great Basin wildrye (*Elymus cinereus*), crested wheat (*Agropyron cristatum*), and cheatgrass (*Bromus tectorum*).

METHODS

Data Collection

From January 2012 through April 2013, female and male sage-grouse were captured and radio-marked following protocols described by Connelly et al. (2003). Birds were captured at night in 2-person teams using an all-terrain vehicle, spotlight, and long-handled net. Each captured bird was fitted with a numbered leg band and a 20 g necklace-type Advanced Telemetry Systems™ (ATS) (Advanced Telemetry Systems, Insanti, MN, USA) radio transmitter (150.000–151.000 MHz) equipped with a mortality sensor. Captured birds were sexed, aged (Eng 1955), and weighed using a Pesola™ (Pesola, Baar, Switzerland) 2,500 g spring scale. The capture location was recorded using a handheld global positioning system (GPS) unit (UTM, 12N, NAD 83). Birds were handled with care and released on site according to protocol approved by the Utah State University Institutional Animal Care and Use Committee (IACUC #1194) and UDWR Certificate of Registration (COR #2BAND8743).

Following capture, radio-marked sage-grouse were located to determine vital rates and habitat use patterns. Telemetry equipment used consisted of Communications Specialists™ (Communications Specialists, Orange, CA, USA) and Telonics™ (Telonics, Mesa, AZ, USA) receivers, handheld 3-element Yagi antennas, and vehicle-mounted omni-directional antennas. We used a small fixed-wing aircraft fitted with ATS™ radio telemetry equipment to locate birds we could not detect through ground radio telemetry. Aircraft services were contracted through Airmotive Service of Brigham City, Utah.

A handheld GPS unit was used to mark the geographic location each time a radio-marked bird was located and observed. Marked females were located at least weekly during the breeding season and twice each week during the nesting period. Marked males were located weekly during the breeding season. Radio-marked birds were located as soon as possible when a transmitter gave a mortality signal.

A female sage-grouse was determined to be nesting when found in the same location on 2 consecutive visits during the breeding season. Nesting females were located using handheld telemetry equipment and binoculars. To mitigate nest abandonment, care was taken to not disturb nesting females. Nest locations were marked by GPS and an inconspicuous physical marker to aid researchers in returning to the nest and to mitigate predation. Nesting females were carefully observed 2–3 times each week until the nest hatched or failed. A successful hatch was determined when egg halves were found intact in or near the nest bowl or the inner membrane of the egg was separated from the shell (Klebenow 1969, Wallestad and Pyrah 1974).

In March and April 2013, sage-grouse flocks were visually located by tracking radio-marked females and males to determine which sagebrush species they selected for forage at the patch level. Initially, radio-marked sage-grouse were randomly selected for observation based on their accessibility within the study area. The most-accessible birds were then selected for multiple observations within the 2-month sampling period, with females given priority over males. Once a sage-grouse flock was located, the sagebrush patch was searched for sagebrush plants which had been freshly browsed by sage-grouse. Plants were determined to have been browsed when the typical cut leaves of sage-grouse foraging were observed (Remington and Braun 1985) (Fig. 3-2). When the patch was determined to have been browsed by the sage-grouse flock, the browsed sagebrush was identified to subspecies and recorded. These observations were made at least 3 times, on different days, for multiple female and male sage-grouse in their associated flocks.

At sage-grouse flock browse sites associated with radio-marked females, leaf tissue samples were collected from browsed, non-browsed, and random sagebrush plants to determine if the plants differed based on nutritional quality and chemical composition. Browsed sagebrush plants were those that exhibited the typical cut leaves of sage-grouse herbivory. Non-browsed plants were selected by finding the nearest plant of the same subspecies which showed no signs of sage-grouse foraging. Random plants of the same subspecies were selected in a random direction and distance between 300 m and 1 km of the browse site. Each sagebrush plant was identified to subspecies and sampled by collecting enough live and leafy stems to fill a 7 oz Nasco™ (Nasco, Fort Atkinson, WI, USA) Whirl-Pak® bag. Plant tissue samples were stored frozen at -10 °C until being lab-tested.

Data Analysis

I analyzed the patch selection patterns by sagebrush species for radio-marked sage-grouse observed at 3 or more browse sites. I calculated proportions, by sex and age, of the number of individual birds which were observed in browsed patches of black sagebrush, big sagebrush, or both sagebrush species. I also used an occupancy estimation model in Program MARK software (MARK Version 7.1, http://warnercnr.colostate.edu/~gwhite/mark/mark.htm, accessed 27 Aug 2013) to calculate probabilities, by sex and age, of the observed sage-grouse using browsed patches of black sagebrush over browsed patches of big sagebrush in their first 3 encounter occasions.

Analyses of the nutritional quality and chemical composition of the collected sagebrush samples were performed at the U. S. Department of Agriculture (USDA) Poisonous Plants Research Lab in Logan, Utah. To determine nutritional quality, sagebrush leaves were oven dried at 40 °C and ground using a mortar and pestle. Each dried sample was analyzed using a Leco Corp.™ (Leco Corporation, St. Joseph, MI, USA) FP-528 testing instrument to determine the percentage of crude nitrogen. The percentage of crude protein on a partial dry sample was calculated by multiplying the percentage of crude nitrogen by 6.25 and 100, then dividing by the percentage of dry matter. Each sample was analyzed twice and the resulting percentages were averaged.

To analyze the chemical composition of the sagebrush samples, 100 mg of non-dried and non-ground sagebrush leaves were weighed and placed in a 10 mL screw-cap test tube. A glass pipette and battery-operated pipettor was used to add 5 mL of 0.186 mg/mL octaphenone methylene chloride solvent to each test tube. The tubes were capped tightly and allowed to sit for 24 hours. Samples were then filtered through a glass pipette containing paper and sodium sulfate and transferred to a 1.5 mL test vial and tightly capped. Samples were then analyzed for monoterpene concentration using a Thermo Finnigan™ (Thermo Finnigan LLC, San Jose, CA, USA) Polaris Trace gas chromatography mass spectrometer testing instrument. Samples were analyzed in groups of approximately 30 samples each per testing period. The analysis was repeated for 1 sample up to 4 times to determine accuracy and consistency between testing periods. The accuracy and consistency of the testing process was further validated by inspecting the profiles of each sample for the typical monoterpene peaks of black or Wyoming big sagebrush (Thacker et al. 2012). The analysis was also verified by plotting the concentration of primary monoterpenes against the total monoterpene concentration to check for a linear regression pattern.

Nest initiation was calculated as the proportion of females alive at the onset of the nesting period which nested. Re-nesting effort was calculated as the proportion of females that survived the failure of an initial nest and made a second attempt to nest. Nest success was calculated as the proportion of nests with at least 1 hatched egg. Hatching success was calculated as the proportion of all eggs that hatched in successful nests. Clutch size was the total number of eggs laid. Egg fertility was calculated as the proportion of eggs laid in a nest that had either hatched or contained a partially-developed embryo. Predated nests were not included in the egg fertility or clutch size calculations because egg shells were often missing or crushed.

Statistical analyses of sagebrush nutrition and chemical content and associated vital rate data consisted of descriptive statistics, 2-sample 2-tailed *t*-tests, and a linear regression model, each performed in R statistical software (R Version 2.15.1, www.r-project.org, accessed 8 Mar 2013). I used *t*-tests to determine if any differences of female age, capture weight (excluding birds captured during or prior to the 2012 breeding season), nest initiation, and nest success occurred in relation to the crude protein and monoterpene concentrations of browsed sagebrush. I also used *t*-tests to determine if any differences occurred in the elevation of browse sites or the content of crude protein and monoterpenes in sagebrush collected at browsed, non-browsed, and random sites associated with individual radio-marked female sage-grouse. The linear regression model was used to analyze the effects of sagebrush nutritional and chemical content on clutch size, egg fertility, and hatching success. All results were considered significant at $P < 0.05$.

I used a known fate analysis with logit link function in Program MARK to calculate monthly survival probabilities of monitored male and female sage-grouse from March to May 2013. I included the percentage of crude protein and total monoterpene concentration of black sagebrush collected at browse sites associated with individual radio-marked females as covariates in this analysis to determine if these were related to their monthly survival during the breeding season. All sage-grouse included in the survival analysis had survived at least 1 week after capture to ensure that mortalities were not related to capture trauma. A 95% confidence interval (CI) was used to determine the significance of covariate effects. A confidence interval including 0 indicated that an effect was not significant.

RESULTS

During the 2013 breeding season, I monitored the vital rates and foraging behavior of 41 (29 female, 12 male) radio-marked sage-grouse which were captured in both 2012 and 2013 in close proximity to their breeding grounds. In the 2013 breeding season, these birds consisted of 15 yearling females, 14 adult females, and 12 adult males. Monthly survival probabilities from March to May 2013 ranged 0.88–1.00 ($\bar{x}$ = 0.94, SE = 0.03) for females, 0.91–1.00 ($\bar{x}$ = 0.94, SE = 0.03) for males, 0.88–1.00 ($\bar{x}$ = 0.95, SE = 0.04) for adults, and 0.93–1.00 ($\bar{x}$ = 0.95, SE = 0.02) for yearlings.

In 2013, female nest initiation rates were 100% (13/13) for adults and 64% (7/11) for yearlings. Starting dates of nest incubation ranged from 10 April to 19 May. For females captured within 4 months prior to nesting in 2013, capture weights ranged 1.35–1.55 kg ($\bar{x}$ = 1.44, SE = 0.05) for adults which nested, 0.90–1.40 kg ($\bar{x}$ = 1.12, SE = 0.11) for yearlings which nested, and 1.07–1.20 kg ($\bar{x}$ = 1.14, SE = 0.03) for females which did not nest. One adult and 3 yearling females were inaccessible during nesting, and 1 yearling died prior to nesting; these were not included in nest initiation calculations. Six (46%) adult and 4 (57%) yearling females nested successfully. One (10%) unsuccessful female initiated a second nest within a week of the first nest being predated; this nest was also predated and was the only re-nest attempt I observed. Of unsuccessful nests, 10 (91%) were predated and 1 (9%) was abandoned. Clutch sizes ranged 5–10 eggs ($\bar{x}$ = 6.6, SE = 0.6). Hatching success and egg fertility both ranged 75–100% ($\bar{x}$ = 93.6, SE = 0.04).

From 1 March to 19 April 2013, I identified 100 (70 female, 30 male) sage-grouse flock browse sites throughout the study area. Flocks ranged from approximately 2–40 birds and usually flushed 100 m or more from the approaching researcher, making it difficult to observe the browsing behavior of individual radio-marked sage-grouse. Flocks were typically segregated by sex but sometimes consisted of both females and males. Observed browse sites occurred in patches of 3 subspecies of sagebrush. Browsed patches consisted of 64 (64%) black sagebrush, 33 (33%) Wyoming big sagebrush, and 3 (3%) mountain big sagebrush. Fifty-one (72.9%) female and 13 (43.3%) male browse sites occurred in black sagebrush.

The browse sites for 27 (18 female, 9 male) sage-grouse, which were located at 3 or more browse sites, were searched to determine sagebrush patch selection patterns. Ten (55.6%) females were observed entirely in black sagebrush, 7 (38.9%) in both black sagebrush and Wyoming or mountain big sagebrush, and 1 (5.5%) entirely in Wyoming big sagebrush (Table 3-1). Four (44.5%) males were observed entirely in Wyoming big sagebrush, 3 (33.3%) in both black sagebrush and Wyoming big sagebrush, and 2 (22.2%) entirely in black sagebrush. Separated by age, 7 of 17 (41.2%) adults were observed entirely in black sagebrush, 6 (35.3%) in both black sagebrush and big sagebrush subspecies, and 4 (23.5%) entirely in Wyoming big sagebrush. Five of 10 (50%) yearlings were observed entirely in black sagebrush, 4 (40%) in both black sagebrush and big sagebrush subspecies, and 1 (10%) entirely in Wyoming big sagebrush. Probabilities that the monitored sage-grouse used patches of black sagebrush over big sagebrush were 0.95 (SE = 0.05) for females, 0.58 (SE = 0.17) for males, 0.77 (SE = 0.10) for adults, and 0.91 (SE = 0.09) for yearlings.

I analyzed the nutritional and chemical content of sagebrush leaf tissue samples collected at 36 sage-grouse browse sites. Of these, 24 were black sagebrush samples of sites associated with 24 individual females, and 12 were Wyoming big sagebrush samples of sites associated with 11 females. Non-browsed and random samples were also analyzed in association with each browse site. Due to female preference for black sagebrush, I was unable to obtain a sufficient number of Wyoming big sagebrush samples to analyze in relation to vital rates. Thus, my analyses of the effects of sagebrush nutrition and chemical composition on vital rates included only black sagebrush samples.

For both black sagebrush and Wyoming big sagebrush, crude protein content varied 0.03–3.01% ($\bar{x}$ = 0.66, SE = 0.08) between the first and second analyses. The average percentage of crude protein did not differ between browsed and non-browsed sites (t = 0.04, P = 0.970) (t = 0.39, P = 0.702), browsed and random sites (t = 0.35, P = 0.728) (t = 0.69, P = 0.499), and non-browsed and random sites (t = 0.39, P = 0.701) (t = 0.85, P = 0.408) for black sagebrush and Wyoming big sagebrush, respectively.

The average percentage of crude protein was greater in Wyoming big sagebrush than black sagebrush at browsed (t = 3.37, P = 0.003), non-browsed (t = 2.40, P = 0.031), and random sites (t = 2.46, P = 0.025). Crude protein in black sagebrush samples averaged 16.78% (SE = 0.36, range = 12.94–20.24) at browsed sites, 16.80% (SE = 0.36, range = 12.80–20.47) at non-browsed sites, and 16.61% (SE = 0.34, range = 13.59–20.92) at random sites (Table 3-2, Fig. 3-3). Crude protein in Wyoming big sagebrush samples averaged 18.93% (SE = 0.55, range = 17.08–23.49) at browsed sites, 19.37% (SE = 0.63, range = 15.82–27.51) at non-browsed sites, and 18.37% (SE = 1.01, range = 15.60–21.98) at random sites. I did not observe a difference between black sagebrush and Wyoming big sagebrush in elevation of browse sites ($t = 0.47$, $P = 0.645$).

In the monoterpene lab analysis of black sagebrush, 1 sample was analyzed 4 times with a day between each analysis. The total concentration of monoterpenes in the sample differed 1.03 mg/g (SE = 0.23) between the first and fourth analyses, which was determined to be an acceptable amount of variation (D. Gardner, USDA Poisonous Plants Research Lab, personal communication). Sixty-nine of the 72 (96%) samples consistently matched the typical black sagebrush profile (Fig. 3-4). The samples with inconsistent profiles were also apparent in the plot of primary and total monoterpene concentration, but overall, the sample points consistently followed a linear regression line (Fig. 3-5). The total monoterpene concentration of the inconsistent samples was within range of the other samples, so I included them in the statistical analyses. Nine primary unidentified monoterpenes (labeled A–I) were determined to exist in the typical profile of the black sagebrush samples.

The monoterpene analysis of Wyoming big sagebrush samples was conducted 2 months after the black sagebrush analysis. Ten of the previously tested black sagebrush samples were re-extracted and included as a control group in this analysis to confirm consistency between the 2 analyses. The black sagebrush samples differed an average of 1.04 mg/g (SE = 0.22) from the first testing period, which considering these samples were re-extracted, was determined acceptable for comparisons between the 2 testing periods (D. Gardner, USDA Poisonous Plants Research Lab, personal communication).

One Wyoming big sagebrush sample was analyzed 3 times and differed 0.09 mg/g (SE = 0.03). Twenty-six (72%) of the Wyoming big sagebrush samples were consistent in profile, while the remaining 10 samples exhibited a similar profile but with 1 particular monoterpene in much greater concentration. Overall, the Wyoming big sagebrush samples varied more than the black sagebrush in presence of individual monoterpenes, ranging from 6–15 primary ($\bar{x}$ = 11.6, SE = 0.3) unidentified monoterpenes.

Total monoterpene concentrations did not differ between browsed and non-browsed sites (t = 0.08, P = 0.933) (t = 0.19, P = 0.853), browsed and random sites (t = 0.06, P = 0.955) (t = 0.45, P = 0.657), and non-browsed and random sites (t = 0.02, P = 0.983) (t = 0.19, P = 0.850) within black sagebrush and Wyoming big sagebrush, respectively. Total monoterpene concentration was greater in black sagebrush than Wyoming big sagebrush at browsed (t = 3.88, $P \leq 0.001$), non-browsed (t = 3.52, $P \leq 0.001$), and random sites (t = 3.39, $P \leq 0.001$). I also analyzed the concentration levels of primary monoterpenes in both species, and these did not differ between browsed, non-browsed, and random sites ($P > 0.05$). Total monoterpene concentration of black sagebrush averaged 6.33 mg/g (SE = 0.64, range = 1.44–11.64) at browsed sites, 6.40 mg/g (SE = 0.52, range = 1.98–13.90) at non-browsed sites, and 6.39 mg/g (SE = 0.26, range = 0.86–16.94) at random sites (Fig. 3-6). Total monoterpene concentration of Wyoming big sagebrush averaged 3.29 mg/g (SE = 0.42, range = 0.96–5.79) at browsed sites, 3.59 mg/g (SE = 0.66, range = 0.90–5.40) at non-browsed sites, and 3.44 mg/g (SE = 0.50, range = 0.83–8.97) at random sites.

Black sagebrush samples did not differ by associated age of nesting females (t = 0.90, P = 0.383) (t = 0.31, P = 0.764), rate of nest success (t = 0.02, P = 0.988) (t = 0.65, *P* = 0.527), clutch size (*P* = 0.907) (*P* = 0.505), and hatching success and egg fertility (*P* = 0.573) (*P* = 0.439) for percent crude protein and total monoterpene concentration, respectively (Table 3-3). I did not observe a difference in capture weight (excluding captures from the previous year) between the associated females by age of nesting female (t = 0.23, P = 0.991) or nest success (t = 0.84, P = 0.296).

The unidentified monoterpene I labeled as "B" was more concentrated in black sagebrush samples from browse sites associated with successful nesting females ($\bar{x}$ = 1.18 mg/g, SE = 0.13) than sites of unsuccessful females ($\bar{x}$ = 0.60 mg/g, SE = 0.13) (t = 3.01, P = 0.002). Overall, monoterpene B was the second most concentrated of the 9 primary monoterpenes, averaging 0.83 mg/g (SE = 0.11). There were no differences in primary monoterpene concentration of black sagebrush samples by age of nesting females ($P > 0.05$).

The nutrition and chemical content of black sagebrush sampled at browse sites was not related to the monthly survival of associated females from March to May 2013 (β = 0.03, CI = -0.11–0.18) (β = 0.14, CI = -0.21–0.49) for average percent crude protein and total monoterpene concentration, respectively.

DISCUSSION

Percent sagebrush canopy cover in the study area consisted of 55% Wyoming and basin big sagebrush, compared to 34% for black sagebrush (USGS 2004). From 10 May to 29 June 2013, I completed 56, 40 m line-intercept (Canfield 1941) surveys at sage-grouse use sites (excluding nest sites) within the same study area, each approximately 1 km from the sampled browse sites. These use sites exhibited mean percent sagebrush canopy cover of 48% Wyoming big sagebrush, 31% black sagebrush, 14% basin big sagebrush, and 7% mountain big sagebrush (B. R. Wing, Utah State University, unpublished data).

Based on availability, the observed radio-marked female sage-grouse preferred black sagebrush over big sagebrush subspecies, selecting the species at 72.9% of observed sites. Males did not exhibit a similar preference. Thacker et al. (2012) reported similar observations within the Box Elder SGMA, finding only black sagebrush in 72% of winter sage-grouse pellets. Frye et al. (2013) reported that sage-grouse in south-central Idaho selected black sagebrush over Wyoming big sagebrush and suggested that black sagebrush was selected because of its lower total monoterpene concentration, despite the higher crude protein content of Wyoming big sagebrush. Similarly, I observed higher crude protein in Wyoming big sagebrush than black sagebrush. However, I also observed a lower total monoterpene concentration in Wyoming big sagebrush than black sagebrush, which suggests that the observed sage-grouse may have selected their preferred sagebrush species based on some aspect of individual monoterpenes rather than the total concentration. My observations of monoterpene concentrations may vary from Frye et al. (2013) due to differences in our sampling periods, as the phytochemistry of sagebrush can change seasonally (Kelsey et al. 1982, Striby et al. 1987).

Within black sagebrush samples, I observed no differences in total monoterpene concentrations between browsed, non-browsed and random sites. Remington and Braun (1985) and Frye et al. (2013) reported similar observations in total concentrations of monoterpenes. Frye et al. (2013) suggested that concentrations of individual monoterpenes, rather than the cumulative concentration, may determine the plants that sage-grouse select within black sagebrush patches. My observations support this concept, as I observed a difference in the concentration of 1 individual unidentified monoterpene between browsed black sagebrush plants associated with successful and unsuccessful nesting females. Although my sample sizes were relatively low at 10 successful and 9 unsuccessful females, the observed differences in concentrations of monoterpene B were about twice as concentrated in samples associated with successful females than in samples of unsuccessful females. I did not observe a difference in the concentration of monoterpene B between associated yearling and adult nesting females.

These results suggest that a higher concentration of this unidentified monoterpene may have actually been beneficial in the nesting condition or behavior of the females that selected it. Though many PSMs have proven to negatively affect the fitness and productivity of herbivores, some studies have demonstrated that, at certain doses, potentially toxic PSMs can actually increase animal fitness by combating bacteria and parasites, stimulating increased vigilance, and aiding in thermoregulation (Forbey et al. 2009). It is possible that the monoterpene I observed in higher concentrations in association with successful females may have provided a positive benefit to their fitness and increased their probability of producing a successful nest. The dietary selections of these females may have enhanced their body condition or increased their nutrient reserves, which would allow them to spend less time away from their nest to forage and thus reduce their exposure to predators (Coates and Delehanty 2008). I did not observe a difference in body weight between successful and unsuccessful females, but this was based on their weight at capture, which was measured up to 4 months prior to the 2013 nesting period of some females.

It is also possible that female sage-grouse in the study area may have selected black sagebrush over Wyoming big sagebrush based on some other aspect of nutritional or chemical content. I tested only for differences in crude protein and monoterpenes. Black sagebrush in the study area may have contained other PSMs, nutrients, sugars, or fats which provided female sage-grouse with an increase of energy reserves to meet the demands of reproduction.

Some studies have reported that forbs are also important in the diet of pre-nesting sage-grouse females. Barnett and Crawford (1994) reported that the diet of pre-nesting females in western Oregon consisted of 18–50% forbs (50–82% sagebrush). Gregg et al. (2008) reported that 89% of pre-nesting females in southeastern Oregon and northwestern Nevada had forb tissue in their crops, and forbs comprised an average of 30% of their diet. In comparison, sagebrush was found in 97% of crops and made up the remaining 70% of the female sage-grouse diet. I did not sample forbs in the study area during the pre-nesting period of 2013 because I did not observe them until the second week of April, when females began to nest. The delay in forb appearance was related to the persistent snow cover and colder-than-average temperatures of the year. It is possible that I may not have detected some forbs and a limited number may have been available for sage-grouse use during the study period. If available, forbs may also be important in the diet of pre-nesting female sage-grouse in the study area.

Based on my sample sizes, I did not detect a definite relationship between sage-grouse vital rates and breeding season foraging behavior. Understanding the effects of foraging patterns on individual sage-grouse vital rates will require larger sample sizes than I was able to obtain. I used radio telemetry to locate individual sage-grouse, which was incredibly time-consuming and did not allow me to get close enough to observe the foraging behavior of the radio-marked bird. Each bird was found in a flock and usually flushed 100 m or more from the approaching researcher (Thacker et al. 2012), making it nearly impossible to even detect which bird was wearing the radio transmitter. Consequently, I can only be certain that the radio-marked individual was part of the flock and was present at the browse site. The sagebrush plants I observed and sampled could have been browsed by any member of the flock, and there may be some differences in forage selection patterns between individual sage-grouse of the same flock.

Future research on sage-grouse foraging patterns may benefit from GPS transmitter technology. By using GPS transmitters, researchers should obtain many more locations of sage-grouse browse sites than they could by tracking each bird one at a time with radio telemetry. This would allow more plant samples to be collected in association with individual marked sage-grouse and may even provide greater precision to increase the likelihood of sampling plants browsed by the individual bird. I also suspect that GPS technology would provide more efficiency in locating browsed plants because this would not depend on the researcher's ability to estimate where a distant flock of sage-grouse flushed from.

MANAGEMENT IMPLICATIONS

My research indicated that pre-nesting female sage-grouse in this management area prefer black sagebrush as forage. Thacker et al. (2012) reported similar observations within this management area. Therefore, management actions in the winter and breeding ranges of sage-grouse in northwestern Utah should conserve patches of black sagebrush. Though more research is needed, black sagebrush appears to be beneficial to the productivity of this sage-grouse population. Black sagebrush is also likely to be important to other wildlife species in the study area (Fryer 2009). Two types of black sagebrush exist in western North America; "type a" is considered highly palatable, while "type b" is low in palatability (Rosentreter 2005). The black sagebrush plants I sampled were of "type a", as they emitted a moderate fluorescence in a UV-light test (Rosentreter 2005).

Wyoming big sagebrush also appears to be adequate forage for sage-grouse in this area and should also be considered important. Wyoming big sagebrush may be of particular importance to wintering sage-grouse when snow levels rise above the lower canopy height of the black sagebrush, making it unavailable as forage. The greater height of Wyoming big sagebrush may also be critically important to this sage-grouse population for nesting or escape cover. The Wyoming big sagebrush plants I sampled were likely hybrids produced with mountain big sagebrush (McArthur et al. 1988, Freeman et al. 1991), as they emitted a moderate fluorescence when I performed a UV-light test (Rosentreter 2005).

LITERATURE CITED

Barnett, J. K., and J. A. Crawford. 1994. Pre-laying nutrition of sage-grouse hens in Oregon. Journal of Range Management 47:114–118.

Bauer, C. A. 1985. Effects of paraquat on reproduction and growth in northern bobwhite. Journal of Wildlife Management 49:1066–1073.

Beck, T. D. I., and C. B. Braun. 1978. Weights of Colorado sage-grouse. Condor 80:241–243.

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

Coates, P. S., and D. J. Delehanty. 2008. Effects of environmental factors on incubation patterns of greater sage-grouse. Condor 110:627–638.

Connelly, J. W., K. P. Reese, M. A. Schroeder. 2003. Monitoring of greater sage-grouse habitats and populations. University of Idaho, College of Natural Resources Experiment Station Bulletin 80, Moscow, USA.

Connelly, J. W., E. T. Rinkes, and C. E. Braun. 2011. Characteristics of greater sage-grouse habitats: a landscape species at micro- and macro-scales. Pages 69–83 *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 38. University of California Press, Berkeley, USA.

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.

Eldridge, J. L., and G. L. Krapu. 1988. The influence of diet quality on clutch size and laying pattern in mallards. Auk 105:102–110.

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

Forbey, J. S., M. D. Dearing, E. M. Gross, C. M. Orians, E. E. Sotka, and W. J. Foley. 2013*a*. A pharm-ecological perspective of terrestrial and aquatic plant-herbivore interactions. Journal of Chemical Ecology 39:465–480.

Forbey, J. S., A. L. Harvey, M. A. Huffman, F. D. Provenza, R. Sullivan, and D. Tasdemir. 2009. Exploitation of secondary metabolites by animals: a response to homeostatic challenges. Integrative and Comparative Biology 49:314–328.

Forbey, J. S., N. L. Wiggins, G.G. Frye, and J. W. Connelly. 2013*b*. Hungry grouse in a warming world: emerging risks from plant chemical defenses and climate change. Wildlife Biology 19:374–381.

Freeman, D. C., W. A. Turner, E. D. McArthur, and J. H. Graham. 1991. Characterization of a narrow hybrid zone between two subspecies of big sagebrush. American Journal of Botany 78:805–815.

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

Fryer, J. L. 2009. Black sagebrush. Fire Effects Information System. U.S. Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. <http://www.fs.fed.us/database/feis/plants/shrub/artnov/all.html#17>. Accessed 27 Jun 2014.

Gregg, M. A., J. K. Barnett, and J. A. Crawford. 2008. Temporal variation in diet and nutrition of pre-incubating greater sage-grouse. Rangeland Ecology and Management 61:535–542.

Kelsey, R. G., J. R. Stephens, and F. Shafizadeh. 1982. The chemical constituents of sagebrush foliage and their isolation. Journal of Range Management 35:617–622.

Klebenow, D. A. 1969. Sage-grouse nesting and brood habitat in Idaho. Journal of Wildlife Management 33:649–661.

McArthur, E. D., B. L. Welch, and S.C. Sanderson. 1988. Natural and artificial hybridization between big sagebrush subspecies. Journal of Heredity 79:268–276.

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

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

Rosentreter, R. 2005. Sagebrush identification, ecology, and palatability relative to sage-grouse. U. S. Department of Agriculture, Forest Service Proceedings RMRS-P-38, Washington, D. C., USA.

Striby, K. D., C. L. Wambolt, R. G. Kelsey, and K. M. Havstad. 1987. Crude terpenoid influence on in vitro digestibility of sagebrush. Journal of Range Management 40:244–248.

Thacker, E. T., D. R. Gardner, T. A. Messmer, M. R. Guttery, and D. K. Dahlgren. 2012. Using gas chromatography to determine winter diets of greater sage-grouse in Utah. Journal of Wildlife Management 76:588–592.

U. S. Fish and Wildlife Service. 2010. Endangered and threatened wildlife and plants; 12-month findings for petitions to list the greater sage-grouse as threatened or endangered. Federal Register 75:13910–14014.

U.S. Geological Survey. 2004. Provisional digital land cover map for the southwestern U. S. Version 1.0. U.S. Geological Survey, National Gap Analysis Program, Reston, Virginia, USA.

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

Wallestad, R. O., and B. D. Pyrah. 1974. Movement and nesting of sage-grouse females in central Montana. Journal of Wildlife Management 38:630–633.

West, N. E. 1983. Great Basin-Colorado Plateau sagebrush semi-desert. Pages 331–349 *in* N. E. West, editor. Temperate deserts and semi-deserts. Elsevier Scientific Publishing Company, Amsterdam, Netherlands.

Western Regional Climate Center. 2014. Monthly climate summary 1981–2010: Park Valley, Utah (426658). <http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?ut6658>. Accessed 30 Jun 2014.

Table 3-1. Sagebrush (*Artemisia* spp.) forage selection patterns of female and male greater sage-grouse (*Centrocercus urophasianus*) observed at 3 or more browse sites in northwestern Utah, March–April 2013

		AN[a]	**ATW**[b]	**Both**[c]
	n	***n (%)***	***n (%)***	***n (%)***
Female				
Yearling	10	5 (50.0)	1 (10.0)	4 (40.0)
Adult	8	5 (62.5)	0 (0)	3 (37.5)
Combined	18	10 (55.6)	1 (5.5)	7 (38.9)
Male				
Adult	9	2 (22.2)	4 (44.5)	3 (33.3)
All				
Yearling	10	5 (50.0)	1 (10.0)	4 (40.0)
Adult	17	7 (41.2)	4 (23.5)	6 (35.3)
Combined	27	12 (44.5)	5 (18.5)	10 (37.0)

[a]Black sagebrush (*A. nova*)

[b]Wyoming big sagebrush (*A. tridentata wyomingensis)*

[c]Black sagebrush and Wyoming big sagebrush

Table 3-2. Nutritional and chemical content of black sagebrush (*Artemisia nova*) and Wyoming big sagebrush (*A. tridentata wyomingensis*) samples collected at browsed, non-browsed, and random female greater sage-grouse (*Centrocercus urophasianus*) sites in northwestern Utah, March–April 2013.

		Crude protein[a]	**Monoterpene**[b]
	n	**$\bar{x}$ (SE)**	**$\bar{x}$ (SE)**
Black sagebrush			
Browsed	24	16.78 (0.36)	6.33 (0.64)
Non-browsed	24	16.80 (0.36)	6.40 (0.52)
Random	24	16.61 (0.34)	6.39 (0.26)
Wyoming big sagebrush			
Browsed	12	18.93 (0.55)	3.29 (0.42)
Non-browsed	12	19.37 (0.63)	3.59 (0.66)
Random	12	18.37 (1.01)	3.44 (0.50)

[a]Average percent crude protein

[b]Total monoterpene concentration (mg/g)

Table 3-3. Greater sage-grouse (*Centrocercus urophasianus*) female nest initiation and success relative to the nutritional and chemical content of black sagebrush (*Artemisia nova*) samples collected at browse sites in northwestern Utah, March–April 2013.

		Wt[a]	**CP**[b]	**Monoterpene**[c]	
				Total	**B**[d]
	n (%)	$\bar{x}$ **(SE)**	$\bar{x}$ **(SE)**	$\bar{x}$ **(SE)**	$\bar{x}$ **(SE)**
Nest Initiation					
Yearling	7 (64%)	1.13 (0.15)	16.41 (0.43)	7.20 (1.61)	0.94 (0.22)
Adult	12 (100%)	1.44 (0.05)	17.08 (0.61)	6.65 (0.68)	0.89 (0.14)
Combined	19 (83%)	1.31 (0.04)	16.84 (0.42)	6.86 (0.71)	0.91 (0.15)
Nest Success					
Successful	10 (53%)	1.41 (0.05)	16.73 (0.59)	7.37 (0.84)	1.18 (0.13)
Unsuccessful	9 (47%)	1.17 (0.18)	16.74 (0.66)	6.27 (0.77)	0.60 (0.13)

[a]Female body weight at time of capture (kg); excluding females captured in previous year

[b]Average percent crude protein

[c]Concentration of monoterpenes (mg/g)

[d]Individual unidentified monoterpene

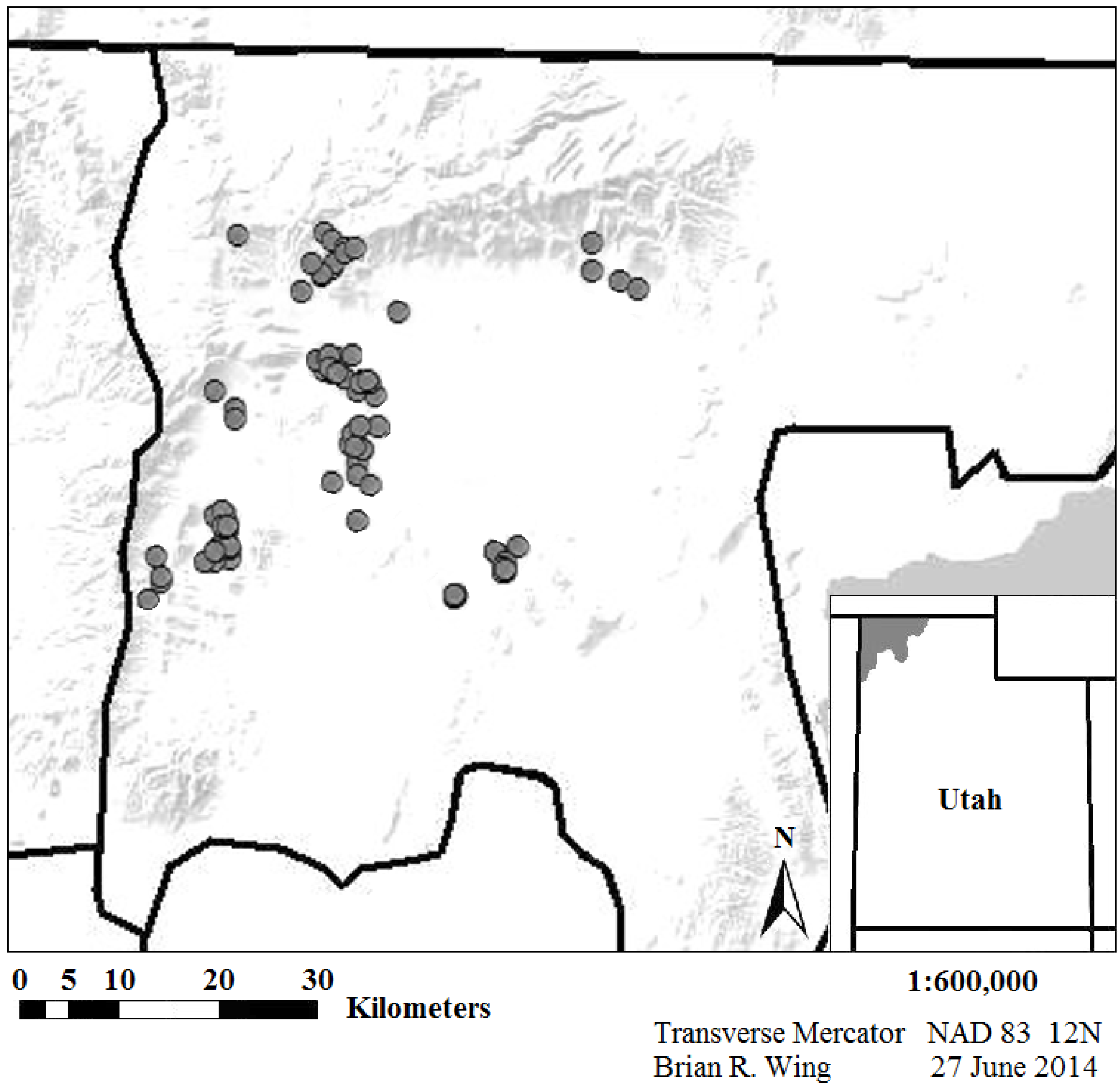

Figure 3-1. Observed sagebrush (*Artemisia* spp.) browse sites of female and male greater sage-grouse (*Centrocercus urophasianus*) in the Raft River subunit of the Box Elder Sage-Grouse Management Area in northwestern Utah, March–April 2013.

Figure 3-2. Mountain big sagebrush (*Artemisia tridentata vaseyana*) leaves collected in northwestern Utah, spring 2013; showing the typical cut leaves of greater sage-grouse (*Centrocercus urophasianus*) browsing.

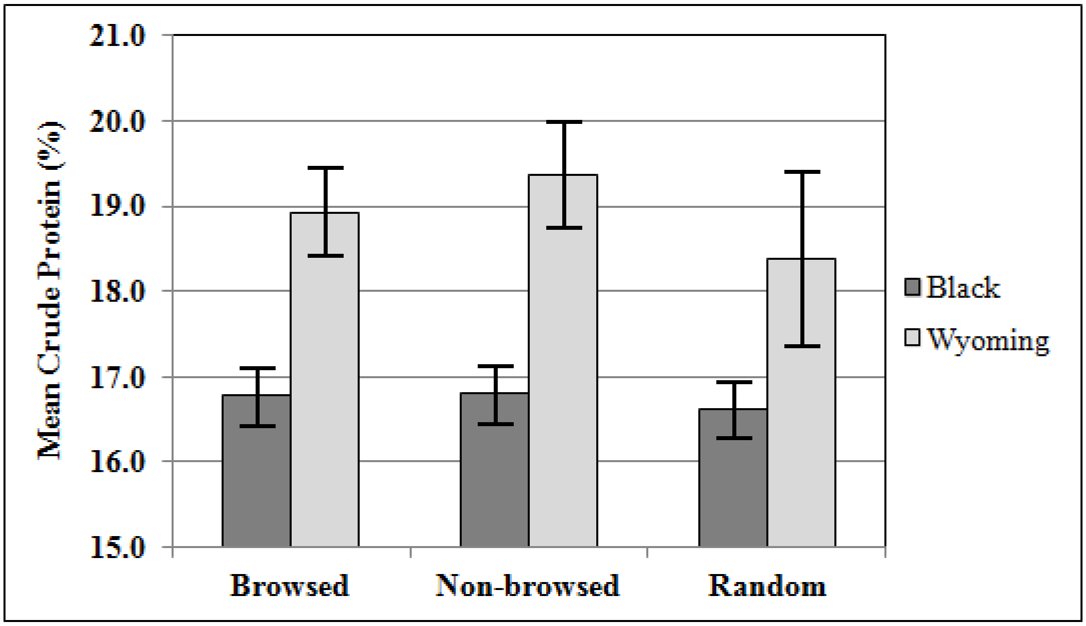

Figure 3-3. Mean percentage of crude protein (± standard error) in black sagebrush (*Artemisia nova*) and Wyoming big sagebrush (*A. tridentata wyomingensis*) at browsed, non-browsed, and random female greater sage-grouse (*Centrocercus urophasianus*) sites in northwestern Utah, March–April 2013.

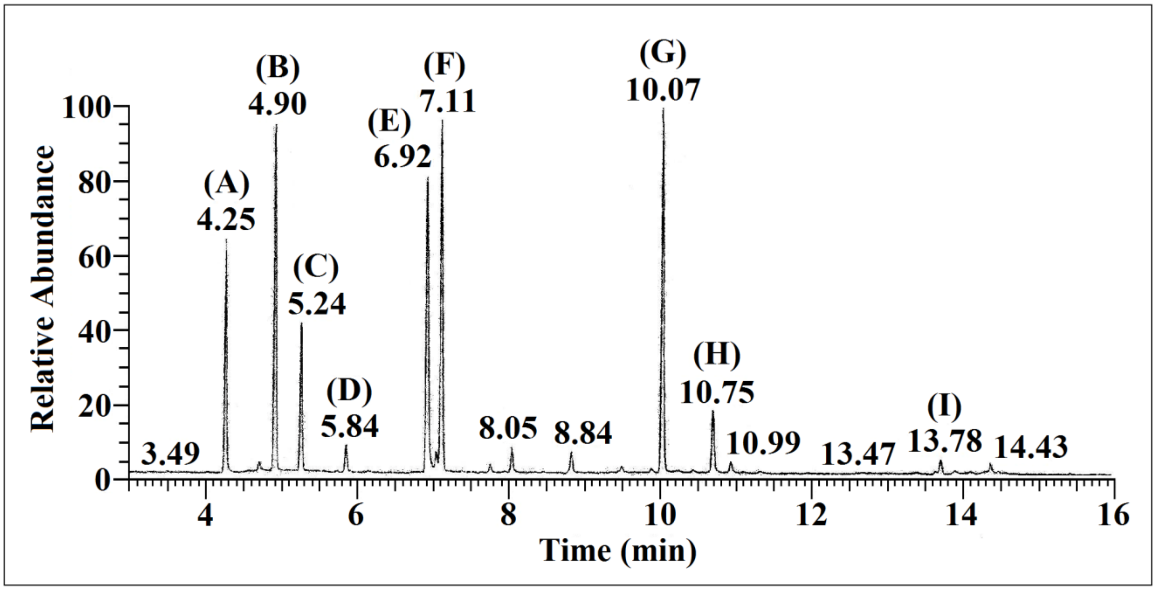

Figure 3-4. Typical monoterpene profile of black sagebrush (*Artemisia nova*) sampled in northwestern Utah, March–April 2013; produced by gas chromatography (primary peaks are labeled A–I).

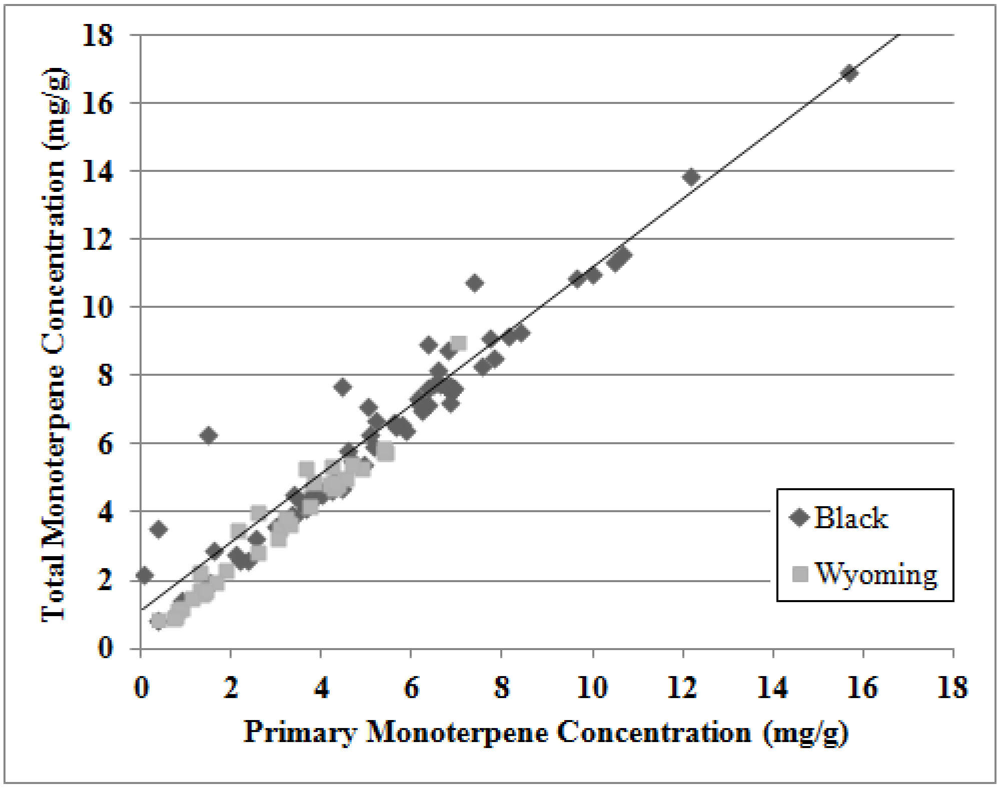

Figure 3-5. Primary vs. total monoterpene concentration in black sagebrush (*Artemisia nova*) and Wyoming big sagebrush (*A. tridentata wyomingensis*) sampled at browsed, non-browsed, and random female greater sage-grouse (*Centrocercus urophasianus*) sites in northwestern Utah, March–April 2013.

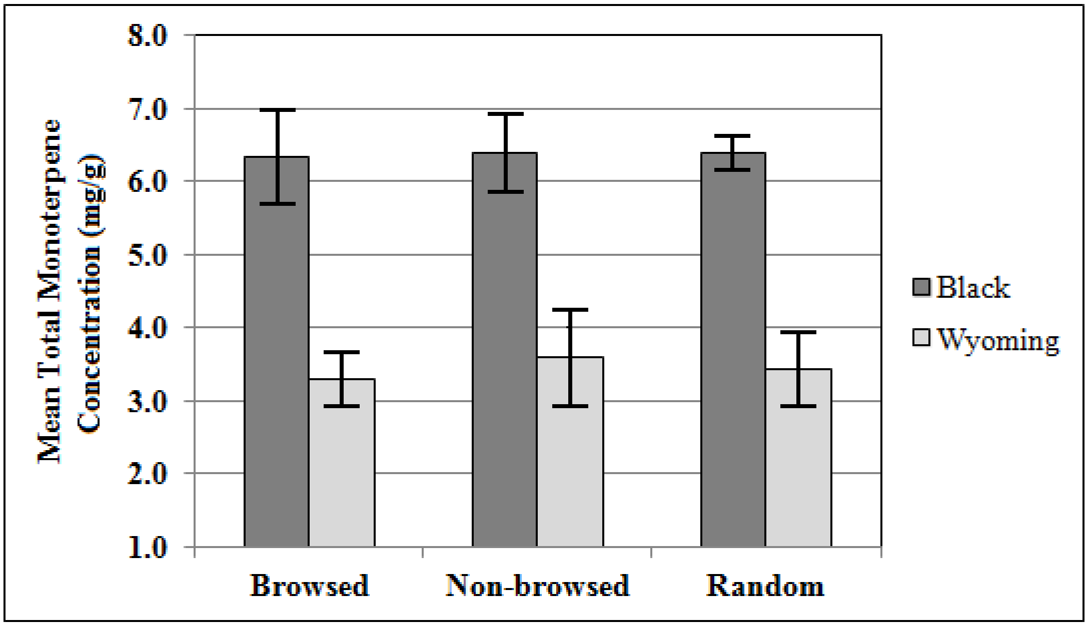

Figure 3-6. Mean total monoterpene concentration (± standard error) in black sagebrush (*Artemisia nova*) and Wyoming big sagebrush (*A. tridentata wyomingensis*) at browsed, non-browsed, and random female greater sage-grouse (*Centrocercus urophasianus*) sites in northwestern Utah, March–April 2013.

CHAPTER 4

CONCLUSIONS

Greater sage-grouse (*Centrocercus urophasianus;* sage-grouse) have been identified by the U.S. Fish and Wildlife Service (USFWS) as a candidate species for listing under the Endangered Species Act of 1973. Habitat loss and fragmentation have been identified as the cause of observed population declines (Connelly et al. 2004, USFWS 2010). Sagebrush (*Artemisia* spp.) is an essential component of sage-grouse habitats, as the species depends on it for both forage and cover. Because sage-grouse are so closely tied to the sagebrush ecosystem, they are a key indicator species of the ecosystem's health. Because of the wide-spread distribution of the species and large remaining expanses of suitable sagebrush habitats, biologists agree that long term species conservation is still possible (Connelly et al. 2011*b*). However, to ensure sage-grouse conservation, better information is needed regarding the vital rates, seasonal movements, and habitat use patterns of individual populations in response to management.

Other than lek locations, little was previously known about the sage-grouse population inhabiting the Raft River subunit of Utah's Box Elder Sage-Grouse Management Area (SGMA) in northwestern Utah (Utah Division of Wildlife Resources 2009). From January 2012 through December 2013, I captured and radio-marked 123 (68 female, 55 male) sage-grouse in this subunit. I monitored the radio-marked sage-grouse to estimate population survival rates, reproductive success, seasonal movements, and habitat use patterns. The purpose of my research was to describe the small-scale habitat use patterns and breeding season foraging behavior of sage-grouse in the study area and to determine if their selection patterns differed by sex and age or affected their survival and reproductive success.

During my research, I completed 492 vegetation surveys at sage-grouse use and random sites to determine which habitat characteristics were preferred by sage-grouse in the study area and contributed most to productivity. Sage-grouse use sites exhibited greater height and percent ground cover of shrubs, forbs, and grasses than random sites. Additionally, successful nests were more often located under sagebrush, and these were also located within sites of greater forb height and cover and greater grass and shrub height than unsuccessful nests. Brooding sage-grouse females selected sites with greater height of forbs, grasses, and shrubs than non-brooding females. The species composition of forbs, grasses, and shrubs were similar between use and random sites but varied in frequency.

The vegetation attributes of the habitats used by sage-grouse in the Box Elder SGMA were comparable to those reported by other studies in Utah. Similar to other reports, I found greater grass height and cover at use sites than at random sites. Percent forb cover ranged 7.4–10.1% at use sites, which is within the 1.0–21.4% reported by similar Utah studies (Dahlgren 2006, Knerr 2007, Duvuvuei 2013). Percent total shrub canopy cover at nest (37.6%) and brood (34.1%) sites was higher than the reported values of other similar Utah studies, which ranged 13.2–23.8% for nest sites and 20.1–27.1% for brood sites (Dahlgren 2006, Knerr 2007, Duvuvuei 2013).

Sagebrush is the preferred nesting substrate of sage-grouse range-wide (Connelly et al. 2011*a*). Most (77.7%) of the sage-grouse nests I monitored were located under sagebrush and were more successful than those located under other shrub species (P =

0.014). In the Grouse Creek subunit of the Box Elder SGMA, Knerr (2007) reported only 55% of nests located under sagebrush. Similar to the findings of Knerr (2007) and Duvuvuei (2013), I observed nests under or in close proximity to junipers (*Juniperus* spp.). Knerr (2007) and Duvuvuei (2013) suggested that this may be an indication that nesting habitat space is limited because of conifer encroachment.

My data suggested that conifer removal in the study area may constitute one strategy to restore and increase nesting and brood-rearing habitat within just a few years. I monitored 4 radio-marked females nesting in areas which had been treated for junipers within the past 5 years, 1 in an area treated within 6 months. Two females successfully hatched nests within these treated areas, and 1 produced a successful brood of at least 3 chicks by remaining in the area for the entire summer.

From 1 March to 19 April 2013, I identified 100 (70 female, 30 male) sites that exhibited sagebrush browsed by sage-grouse (Remington and Braun 1985). These sites were located by tracking 41 (29 female, 12 male) individual radio-marked sage-grouse. Each radio-marked sage-grouse was located in a flock ranging from approximately 2–40 birds. Sage-grouse flocks typically flushed 100 m or more from the approaching researcher (Thacker et al. 2012), which meant I was unable to observe the foraging patterns of individual sage-grouse.

The observed sage-grouse browse sites occurred in patches of 3 subspecies of sagebrush. Browsed patches consisted of 64 (64%) black sagebrush (*A. nova*), 33 (33%) Wyoming big sagebrush (*A. tridentata wyomingensis*), and 3 (3%) mountain big sagebrush (*A. t. vaseyana*). Based on availability, females demonstrated a preference for black sagebrush at 51 (72.9%) sites, whereas this species was browsed at 13 (43.3%) male sites.

Of the radio-marked birds I tracked, 27 (18 female, 9 male) were located at 3 or more browse sites to record their sagebrush patch selection patterns. Ten (55.6%) females were observed entirely in black sagebrush, 7 (38.9%) in both black sagebrush and Wyoming or mountain big sagebrush, and 1 (5.5%) entirely in Wyoming big sagebrush. Four (44.5%) males were observed entirely in Wyoming big sagebrush, 3 (33.3%) in both black sagebrush and Wyoming big sagebrush, and 2 (22.2%) entirely in black sagebrush. Probabilities that the monitored sage-grouse used patches of black sagebrush over big sagebrush were 0.95 (SE = 0.05) for females, 0.58 (SE = 0.17) for males, 0.91 (SE = 0.09) for yearlings, and 0.77 (SE = 0.10) for adults.

Thacker et al. (2012) observed a similar preference for black sagebrush in this SGMA. They reported finding only black sagebrush in 72% of sage-grouse pellets and the remainder containing Wyoming big sagebrush. In south-central Idaho, Frye et al. (2013) also observed a similar preference for black sagebrush over Wyoming big sagebrush. These and my own observations indicate that patches of black sagebrush should be considered important in the winter and spring sage-grouse habitats of northwestern Utah. Wyoming big sagebrush is also adequate forage and should not be disregarded because its greater height may be of particular importance for nesting and escape cover and when black sagebrush is unavailable for forage due to high snow levels.

I analyzed the nutritional quality (i.e, crude protein) and chemical composition (i.e., monoterpenes) of browsed, non-browsed, and random black sagebrush and Wyoming big sagebrush leaf tissue samples collected at 36 sites associated with individual radio-marked female sage-grouse. Because of female species preference, I was only able to obtain a sufficient number of black sagebrush samples to analyze in relation to vital rates. Sagebrush nutritional and chemical analyses were conducted at the U.S. Department of Agriculture Poisonous Plants Research Lab in Logan, Utah.

Within black sagebrush and Wyoming big sagebrush samples, the average percentage of crude protein and the total concentration of monoterpenes did not differ between browsed, non-browsed, and random sites ($P > 0.05$). However, black sagebrush was lower in percent crude protein ($P < 0.05$) and higher in total monoterpene concentration ($P \leq 0.001$) than Wyoming big sagebrush at browsed, non-browsed, and random sites. These results are unlike those reported by Frye et al. (2013), who observed a lower total content of both crude protein and monoterpenes in black sagebrush than in Wyoming big sagebrush. My results suggest that the sage-grouse I monitored may have selected black sagebrush based on some aspect of individual monoterpenes rather than the total concentration.

Based on my sample sizes, I did not detect a relationship between percent crude protein or total monoterpene concentration and the reproductive success (i.e., nest initiation and success, clutch size, hatching success, and egg fertility) ($P > 0.05$) or monthly survival (CI = -0.21–0.49) of associated females. However, I observed that 1 unidentified individual monoterpene was about twice as concentrated in browsed black sagebrush plants associated with successfully nesting females than in plants associated with unsuccessful females ($P = 0.002$. This suggests that this particular monoterpene may have contributed to the nesting success of the associated females. This monoterpene, or perhaps some other dietary component, may have enhanced the nesting condition or behavior of these females and reduced their exposure to predators (Coates and Delehanty 2008).

More research is needed to describe the effects of forage selection patterns and plant phytochemistry on sage-grouse reproduction and survival. Future studies should focus on obtaining a large sample size of marked sage-grouse, collecting plant samples from multiple browse sites for each individual bird, and gathering data for multiple years. Efficiency and precision will likely be increased in such studies by using GPS transmitter technology rather than radio telemetry.

My research demonstrated that this population of sage-grouse has great potential for conservation. Despite conifer encroachment and other forms of habitat loss and fragmentation, these birds exhibited above-average reproductive rates and relatively high survival rates. Nest success rates were high in the study area at 63.6% overall; the average is 46% for other telemetry studies range-wide (Connelly et al. 2011*a*). In the adjacent Grouse Creek subunit, Knerr (2007) and Graham (2013) reported nest success rates of 45% and 36%, respectively. I observed an overall brood success rate of 71.4% in the study area, which is impressive when compared to similar studies in Utah ranging 44–66% (Dahlgren 2006, Knerr 2007, Duvuvuei 2013). The average annual survival rate of sage-grouse in the study area was 68%, whereas Utah studies have reported 37–88% (Dahlgren 2006, Knerr 2007, Duvuvuei 2013, Graham 2013) and the range-wide average is 30–78% (Connelly et al. 2011*a*).

My research provides important data and information regarding the seasonal movements, survival, reproductive rates, and the ecological effects of microhabitat use for sage-grouse in the Raft River subunit of Utah's SGMA in Box Elder County, northwestern Utah. This research can guide the design of future studies and management actions in the long-term conservation of this sage-grouse population. This research provides managers with valuable information regarding the vegetation and microhabitat characteristics which are preferred by this population and contribute most to its growth. Conservation of sage-grouse in northwestern Utah depends on the protection and restoration of preferred vegetation characteristics within utilized and potential habitats.

LITERATURE CITED

Coates, P. S., and D. J. Delehanty. 2008. Effects of environmental factors on incubation patterns of greater sage-grouse. Condor 110:627–638.

Connelly, J. W., C. A. Hagen, and M. A. Schroeder. 2011*a*. Characteristics and dynamics of greater sage-grouse populations. Pages 53–67 *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 38. University of California Press, Berkeley, USA.

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*b*. Conservation of greater sage-grouse: a synthesis of current trends and future management. Pages 549–563 *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 38. University of California Press, Berkeley, 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.

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

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

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

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

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

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

Thacker, E. T., D. R. Gardner, T. A. Messmer, M. R. Guttery, and D. K. Dahlgren. 2012. Using gas chromatography to determine winter diets of greater sage-grouse in Utah. Journal of Wildlife Management 76:588–592.

U.S. Fish and Wildlife Service. 2010. Endangered and threatened wildlife and plants; 12-month findings for petitions to list the greater sage-grouse as threatened or endangered. Federal Register 75:13910–14014.

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