EFFECTS OF LIVESTOCK GRAZING MANAGEMENT PRACTICES ON GREATER SAGE-GROUSE NEST AND FEMALE SURVIVAL

by

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

of

DOCTOR OF PHILOSOPHY

in

Ecology

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UTAH STATE UNIVERSITY
Logan, Utah

2018

ABSTRACT

Effects of Livestock Grazing Management Practices on Greater Sage-Grouse Nest and Female Survival

by

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My research provided new information regarding the effects of livestock grazing on grouse species worldwide and greater sage-grouse (*Centrocercus urophasianus*) nesting and female survival in particular. When I began my graduate studies, there were no studies published in the literature that had investigated the direct effects of livestock grazing on sage-grouse. I completed a meta-analysis of the peer-reviewed literature to determine the current knowledge of the effects of livestock grazing on grouse populations (i.e., chick production and population indices) worldwide. My meta-analysis revealed that only studies conducted in Great Britain reported these data and these studies suggested an overall negative effect of livestock grazing on the black (*Lyrurus tetrix*) and red (*Lagopus lagopus scotica*) grouse. More importantly, the meta-analysis identified an information void regarding the direct effects of livestock grazing on the majority of grouse species including the greater sage-grouse.

In the second paper, I modeled sage-grouse nest survival for two populations of sage-grouse in study areas managed under differing livestock grazing practices. Sage-grouse nest survival estimates did not differ under prescriptive grazing practices when compared to seasonal grazing. The best habitat model indicated that drought and rabbitbrush (*Chrysothamnus viscidiflorus*) were good predictors of nest survival in the studied populations. Additionally, habitat vegetation parameters (i.e., visual obstruction, sagebrush, and perennial bunchgrass height) considered important in concealing nests from predation were also greater under the prescriptive grazing strategy resulting in better visual concealment from predators. Although my results demonstrated the potential for prescriptive grazing strategies implemented in xeric sagebrush rangeland areas benefit sage-grouse, they also highlighted the complexities in designing research to address fundamental questions regarding the role of livestock grazing in species conservation.

In my final paper, I report on the results of an exploratory analysis of the relative contribution of sagebrush (*Artemisia* spp.) treatments implemented specifically to improve forage for livestock and their subsequent grazing by livestock on female sage-grouse survival. Based on previously published research I hypothesized that the greater impact to female survival would come from sagebrush treatments that alter sage-grouse habitat more drastically than livestock grazing, which tends to have relatively diffuse effects on landscapes as a whole. The results of my analysis demonstrated that sagebrush treatments were more likely to affect female survival than livestock grazing.

(125 pages)

PUBLIC ABSTRACT

Effects of Livestock Grazing Management Systems on Greater Sage-Grouse Nest and Female Survival

Seth J. Dettenmaier

The decline in greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) populations across western North America has been primarily attributed to loss and fragmentation of their sagebrush (*Artemisia* spp.) habitats. This habitat loss is largely the result of increased human activities, with grazing by domestic livestock as the most predominant land use across the sagebrush ecosystem in North America. The goal of my research was to increase our understanding of the effects of livestock on sage-grouse populations. I reviewed the peer-reviewed literature for all published studies that reported potential effects of grazing on grouse species worldwide. I found that there was an overall negative effect of domestic livestock grazing on grouse populations in general.

I compared sage-grouse nest success on two study sites managed under differing prescribed livestock grazing practices to determine their relative effects on sage-grouse nest survival. I found that nest survival was slightly higher in areas managed under high-intensity low-frequency rest-rotation practices. The difference was not statistically significant ($P < 0.05$). However, these areas received lower precipitation and were grazed at a higher stocking rate ($\mathrm{AUM} \cdot \mathrm{ha}^{-1}$) without negatively affecting nest survival compared to areas of that were mostly grazed as single pastures from May-September.

Because livestock grazing in the sagebrush ecosystem has been historically facilitated with sagebrush reduction treatments to increase forage for livestock, I compared the relative effects of these treatments with the more direct effect from livestock grazing. Sagebrush treatments were found to have a greater effect on female sage-grouse survival than livestock grazing. This understanding can be useful for land managers looking to attenuate the effects of management decisions related to livestock grazing systems in the sagebrush ecosystem.

DEDICATION

To Nick and Luke, each equally my pride and joy. You are the motivation to finish what has proven to be many years of dedication and effort.

To my mom, who demonstrated perseverance and patience while completing her doctorate all while raising four kids on her own.

To my loving wife, Megan. Without your endless support, years of patience, and love this journey would have never been possible.

ACKNOWLEDGMENTS

Firstly, I would like to express my sincere gratitude to my major advisor Dr. Terry Messmer for the continuous support of my graduate research, for his patience, and motivation. I would also like to thank the members of my committee (Dr. Mark Brunson, Dr. David Koons, Dr. Eric Thacker, and Dr. Kari Veblen) for their patience while I faced numerous obstacles and for challenging me.

My success as a doctoral student was only possible through the effort of numerous field technicians who collected the data required for my research. I would like to thank Nicole Benson, Todd Black, Molly Brown, Caylen Cummins, Dan Fotheringham, Seth Hulett, Phil Krening, Leah Mabee, Brittany McAlpin, Mary Meyerpeter, Sarah Morrow, Rebecca Quist, Megan Rabinowich, Will Reynolds, Andrew Todachinnie, and Andrew Wiley for the long hours, freezing nights, sweltering days, endless vegetation surveys, all while enduring the relentless beep of the receiver day after day.

I also wish to acknowledge all those who helped fund what has proven to be an expensive endeavor. My research was generously funded by numerous groups and agencies including the Natural Resources Conservation Service, Sage Grouse Initiative; Pheasants Forever LLC; Utah State University Extension; the Quinney Professorship for Wildlife Conflict Management; Jack H. Berryman Institute; Rich County Commissioners and Utah State University Ecology Center. The U.S. Bureau of Land Management provided housing for technicians working out of Randolph, Utah. Deseret Land and Livestock provided additional housing and technician support as well as access to their

wildlife biologist and an amazing landscape for wildlife studies. The Utah Department of Wildlife Resources provided logistical support and help with data collection. I’m also deeply grateful for the additional financial help I received from the Stokes-Leopold Scholarship, Elizabeth Bullock Haderlie Scholarship, and the Ecology center.

Seth J. Dettenmaier

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CHAPTER 1

INTRODUCTION AND BACKGROUND

1 INTRODUCTION

One-fifth of the world’s vertebrates have been classified as Threatened on the International Union for Conservation of Nature (IUCN) Red List with approximately 52 species moving one category closer to extinction every year (“The IUCN Red List of Species. Version 2015-04,” 2015). In 2010 most indicators of the state of biodiversity (i.e., population trends, extinction risk, habitat extent and quality, community composition) declined, whereas the indicators of pressures on biodiversity increased (Butchart et al., 2010). Increased anthropogenic land use is implicated as a major factor in decreased biodiversity (Baan, Alkemade, & Koellner, 2012; Jetz, Wilcove, & Dobson, 2007; Sala et al., 2000; Sisk, Launer, Switky, & Ehrlich, 1994).

Globally, livestock grazing is the predominant anthropogenic land use (Alkemade, Reid, van den Berg, de Leeuw, & Jeuken, 2013) and occurs on approximately 60 percent of the world's agricultural lands. Since the 1960s, global livestock production has more than doubled (Speedy, 2003) with the demand for livestock products projected to increase 70 percent by 2050 (Alexandratos & Bruinsma, 2012; Thornton, 2010).

Over 70% of the forage consumed by livestock worldwide is provided by rangelands (i.e., grasslands, shrublands, woodlands, and tundra) (Lund, 2007). Rangelands are also important in supporting a diversity of wildlife species (Krausman et al., 2009). Thus, the management of rangelands can have important consequences for wildlife diversity worldwide (Alkemade et al., 2013; Bock, Saab, Rich, & Dobkin, 1993; Jankowski et al., 2014; Kantrud & Kologiski, 1982; Krausman et al., 2009; Owens & Myres, 1973). Ground nesting birds, such as grouse species (Tetraonidae), are of particular concern as their habitats are often associated with livestock grazing throughout the northern hemisphere. Livestock grazing has been indirectly associated with declines of habitat and grouse populations in rangeland environments (Baines, 1996; C. S. Boyd, Beck, & Tanaka, 2014; Calladine, Baines, & Warren, 2002; Jenkins & Watson, 2001; Warren & Baines, 2004).

Of the 20 species of *Tetraonidae*, 18 populations are declining while thirteen have been red-listed by the IUCN (Storch, 2007, 2015). The primary threats to these populations include habitat loss and degradation (Storch, 2007, 2015) with intense livestock grazing implicated as a conservation threat for 6 of the 7 grouse species that occupy rangeland habitats ("The IUCN Red List of Species. Version 2015-04," 2015).

In North America several rangeland grouse species are considered the most imperiled and at the greatest risk to improper livestock grazing practices (Silvy & Hagen, 2004). The Gunnison sage-grouse (*Centrocercus minimus*) was listed as a threatened species by the U.S. Fish and Wildlife Service (USFWS) under the Endangered Species Act (ESA) and Endangered by the IUCN because of low population sizes, restricted range, and ongoing population decline (USFWS 2014, The IUCN Red List of Species. Version 2015-04 2015). Similarly, the greater sage-grouse (*C. urophasianus*; hereafter, sage-grouse) which is listed by the IUCN as near threatened (Storch, 2015), was also considered by the USFWS for ESA protection (USFWS 2015). Despite being the predominant land use across the sage-grouse range and its ability to alter the composition and structure of sage-grouse habitat, the direct effects of livestock grazing on these populations remains poorly understood (Beck & Mitchell, 2000; C. S. Boyd et al., 2014; Knick et al., 2011; Monroe et al., 2017). Given the projected increase in livestock production (Thornton, 2010), better information of the effects of livestock grazing will be needed to mitigate potential impacts on rangeland ecosystems and sage-grouse populations.

To address this knowledge gap, I completed a systematic data-driven literature review assess the current knowledge of the effects of livestock grazing on grouse populations worldwide. While the meta-analysis revealed an overall negative effect of livestock grazing these populations, it also identified an information void with respect to the effects of livestock grazing on grouse species. Future studies must include the documentation of 1) livestock type, 2) timing and frequency of grazing, 3) duration, and 4) stocking rate (AUM $\cdot$ ha^{-1}). Much of this information was lacking from the studies I reviewed but is important when comparing between livestock grazing management practices and their impacts on grouse populations.

1.1 Grazing and Greater Sage-grouse

The greater sage-grouse was designated as candidate species for listing for protection by the U.S. Fish and Wildlife Service (USFWS) under the Endangered Species Act (U.S. Fish and Wildlife Service 2010). The USFWS identified habitat loss and fragmentation as the major threat to the species. Grazing by domestic livestock was not identified as a range wide species conservation threat.

In Utah, the Division of Wildlife Resources (UDWR) estimated that sage-grouse were historically found in all 29 Utah counties (UDWR 2009). Today, sage-grouse are found in 26 of Utah's counties. A UDWR analysis indicated that 11,514 mi² (29,821 km²) (13.6%) of Utah currently provides habitat for sage-grouse, and they are thought to only occupy 41% of their historic habitat (Beck, Mitchell, & Maxfield, 2003).

The complex mosaic of land ownership, competing resource uses, and administration of the habitat complicate sage-grouse management and conservation in Utah. A population of sage-grouse can utilize land administered by several federal and state agencies as well as private land. Current occupied sage-grouse habitat in Utah occurs primarily on Bureau of Land Management (BLM) administered and private lands. Private lands provide the greatest amount of sage-grouse habitat (40.5%), with BLM administered lands next (34.4%). United States Forest Service (USFS) administers 9.7% of the current sage-grouse habitat and Utah State owned land accounts for 9.5% [School and Institutional Trust Land Administration (SITLA) (8.0%), Division of Parks and Recreation (<1%), and UDWR (1.5%)]. Ute Tribal land covers 5.2% and National Park Service and military reservations cover less than one percent each (UDWR 2009).

Sage-grouse habitat quality and quantity has declined throughout Utah and coincides with declines in sage-grouse numbers. The reasons for habitat loss vary by population but include wildfire, urban expansion, development, agricultural conversion, herbicide treatments, rangeland seeding, noxious weeds/invasive species expansion, conifer encroachment, drought, and improper livestock grazing management (Utah Division of Wildlife Resources, 2009). The primary land use in Utah is grazing by domestic livestock.

Reported effects of grazing on sage-grouse and sagebrush habitats range vary from positive to negative (Beck and Mitchell 2000). Most researchers describe grazing as being somewhat neutral, however, few studies have been undertaken to specifically address the long-term impacts on greater sage-grouse and grouse habitats of contrasting grazing practices. Changes to vegetation communities can happen slowly on rangelands. The prohibitive costs of meaningfully monitoring vegetation and grouse population changes adequate periods of time have precluded meaningful documentation of grazing effects on greater sage-grouse (Beck & Mitchell, 2000; Connelly, Knick, Schroeder, & Stiver, 2004).

The Utah Sage-grouse Strategic Management Plan (UDWR 2009) has identified the following research priorities regarding livestock and sage-grouse:

a) How does domestic grazing directly affect sage-grouse populations?

b) How does domestic grazing directly or indirectly affect sage-grouse habitats (all seasonal)?

The Natural Resources Conservation Services (NRCS) Sage-Grouse Initiative (SGI) seeks to engage private landowners and other partners in cooperative efforts to threats to sage-grouse populations. The SGI provides targeted technical and financial assistance through Farm Bill programs to assist cooperators with implementing sage-grouse conservation.

The SGI is focused on prescribed grazing of private and public lands as a means to 1) improve sage-grouse habitat, 2) improve sage-grouse vital rates and population size, 3) prolong or enhance the desired effects of other land treatments and 4) broader land management benefits to include other wildlife and livestock producers. By assisting producers to improve range condition in core sage-grouse population areas, SGI seeks to improve sage-grouse habitat quality while ensuring the sustainability of working rangelands. An important component of the SGI is scientifically demonstrating the effectiveness of the conservation efforts by measuring sage-grouse response to prescribed grazing practices.

1.2 Study Purpose

Implementing the guidance provided in my meta-analysis, I compared sage-grouse nest survival estimates obtained on paired sagebrush-steppe landscapes located in northeastern Utah, USA. The purpose of this assessment is to scientifically document greater sage-grouse individual and population responses to vegetation changes within these landscapes.

The study sites consisted of a 569 km^2 rangeland managed by the BLM and USFS as mostly single pastures grazed May-September (Dahlgren et al., 2015). The second site was an 870 km^2 privately-owned ranch (Deseret Land and Livestock; DLL) managed under a prescriptive grazing strategy that emphasized growing-season rest (Dahlgren et al., 2015).

Chapter 2 is a review and meta-analysis of studies that were published on the effects of livestock grazing on grouse species worldwide. This chapter is in the style of Ecology and Evolution and was published in that journal in 2017. I found few studies that were appropriate for use in a meta-analysis. However, in the studies that were available I found an overall negative effect of grazing on sage-grouse. Further, of these studies, only two species of grouse were represented and many aspects of the grazing system were lacking. These issues highlight the current lack of understanding and the need for research designed to elucidate the effects of livestock grazing on these populations.

Chapter 3 was written in the style of Ecology and Evolution and presents the results of the effects of livestock grazing practices on sage-grouse nest survival. I compared nest survival on two study sites managed under differing livestock grazing practices. Although there were no differences in nest survival based on grazing management, areas that employed sagebrush reductions and emphasized grazing rest had greater vegetation cover associated with high quality nesting habitat. These results can help managers when developing livestock grazing plans in sage-grouse nesting habitat.

Chapter 4 presents the results of a comparison of the relative effects of sagebrush management used to support grazing and livestock grazing practices on sage-grouse female survival. This chapter highlights the need to account for sagebrush removal in the effort to increase livestock forage. These results will help inform managers of the need to also account for sagebrush removal efforts when thinking about the impacts that livestock grazing practices may have on local sage-grouse populations.

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CHAPTER 2

EFFECTS OF LIVESTOCK GRAZING ON RANGELAND BIODIVERSITY: A META-ANALYSIS OF GROUSE POPULATIONS

ABSTRACT

Livestock grazing affects over 60% of the world’s agricultural lands and can influence rangeland ecosystem services and the quantity and quality of wildlife habitat, resulting in changes in biodiversity. Concomitantly, livestock grazing has the potential to be detrimental to some wildlife species while benefiting other rangeland organisms. Many imperiled grouse species require rangeland landscapes that exhibit diverse vegetation structure and composition to complete their life cycle. However, because of declining populations and reduced distributions, grouse are increasingly becoming a worldwide conservation concern. Grouse, as a suite of upland gamebirds, are often considered an umbrella species for other wildlife and thus used as indicators of rangeland health. With a projected increase in demand for livestock products, better information will be required to mitigate the anthropogenic effects of livestock grazing on rangeland biodiversity. To address this need we completed a data-driven and systematic review of the peer-reviewed literature to determine the current knowledge of the effects of livestock grazing on grouse populations (i.e., chick production and population indices) worldwide. Our meta-analysis revealed an overall negative effect of livestock grazing on grouse populations. Perhaps more importantly, we identified an information void regarding the effects of livestock grazing on the majority of grouse species. Additionally, the reported indirect effects of livestock grazing on grouse species were inconclusive and more

reflective of differences in the experimental design of the available studies. Future studies designed to evaluate the direct and indirect effects of livestock grazing on wildlife should document 1) livestock type, 2) timing and frequency of grazing, 3) duration, and 4) stocking rate. Much of this information was lacking in the available published studies we reviewed but is essential when making comparisons between different livestock grazing management practices and their potential impacts on rangeland biodiversity.

1 INTRODUCTION

A recent assessment of vertebrates found one-fifth classified as Threatened on the International Union for Conservation of Nature (IUCN) Red List ("The IUCN Red List of Species. Version 2015-04," 2015). On average, 52 species move one category closer to extinction each year. In 2010 most indicators of the state of biodiversity (i.e., population trends, extinction risk, habitat extent and quality, community composition) declined, whereas the indicators of pressures on biodiversity increased (Butchart et al., 2010). Increased anthropogenic land use is implicated as a major factor in decreased biodiversity (Baan et al., 2012; Jetz et al., 2007; Sala et al., 2000; Sisk et al., 1994).

Globally, livestock grazing is the predominant anthropogenic land use (Alkemade et al., 2013). Livestock grazing occurs on approximately 60 percent of the world's agricultural land and supports approximately 1.5 billion cattle and buffalo (Bovinae) and 1.9 billion sheep (*Ovis* spp.) and goats (*Capra* spp. and related species) (Alexandratos & Bruinsma, 2012). Global production of livestock for human consumption has more than doubled since the 1960s (Speedy, 2003). Concomitantly, the demand for livestock products is projected to increase 70 percent by 2050 in response to human population growth, increased discretionary income, and urbanization (Alexandratos & Bruinsma, 2012; Thornton, 2010).

Rangelands (i.e., grasslands, shrublands, woodlands, and tundra) are estimated to provide over 70% of the forage consumed by livestock worldwide (Lund, 2007). Rangelands also provide habitat for a diversity of wildlife species (Krausman et al., 2009). Thus, how these areas are managed can have important consequences for wildlife worldwide (Alkemade et al., 2013; Bock et al., 1993; Jankowski et al., 2014; Kantrud & Kologiski, 1982; Krausman et al., 2009; Owens & Myres, 1973). Of particular concern, are ground nesting birds, such as grouse species (Tetraonidae), whose habitats are often associated with livestock grazing throughout the northern hemisphere. Livestock grazing has been implicated as both a source of mortality and an indirect driver of declines in habitat and populations in rangeland environments (Baines, 1996; C. S. Boyd et al., 2014; Calladine et al., 2002; Jenkins & Watson, 2001; Warren & Baines, 2004). Additionally, many of these grouse species depend on disturbances such as grazing or grazing in combination with fire during some or all of their life history, underscoring the importance of informed grazing practices (Hovick, Elmore, Fuhlendorf, & Dahlgren, 2015; McNew, Winder, Pitman, & Sandercock, 2015).

There are 20 species in the *Tetraonidae* family worldwide (Storch, 2007, 2015), thirteen of which have been red-listed by the IUCN (Table 2-1). In addition, populations for 18 of these species are declining (Storch, 2007, 2015). Habitat loss and degradation have been identified as the primary threat to grouse (Storch, 2007, 2015) and intense livestock grazing has been implicated as a conservation threat for 6 of the 7 grouse species that occupy rangeland habitats ("The IUCN Red List of Species. Version 2015-04," 2015).

As an example, the prairie grouse species that inhabit rangelands of North America are considered some of the most imperiled and at the greatest risk to improper livestock grazing practices (Silvy & Hagen, 2004). The Gunnison sage-grouse (*Centrocercus minimus*) in North America (NA) was listed as a threatened species by the U.S. Fish and Wildlife Service (USFWS) under the Endangered Species Act (ESA) and Endangered by the IUCN because of low population sizes, restricted range, and ongoing population decline ("The IUCN Red List of Species. Version 2015-04," 2015; U.S. Fish and Wildlife Service, 2014). Similarly, greater and lesser prairie-chickens (*Tympanuchus cupido* and *T. pallidicinctus,* respectively) are listed as Vulnerable. The sharp-tailed grouse (*T. phasianellus*), once considered to have the most extensive range in NA has declined markedly (Connelly, Gratson, & Reese, 1998; Johnsgard, 1983). Moreover, the greater sage-grouse (*C. urophasianus*; here-after sage-grouse) which is listed by the IUCN as near threatened (Storch, 2015), was also considered by the USFWS for ESA protection (U.S. Fish and Wildlife Service, 2015). Grazing by livestock is the predominant land use within the current sage-grouse range and a paucity of information exists on the direct effects of grazing on these populations (Beck & Mitchell, 2000; Knick et al., 2011).

Given the projected global increase in demand for livestock production (Thornton, 2010), better information will be needed to mitigate the potential for increased impacts on rangeland ecosystems and associated wildlife species. However, our collective understanding of how grazing influences grouse species, which are often considered indicators for their ecosystems, is poorly understood despite the volumes of research that has been published about the ecology of these species (Haukos & Boal, 2016; Knick & Connelly, 2011) . Therefore, a data-driven and systematic review of the influence of grazing on grouse populations across the northern hemisphere is warranted to inform future conservation actions for these highly imperiled species.

We completed a data-driven and systematic review of the peer-reviewed literature to determine the current knowledge of the effect of livestock grazing on grouse populations (i.e., population indices represented by adult counts and chick production) worldwide. We used meta-analytical methods to calculate unbiased estimates of *Hedges' g* (Hedges, 1981) as a measure of the direct effect of livestock grazing on grouse populations in addition to a categorical model meta-analytic technique to quantify overall effects. We highlight knowledge gaps and research needs related to the effects of livestock grazing, the broadest anthropogenic land use on rangelands, on grouse populations.

2 MATERIALS AND METHODS

We conducted a literature search in May 2017 using the ISI Web of Science and Scopus databases. Searches were limited to peer-reviewed journals or edited book series (e.g., Studies in Avian Biology). We developed keyword combinations to identify papers that included livestock, grazing, and grouse (Table 2-2). We used all terms for both title and topic searches to ensure returning the greatest number of papers possible. Common names of grouse species were included to capture studies that examined other grouse species absent from searches using the generic term “grouse”. As part of our search strategy, we included literature cited from the papers used in our analysis. No temporal or language restrictions were applied to our searches.

2.1 Study Inclusion Criteria

To refine our search, we removed papers that lacked our specific search terms within the title, abstract, or keywords. We then reviewed the remaining papers to determine if they quantified and reported the effects of livestock grazing on grouse populations. Finally, we only retained papers that compared grouse population metrics within ≥2 grazing intensities (e.g., heavy grazing, reduced grazing, or no grazing) for the meta-analysis. Of the initial 5,637 topic search results, only 4 studies met our inclusion criteria (Figure 2-1).

2.2 Data Extraction

Because of the limited number of published papers that met our search criteria, we maximized the number of metrics obtained from each study. For example, Baines (1996) and Calladine et al. (2002) each reported grazing effects on both adult counts (a population indices comprised of the total males counted on leks) and chick production (chicks per female). In each study, direct effects were independently determined and analyzed separately in the meta-analysis. Finally, one study (Jenkins & Watson, 2001) involved two species of grouse and were separated in the analysis.

2.3 Meta-Analysis

We quantified the direct effects of livestock grazing on grouse populations using calculated effect sizes with analyses similar to Hovick et al. (2014). We standardized the reported results from each study by estimating effect sizes using the means, standard deviation, and sample sizes. To control for small sample size bias we used *Hedges' g* effect sizes (Hedges, 1981) calculated using ‘compute.es’ package (Del Re, 2013) in the R 3.2.3 programming environment (R Development Core Team, 2015). Because field studies often lack true treatment and control levels (Hovick et al. 2014) and quantifiable grazing intensities, we categorized groups of grouse from each study into either higher intensity grazing sites or reduced or absent grazing sites. All meta-analytic models were calculated using MetaWin 2.1.5 (Rosenberg, Adams, & Gurevitch, 2000). Generally, effect sizes are interpreted as $<|0.2|$ low, $|0.5|$ moderate, and $>|0.8|$ high (Cohen, 1988).

Because our meta-analysis relied on small sample sizes, we ran bootstrapping replications with replacement to improve approximations of the confidence intervals (Efron & Tibshirani, 1986). We analyzed these data using a categorical random-effects model in Meta-Win 2.1.5. We selected a categorical model based on the separation of our data into two distinct population measurement groups, adult counts (population indices) and chick production. Because studies differed spatially, temporally, by grazing system, and level of grazing pressure, there may be different effect sizes underlying each (Borenstein, Hedges, Higgins, & Rothstein, 2010). To address variation in the true effect size of livestock grazing based on the unique environmental and temporal factors of each study we selected a random-effects model. Weighted averages were used in the models to estimate the cumulative effect size by calculating the reciprocal of each studies' sampling variance, $w_i = 1/v_i$. Because individual studies within a meta-analysis often vary in sample size, weighting becomes necessary (Rosenberg et al., 2000). We calculated the percentage of total variation across studies that is due to heterogeneity using the I^2 statistic (Borenstein, Hedges, Higgins, & Rothstein, 2009).

We tested for publication bias, or the ‘file drawer problem’ (i.e., when only studies reporting significant results are published) using the approaches developed by Egger et al. (1997). Egger’s test uses linear regression in which the standardized effect estimate z_i is regressed against its precision $prec_i$ (Rothstein, Sutton, & Borenstein, 2006):

$$E[z_i] = \beta_0 + \beta_1 prec_i$$

3 RESULTS

We analyzed 6 measurements of grazing’s effect on adult grouse numbers and 3 on chick production. Our results demonstrated that livestock grazing had a negative impact on adult grouse numbers (random effects $\bar{E}$= -1.28, d.f. = 5, 95% CI: -2.02, -0.85). Additionally, we estimated a negative effect of livestock grazing on grouse chick production (random effects $\bar{E}$= -0.84, d.f. = 2, 95% CI: -1.34, -0.59). Based on these studies, there is evidence supporting an overall moderate to high negative effect of livestock grazing on adult grouse numbers and chick production (random effects $\bar{\bar{E}}$= -1.12, d.f. = 8, 95% CI: -1.63, -0.59) (Figure 2-2).

We tested total proportion of variance owing to heterogeneity (I^2=12.5%, d.f. = 8) for both adult counts and chick production. Our results indicate that the variance among effect sizes were within expected sampling error (Cooper, 1998) and that grazing level is a valid explanatory variable for the model. However, results of Egger’s test (z = -3.62, p = 0.0003) showed that publication bias was an issue within our meta-analysis (Figure 2-3).

4 DISCUSSION

Rangelands provide habitat for a diversity of wildlife and grouse species (Krausman et al., 2009). Livestock grazing is not only the predominant use of rangelands (Alkemade et al., 2013) but has been implicated in declines of grouse populations (Baines, 1996; C. S. Boyd et al., 2014; Calladine et al., 2002; Jenkins & Watson, 2001; Warren & Baines, 2004). Our investigation of the influence of grazing on grouse found an overall negative effect on both adult counts and chick production for two populations of European grouse species that are in decline (Baines, 1996; Calladine et al., 2002; Jenkins & Watson, 2001; Jouglet, Ellison, & Léonard, 1999; Storch, 2015). The largest reported individual effect was on adult numbers that resulted from the introduction of heavy sheep grazing into a previously ungrazed area which negatively altered the native vegetation composition (Jenkins & Watson, 2001). This review of the effects of grazing on wildlife suggests that grazing has a general negative effect on the studied grouse populations, and presents some concern for grazing in areas where grouse conservation is a main objective. However, the number of studies that reported a measurable effect of grazing on adult counts and production was limited and many considerations of grazing management warrant discussion.

These studies lend support to concerns that livestock grazing management focused on maximizing meat production through high stocking rates can negatively impact grouse populations (Beck & Mitchell, 2000; C. Boyd et al., 2011; Silvy & Hagen, 2004) and other wildlife species (Krausman et al., 2009). Our analysis was limited to studies of black (*Lyrurus tetrix*) and red (*Lagopus lagopus scotica*) grouse (Figure 2-4) and lacked studies for NA prairie grouse, Arctic species of ptarmigan and the forest species of Eurasia. Also, the total number of papers meeting our criterion were limited. There was much specific information on grouse ecology that was lacking from our data set. This paucity of information highlights a need for more research that directly measures the effects of livestock grazing on grouse. Also, despite efforts to limit issues of publication bias within our meta-analysis we couldn’t overcome the scarcity of appropriate studies in the published literature.

There was consensus in the published literature that overgrazing of rangelands by livestock has predominately negative effects on wildlife and their habitats (C. Boyd et al., 2011; Krausman et al., 2009; Silvy & Hagen, 2004). However, our meta-analysis highlighted the general lack of knowledge of the direct effects of livestock grazing needed to develop best management practices (BMPs) for grouse in general and individual species specifically. With so few published studies, it is inappropriate to make broad general statements regarding the impact of livestock grazing on grouse and the BMPs for the conservation of rangelands and grouse populations without further research (C. Boyd et al., 2011).

The studies we analyzed were missing specific information regarding grazing management practices. They also lacked consistency in the reporting of quantifiable stocking rates for both the treatment and control groups (Baines, 1996; Jenkins & Watson, 2001). Although Calladine et al. (2002) and Jouglet et al. (1999) provided stocking rates for both the treatment and reference sites, this information was not included in their analysis. Additionally, stocking rates were not comparable across biomes. Understanding the effects of stocking rates in similar vegetation communities can help inform land-use management decisions regarding the effect of grazing management on wildlife (Dahlgren et al., 2015; Krausman et al., 2009).

Livestock grazing systems are a complex combination of factors that include animal type, stocking rate, animal distribution, timing, duration, frequency, and many more (D. D. Briske et al., 2008; Heitschmidt & Walker, 1996; Teague et al., 2008; Veblen & Young, 2010; Veblen, Nehring, McGlone, & Ritchie, 2015). Livestock grazing may not be invariably “good” or “bad” for wildlife – rather, there can be positive, negative, or benign effects dependent on aforementioned factors in combination with soil conditions, precipitation, plant community, and the organism of concern (Krausman et al., 2009). Livestock grazing can have direct negative effects on grouse including destruction of habitat, trampling eggs, nest abandonment, and reducing food availability (Beck & Mitchell, 2000). While direct effects are often infrequent (Hovick et al., 2012), indirect effects can be more common and include conversion of habitat to forage, introduction of invasive plant species (Beck & Mitchell, 2000), and subsidizing increased predator densities (Coates et al., 2016).

The role of human dimensions in grazing systems can indirectly contribute to the ecological outcome of grazing systems (David D. Briske et al., 2011). The manner in which livestock grazing is managed affects the structure of rangeland ecosystems, which in turn influences the flows of other ecosystem goods and services from rangelands and ultimately affects wildlife populations (Dahlgren et al., 2015; Heitschmidt & Walker, 1996; Veblen, Nehring, McGlone, & Ritchie, 2015). While grazing has been a part of many researched systems its effects on wildlife populations are rarely investigated in an explicit and rigorous scientific manner. The effects of livestock grazing are generally diffuse across large landscapes and research of these effects will need to occur on scales that encompass those vast landscapes (Knick et al., 2011).

Future research investigating the effects of livestock grazing on wildlife populations should account for the complex ecological landscape of rangelands. For future research, we provide the following recommendations. Studies should document the 1) livestock type, 2) timing and frequency of grazing, 3) duration, and 4) stocking rate. For example, livestock type has been demonstrated to differentially affect plant composition (Rook et al., 2004) while timing and duration affect vegetation structure (Fischer et al., 2009; Hockett, 2002). These habitat changes have been demonstrated to ultimately affect wildlife biodiversity on rangelands (Alkemade et al., 2013; Krausman et al., 2009). The implementation of standardized measures of vegetation composition cover and height across all studies would help in quantifying the effects on wildlife habitats. Additionally, researchers may need to account and control for other drivers of population and habitat change such as climate and predators (Fuhlendorf, Briske, & Smeins, 2001; Guttery et al., 2013).

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TABLES AND FIGURES

TABLE 2-1 Twenty recognized grouse species, their population estimate, and population status.

Common Name	Scientific Name	Pop. estimate[a]	Status[b]
Black Grouse*	Lyrurus tetrix	27 500 000	Least concern
Black-billed Capercaillie	Tetrao urogalloides	<550 000	Least concern
Western Capercaillie	Tetrao urogallus	7 500 000	Least concern
Caucasian Black Grouse	Lyrurus mlokosiewiczi	<46 600	Near threatened
Chinese Grouse	Bonasa sewerzowi	Not quantified	Near threatened
Hazel Grouse	Bonasa bonasia	27 500 000	Least concern
Ruffed Grouse	Bonasa umbellus	Not quantified	Least concern
Dusky Grouse	Dendragapus obscurus	3 000 000	Least concern
Sooty Grouse	Dendragapus fuliginosus	Not quantified	Least concern
Greater Prairie-Chicken*	Tympanuchus cupido	<700 000	Vulnerable
Lesser Prairie-Chicken*	Tympanuchus pallidicinctus	30 000	Vulnerable
Sharp-tailed Grouse*	Tympanuchus phasianellus	Not quantified	Least concern
Greater Sage-Grouse*	Centrocercus urophasianus	<150 000	Near threatened
Gunnison Sage-Grouse*	Centrocercus minimus	<2 500	Endangered
White-tailed Ptarmigan	Lagopus leucura	Not quantified	Least concern
Willow Ptarmigan*	Lagopus lagopus	>40 000 000	Least concern
Rock Ptarmigan	Lagopus muta	>8 000 000	Least concern
Siberian Grouse	Falcipennis falcipennis	Not quantified	Near threatened
Spruce Grouse	Falcipennis canadensis	Not quantified	Least concern
Franklin's Grouse	Falcipennis franklinii	Not quantified	Least concern

[a] We report the mid-point of population estimates.

[b] All status, trend, and population estimates was gathered from BirdLife International 2016.

* Species that inhabit rangelands.

TABLE 2-2 Search terms and resulting number of publications using the ISI Web of Science and Scopus databases to locate peer-reviewed literature assessing the effects of livestock grazing on grouse populations.

	Search Results (Number of publications)	
Search term(s)	ISI Web of Science	Scopus
grouse*	3,083	2,554
(grouse* and livestock*)	64	49
(grouse* and grazing*)	107	98
(grouse* and habitat* and grazing*)	76	65
(prairie-chicken* and livestock*)	8	9
(prairie-chicken* and grazing*)	23	21
(prairie-chicken* and habitat* and grazing*)	20	17
(capercaillie* and livestock*)	5	3
(capercaillie* and grazing*)	8	3
(capercaillie* and habitat* and grazing*)	6	1
(ptarmigan* and livestock*)	3	3
(ptarmigan* and grazing*)	6	8
(ptarmigan* and habitat* and grazing*)	4	5

In cases of irregular plurals, "*" allows search engines to retrieve all forms of the root word.

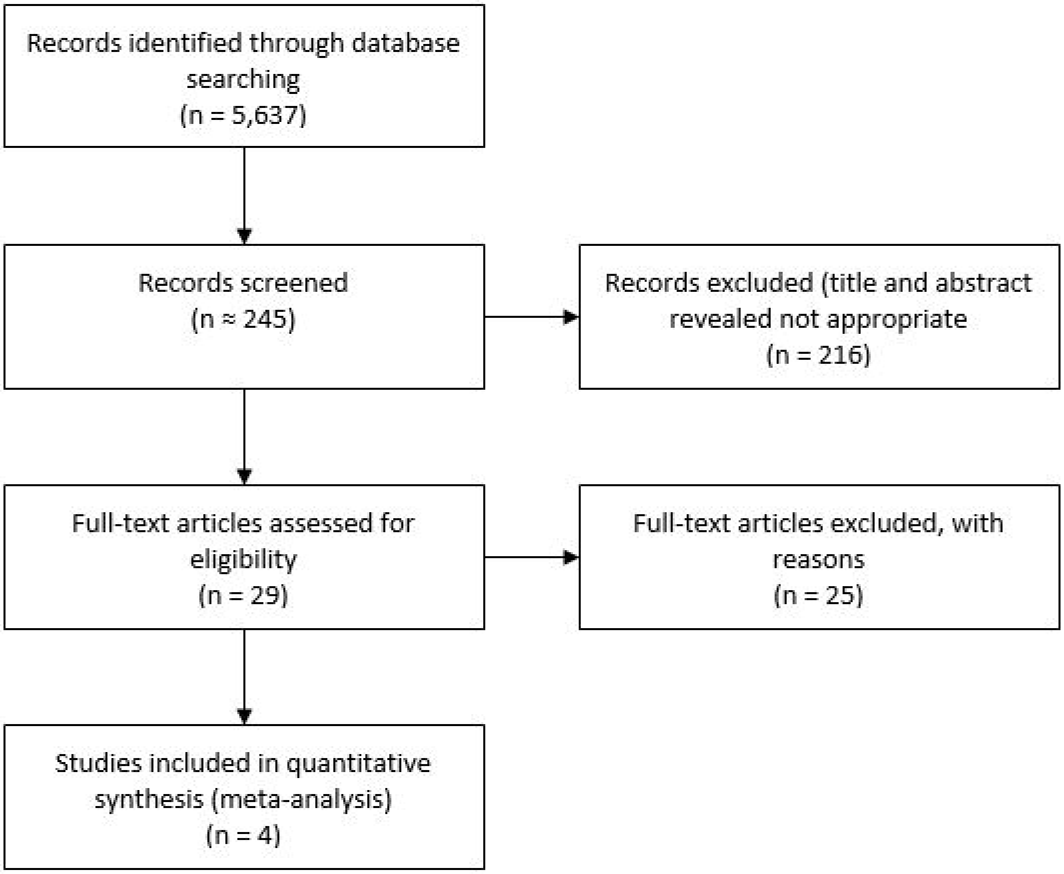

FIGURE 2-1 Preferred Reporting Items for Systematic reviews and Meta-analyses (PRISMA) diagram illustrating study selection process.

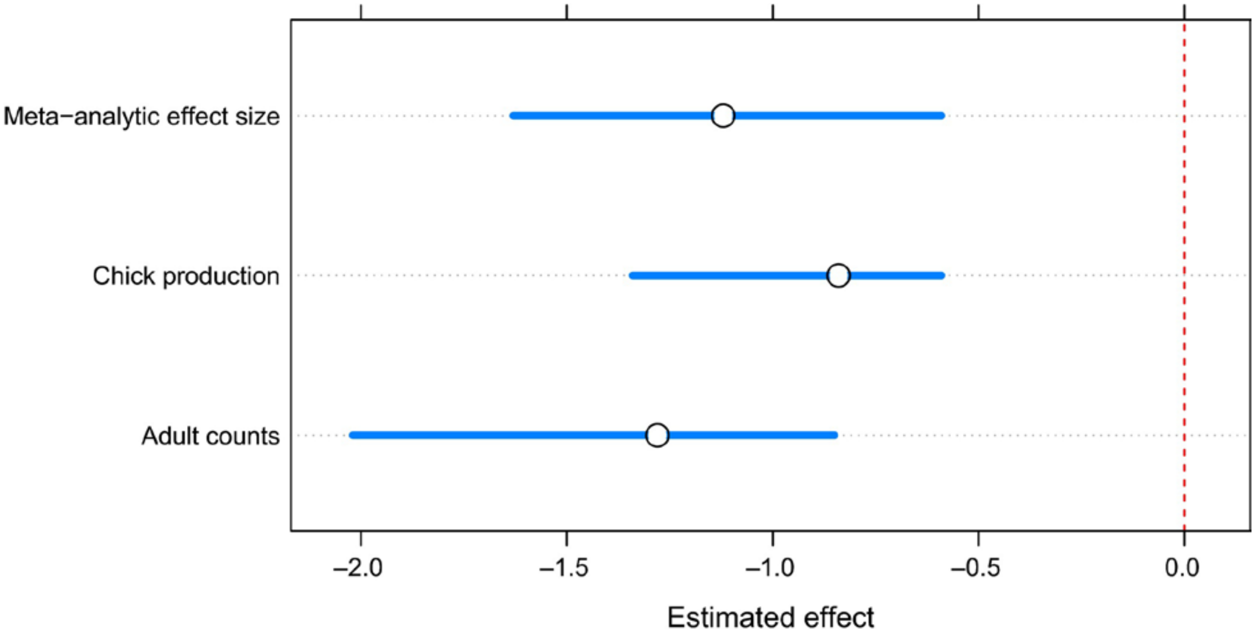

FIGURE 2-2 Livestock grazing had a negative effect on *Lagopus lagopus scotic*a and *Lyrurus tetrix* adult counts and chick production. Estimated effect sizes (circle) and 95% confidence interval (line) of mixed-effects model results for adult counts, chick production, and pooled mean effect size.

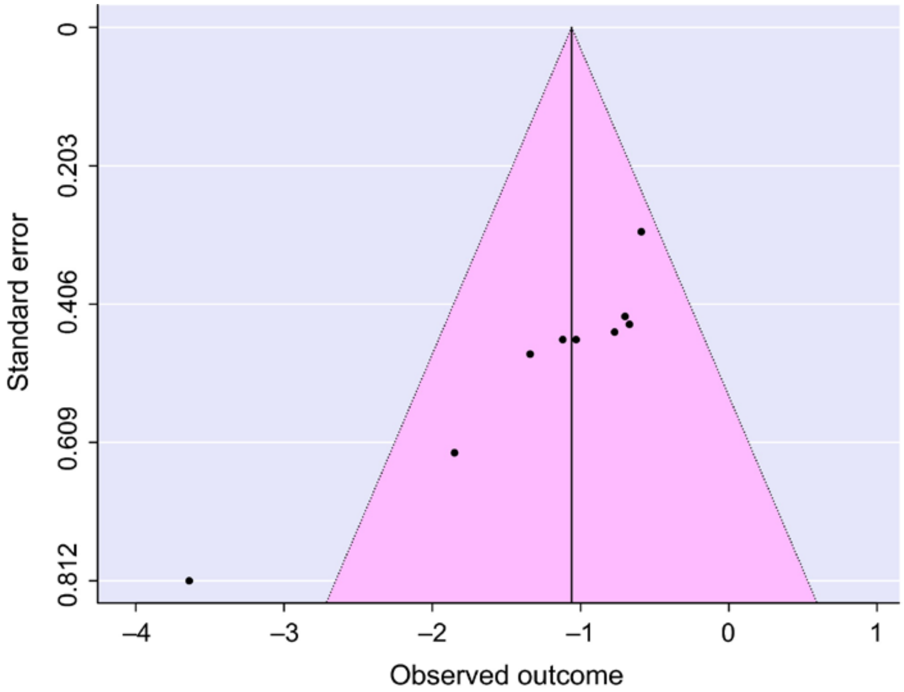

FIGURE 2-3 Studies meeting selection criteria demonstrate potential publication bias. Funnel plot of reported effect sizes against precision illustrates the asymmetry and potential bias of study results.

FIGURE 2-4 Often considered a subspecies of the willow grouse (Lagopus l. lagopus), red grouse (Lagopus lagopus scotica) are endemic to the heather moorlands of Great Britain.

CHAPTER 3

GREATER SAGE-GROUSE NEST SURVIVAL UNDER PRESCRIBED GRAZING MANAGEMENT PRACTICES IN SAGEBRUSH RANGELANDS

ABSTRACT

Declines in greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) populations across their range in North America have been attributed to the loss and fragmentation of sagebrush (*Artemisia* spp.) landscapes resulting from anthropogenic disturbances. Grazing by domestic livestock is the most widespread anthropogenic land-use of sagebrush landscapes. Although improper livestock grazing has been identified as having negative impacts on sagebrush landscapes and sage-grouse populations at local scales, it was not considered a range-wide species conservation threat by the U.S. Fish and Wildlife Service in their 2015 decision to not provide the species protection under the U.S. Endangered Species Act. While research reporting the potential effects of livestock grazing on sage-grouse habitat has been widely published, information regarding the direct effects of livestock grazing on sage-grouse population vital rates is limited. To address this need, we compared sage-grouse nest survival estimates obtained from 2012-2015 for two paired sagebrush-steppe landscapes located in northeastern Utah, USA that were grazed by domestic livestock. The study sites consisted of a 569 km^2 rangeland managed by the Bureau of Land Management and U.S. Forest Service consisting as mostly single pastures grazed May-September in north Rich County (North Rich) and an 870 km^2 privately-owned ranch (Deseret Land and Livestock; DLL) managed under a prescriptive grazing management framework that incorporated annual periods of rest

from grazing. Our models failed to support at a 95% level of confidence (i.e., $\alpha = 0.05$), the hypothesis that a prescriptive grazing strategy would increase sage-grouse nest survival in our study populations. However, habitat vegetation parameters (i.e., visual obstruction, sagebrush, perennial bunchgrass, and forb height) considered important in concealing nests from predation were enhanced under DLL prescriptive grazing strategy. Although our results demonstrated potential benefits to sage-grouse habitat when prescriptive grazing strategies are implemented in sagebrush rangelands, they also highlighted the complexities in designing research to address fundamental questions regarding the role of livestock grazing in species conservation. These complexities included the need for better information regarding the effects of historic land management practices coupled with contemporary livestock grazing practices on vegetation production and utilization.

1 INTRODUCTION

The decline in greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) populations across western North America has been primarily attributed to loss and fragmentation of their sagebrush (*Artemisia* spp.) habitats (Connelly & Braun, 1997; Garton et al., 2011; Knick et al., 2003; M. A. Schroeder et al., 2004). Concomitantly, in 2010, the U.S. Fish and Wildlife Service (USFWS) classified sage-grouse as a candidate species for protection under the Endangered Species Act (USFWS 2010). This decision prompted state and federal agencies, industry, private landowners, and many stakeholders to initiate unprecedented efforts to mitigate the species’ range-wide conservation threats.

Collectively, these efforts resulted in the 2015 decision by USFWS that the species no longer warranted consideration for ESA protection (USFWS 2015).

The loss and fragmentation of the sagebrush habitats on which sage-grouse and other sagebrush-obligate species depend has largely been attributed to increased anthropogenic activities (Connelly et al., 2004; M. A. Schroeder et al., 2004). Grazing by domestic livestock remains the predominant anthropogenic land-use across the sagebrush ecosystem in North America (Brussard, Murphy, & Tracy, 1994; Crawford et al., 2004; Dettenmaier, Messmer, Hovick, & Dahlgren, 2017; Knick & Connelly, 2011; Noss, 1994). However, compared to other anthropogenic activities the impacts of livestock grazing are more diffuse across the landscape (C. S. Boyd et al., 2014; Knick et al., 2011). The USFWS identified improper livestock grazing as potentially a local, but not range-wide, conservation threat for sage-grouse (USFWS 2010, 2015).

Improper grazing by domestic livestock may reduce herbaceous cover (Beck & Mitchell, 2000). Because of the potential for increased risk of nest predation associated with reductions of herbaceous cover required for nest concealment (Connelly, Wakkinen, Apa, & Reese, 1991), improper grazing by domestic livestock was considered to have a negative impact on sage-grouse nest survival (Gregg, Crawford, Drut, & DeLong, 1994; Holloran et al., 2005). However, Smith et al. (2017) reported that the methods used to sample herbaceous cover, particularly grass height, at sage-grouse nest sites were biased and may have contributed to erroneous recommendations regarding the role of grass height to nest fate. Regardless, Schroeder (1997), Schroeder et al. (1997; 1999), Aldridge and Boyce (2007), Taylor et al. (2012) and Dahlgren et al. (2015) identified nest survival as an important driver of sage-grouse population dynamics.

While research reported in peer-reviewed literature demonstrates the potential effects of livestock grazing on sage-grouse habitat (Beck & Mitchell, 2000), few studies have linked livestock grazing at the landscape level to vital rates for ground-nesting grouse species such as the sage-grouse (Dettenmaier et al., 2017). Danvir et al. (2005) and Dahlgren et al. (2015) reported that sage-grouse populations responded positively (i.e., increased numbers of males counted on leks, and number of broods observed) to long-term (> 25 years) rest-rotation grazing practices and associated habitat treatments implemented on a 200,000 ha private ranch located in northeastern Utah. Changes in the male-based lek counts can assess the response of sage-grouse populations to conservation actions such as prescribed grazing management (Dahlgren et al., 2016).

In a study of 743 leks across Wyoming, Monroe et al. (2017) found that sage-grouse populations responses to grazing were dependent on the timing and level of grazing. More recently, Smith et al. (2018) reported that contrary to their stated hypothesis, sage-grouse nest survival did not improve under rotational grazing practices implemented in central Montana, USA. However, they argued that the temporal scale of their study may not have been adequate for the rangeland habitats they studied to respond to the grazing treatment. Additionally, their Montana study site exhibited less sagebrush cover, greater perennial bunchgrass cover, was lower in elevation, and received more precipitation then the Utah study site (Dahlgren et al., 2015; Smith et al., 2018). Thus, the inherent differences in the ecological sites and vegetation productivity limits comparisons between the two studies.

Dettenmaier et al. (2017) stated that research implemented to quantify the effects of livestock grazing on wildlife, particularly sage-grouse vital rates should document; 1) livestock type, 2) timing and frequency of grazing, 3) duration of grazing or rest, and 4) stocking rates. Additionally, researchers must account and control for other abiotic and biotic drivers of population and habitat change such as climate and predators (Fuhlendorf & Engle, 2001; Guttery et al., 2013).

Using these parameters, we compared the relative effects of a mostly single pasture system grazed May-September and a prescriptive grazing strategy that emphasized growing-season rest on sage-grouse nest survival and reported important habitat metrics for two sagebrush-dominated areas grazed by domestic livestock in northeastern Utah. To conduct our analysis, we developed sets of a priori models that incorporated livestock grazing management prescriptions (i.e., livestock type, timing and frequency of grazing, duration of grazing or rest, stocking rates) with micro-habitat vegetation characteristics, temporal, predator indices, and climatic conditions on sage-grouse nest survival. We tested these models using information theory (Anderson, 2008). Based on previously published research (C. S. Boyd et al., 2014), we predicted that sage-grouse nest survival rates and important habitat metrics would be higher under a combination of prescribed rest-rotation grazing management practices compared to seasonal grazing practices.

2 MATERIALS AND METHODS

2.1 Study Area

We conducted this research on two study areas that incorporated portions of Rich, Cache, Morgan, Weber, and Summit Counties in Utah, USA (Figure 3-1). The northern study area, North Rich, occupies 569 km^2 with 73% managed under federal ownership

(47% BLM, 26% USFS), 20% private, and <7% state lands. Grazing allotments on North Rich involved single pastures grazed May-September (Dahlgren et al., 2015). The southern study area was an 870 km^2 ranch, Deseret Land and Livestock (DLL), composed of 93% private and 7% BLM lands. Grazing practices on DLL employed a prescriptive grazing strategy that emphasized growing-season rest (Dahlgren et al., 2015). The study areas were separated geographically by approximately 13km.

Topographically the study areas were characterized by steep canyons and wide ridges at higher elevations in the west while transitioning to open valleys towards the eastern boundaries. Elevations ranged from 1800-2700 m. Primary soil orders included Mollisols, Inceptisols, Aridisols, and Alfisols (Natural Resources Conservation Service (NRCS), 2009).

Average annual precipitation from 1981-2010 was 34.8 cm in Randolph, Utah and 25.5 cm in Woodruff, Utah. These Cooperative Observer Program (COOP) weather stations represented the 2 closest to North Rich (1.5 km) and DLL (13 km) respectively ("Western Regional Climate Center," 2016). Average temperatures were similar at both COOP weather stations and ranged from -12-3.5° C between November and May and 1.5-22.5° C between May and October.

Lower elevations across both study areas were dominated by Wyoming big sagebrush (*A. tridentata* ssp. *wyomingensis*) intermixed with rabbitbrush (*Chrysothamnus spp.* and *Ericameria nauseosa*) and spineless horsebrush (*Tetradymia canescens*). Higher elevations were typically dominated by mountain big sagebrush (*A. t.* ssp. *vaseyana*) and incorporated stands of black sagebrush (*A. nova*), snowberry (*Symphoricarpos spp.*), and antelope bitterbrush (*Purshia tridentata*). Common grasses included bluebunch wheatgrass (*Pseudoroegeneria spicata*), western wheatgrass (*Pascopyrum smithii*), needle-and-thread (*Hesperostipa comata*), and Sandberg bluegrass (*Poa secunda*). At high elevations mountain sagebrush mixed with stands of aspen (*Populus tremuloides*) and conifers (Danvir et al., 2005). Basin big sagebrush (*A. t.* ssp. *tridentata*) patches were common in draws and valley bottoms across both study areas. Livestock grazing by domestic cattle was the dominant land use in both study areas.

Sage-grouse lek densities were 0.01 km^{-2} in North Rich (n=6) and 0.02 km^{-2} in DLL (n=19). From 2006-2015 North Rich averaged 15.4 males per lek and DLL averaged 25.3 males per lek (Utah Division of Wildlife Resources [UDWR] 2015, unpublished data). Despite differences in annual lek counts between study areas, long-term lek counts demonstrated a similar population cycle (Figure 3-2).

Livestock grazing under DLL’s prescriptive grazing strategy differs from that of North Rich in several ways. Some of the most important differences in our study area during the research period included longer periods of rest (DLL 349 d vs. North Rich 264 d) coupled with shorter grazing periods (DLL 11 d vs. North Rich 47 d) for pastures managed under the prescriptive grazing strategy. Deferment during the active growing season provides recovery for bunchgrasses during the critical growing period (Teague et al., 2011). Higher stocking rates (AUM · ha^{-1}) shorter grazing periods can reduce selective grazing that results in repeated defoliation events that may occur during the longer grazing periods associated with the longer grazing periods on North Rich (Morris & Tainton, 1996; Norton, 1998; O’Connor, 1992; Provenza, 2008; W. R. Teague et al., 2011; Teague, Dowhower, & Waggoner, 2004). These factors have been identified as crucial in sustaining wildlife habitat, particularly for ground nesting birds such as the sage-grouse (Boyd et al., 2014; Teague, Provenza, Kreuter, Steffens, & Barnes, 2013).

The prescriptive grazing strategy on DLL incorporates five large herds (845-1750 head) of domestic cattle (*Bos taurus*). The DLL has approximately 100 different pastures, of these, approximately 75% are upland dry range pastures where productivity is highest during the early spring and late fall (Payne, 2011). The remaining 25% of pastures are irrigated meadows. The grazing management plan on DLL incorporated resting approximately 20% of the pastures from livestock grazing each year during the growing season (Danvir et al., 2005). Livestock grazing was deferred until later in the growing season for pastures that were grazed during the previous growing season, to provide forage species the opportunity to grow and complete their life cycle without the competition of cyclic grazing pressure. During our study, the stocking densities (head · ha^{-1}) for pastures in sage-grouse nesting habitat on DLL (1.48) was higher than that of North Rich (0.24).

In 1993, DLL incorporated multiple vegetation treatments methods to reduce woody, primarily sagebrush, vegetation and increase forage. Treatments included prescribed burning, chemical (tebuthiron), and mechanical (aerators and disking) methods and have been implemented on 1-2% of DLL’s sagebrush annually. Treated areas were distributed across the landscape and ranged in size from <100 ha to > 400 ha. Sagebrush treatments were designed to have a high edge/area ratio, be irregular in shape, and simultaneously improve forage of livestock and habitat for elk (*Cervus canadensis),* pronghorn (*Antilocapra americana*), and sage-grouse (Danvir et al., 2005).

North Rich consists of a mosaic of different land ownerships, federal land grazing allotments, and 29 permittee ranchers, many of which have been grazing their livestock on the allotments for multiple generations (Payne, 2011). North Rich consists of 10 allotments; five managed by the BLM and five by the USFS. Private lands exist within allotments at North Rich; these were owned by permittees that graze them in conjunction with the federal allotment's management plans. State-owned lands were incorporated in the North Rich study area and they were managed under federal grazing plans. The rangelands at North Rich were grazed by < 3,000 cow-calf pairs from May through September as large open pastures with little rest during the vegetation's growing period (Payne, 2011). Seasonal rotation of livestock typically followed the vegetation production based on an elevation. Cattle grazed the higher elevation pastures in late summer and the lower elevation pastures in the spring and fall. Additionally, three small bands (< 500 head) of sheep (*Ovis aries*) grazed in the high, rocky, steep elevation habitat, which are often inaccessible to cattle.

2.2 Sage-grouse Capture and Monitoring

We captured female sage-grouse during 2012-2015 on and near leks across both study areas. To minimize capture effects on nest initiation, we concentrated captures to early spring (February-April) and concluded before the start of the nesting season (mid-April). Sage-grouse were captured at night using all-terrain vehicles, spotlights, binoculars, and long handled nets (Giesen, Schoenberg, & Braun, 1982; Wakkinen, Reese, Connelly, & Fischer, 1992). We deployed 15–19 g necklace style radio-transmitters (Advanced Telemetry Systems, Isanti, MN, USA; Holohil Systems, Carp, Ontario, Canada) on 217 female sage-grouse. The radio-marked sage-grouse were released at the point of capture. Study protocols were approved by the Utah State University Institutional Animal Care and Use Committee (IACUC no. 2411) and the UDWR (COR no. 2BAND8744).

We located radio-marked females 2-3 times each week from April through June in efforts to detect nest initiation attempts. Nest initiation was confirmed using binoculars at a distance of ≥ 10 m. This reduced the risk of flushing the female as nest abandonment has been problematic in other sage-grouse research (Baxter, Flinders, & Mitchell, 2008; Holloran et al., 2005). We monitored nesting females every 2-3 days until they were no longer detected at the nest site. Once the nest was vacated, we determined nest fate by examining any remaining eggshells. Nests with eggshell fragments separated laterally in two portions with detached membranes were classified as successful (Rearden, 1951). Nests with complete, crushed, punctured, shattered, or absent eggshells were classified as unsuccessful (Patterson, 1952). We continued to locate unsuccessful females 1-2 times each week through the nesting season to detect potential re-nesting attempts.

2.3 Habitat Surveys

We measured nest site vegetation characteristics previously reported to be important aspects of sage-grouse ecology at all nests (Connelly, Schroeder, Sands, & Braun, 2000), typically within one week of the determination of nest fate (Connelly, Reese, & Schroeder, 2003). Surveys consisted of four 15 m transects oriented in the cardinal directions and converging at the nest bowl. We estimated visual obstruction (VOR) at the nest bowl by centering a Robel pole in the nest bowl and recording the lowest decimeter mark that was >50% visible (Robel, Briggs, Dayton, & Hulbert, 1970) from a distance of 4 m and height of 1 m along each transect. We recorded the VOR at the nest as the mean of four Robel measurements.

We recorded measurements of both vegetation cover and structure along each transect. We estimated forb and grass cover using 0.1-m^2 quadrats (Daubenmire 1959, Bureau of Land Management 1996) placed at 3, 6, 9, 12, and 15 m along each transect. We identified all forb and grass species within each quadrat and assigned them to a cover category based on the estimated percent cover. To reduce estimation bias between observers, we used Daubenmire’s class system: 1 (no cover-5%), 2 (5.1-25%), 3 (25.1-50%), 4 (50.1-75%), 5 (75.1-95%), and 6 (95.1-100%) (Daubenmire, 1959). Plants that could not be identified in the field were recorded by their growth habit classification (forb or grass) and lifespan (annual, perennial, or biennial). Consistent with other vegetation studies with similar objectives, we measured heights for each species using the closest individual to a predetermined corner of the Daubenmire frame that was in contact with the transect tape.

We measured shrub canopy cover for each species using the canopy line intercept method (Canfield 1941, Bureau of Land Management 1996, Connelly et al. 2003). Because of the open nature of shrub canopies in sagebrush-steppe, gaps in foliage that were <5 cm were considered continuous. The line intercept method was preferred for estimating shrub canopy because it converges on actual shrub cover at lower sample sizes when compared to Daubenmire plots (Hanley, 1978). We included measurements of shrub height along each transect and calculated the mean shrub height for each species at that site. We also measured the maximum shrub width and height for the shrub(s) that provided primary concealment of the nest bowl.

2.4 Predator Surveys

Because predation may be limiting factor in some sage-grouse populations (Nelson 1955, Gregg et al. 1994, Schroeder and Baydack 2001), we estimated both common raven (*Corvus corax*) and coyote (*Canis latrans*) densities across each study area using point counts and scat transects. These two species represented the most common predators of sage-grouse nests in our study area. We estimated raven abundance by surveying at seven points across each study area. We conducted surveys every year during their nesting season, from April-July. Raven survey points were located along survey routes that followed unimproved dirt track or low speed (<40 kph) gravel roads. Counts were limited to days with light winds (<19 kph) and little or no precipitation (Luginbuhl, Marzluff, Bradley, Raphael, & Varland, 2001). We used binoculars to locate ravens visually and listened for calls of individuals not visually detected. Each point count consisted of a 10-minute sampling period. We mitigated potential issues of double counting by separating survey points by >3 km and tracking all detected birds prior to starting the next survey (Luginbuhl et al., 2001).

At each study area, we used 20, 1 km scat transects along unimproved dirt tracks to estimate coyote abundance (Henke & Knowlton, 1995) Transects were initially cleared of all detected scats during June of each year following the denning season. We surveyed transects for new scats after a 14-day deposition period. To address any bias associated with undetected scats, we surveyed transects in both directions (Knowlton & Gese, 1995). We used the methods developed by Gese and Terletzky (2009) and calculated coyote abundance as: coyotes/km^2 = 4.9052* scats/km/day

2.5 Analysis

We used the RMark 2.2.4 (Laake, 2015) nest survival models in R 3.4.2 (R Development Core Team, 2015) to evaluate sage-grouse nest survival models and estimate the effects of biotic and abiotic factors on the daily survival rate (DSR). We defined nest success as the probability of a nest hatching ≥1 egg (M. A. Schroeder, 1997). We calculated overall nest survival as the product of the DSR across a 37-d (laying and incubation) exposure period (Blomberg, Gibson, & Sedinger, 2015; Coates & Delehanty, 2010). We estimated the 95% confidence limits for overall nest survival using delta method (Seber, 1982).

We built candidate model sets to identify the models that were best supported by our data. Model sets were designed to independently test a variety of grazing, temporal, spatial, climatic, predator, and habitat covariates. We calculated normalized Akaike weights (w_i) to evaluate the predictive power of each model (Burnham & Anderson, 1998) and used these values to gauge the weight of evidence that the top performing model was the most parsimonious for the given model set. Covariates from models in each set that outperformed the null (ΔAIC_c >2) were then used to generate a final competitive model set.

Our grazing models included mean stocking rate (AUM · ha^{-1}), current year stocking rate, mean days grazed annually, total days rested, livestock presence in the pasture while the nest was active, and number of days during the active growing season that the pasture was grazed. We calculated these livestock grazing covariates for the study period using grazing management plans provided by DLL and the state and federal agencies that monitored grazing management in North Rich. All grazing covariates were applied at the pasture level.

Parameters in our habitat model set included measurement of height and percent cover of shrubs, forbs and perennial bunchgrasses. Because bunchgrass heights measured at date of nest fate (hatch or failure) have been demonstrated to estimate model slope coefficients that are biased high (Gibson, Blomberg, & Sedinger, 2016), we corrected for this methodological bias by estimating the heights of bunchgrasses and forbs at predicted nest hatch using the linear regression calculations developed by Smith et al. (2017).

Our climatic model set included estimates of the standardized precipitation-evapotranspiration index (SPEI) (Vicente-Serrano, Beguería, & López-Moreno, 2010). The SPEI is a climatic drought index that is based on precipitation and temperature. Interpolation of mean monthly SPEI was performed in R package SPEI (Beguería & Vicente-Serrano, 2013) using Parameter-elevation Relationships on Independent Slopes Model (PRISM) data at a 4 km resolution. The SPEI values account for both precipitation and potential evapotranspiration in estimates of drought conditions. Maximal temporal resolution is limited to one month. To capture any lag effects of this parameter on plant growth and productivity, we included SPEI values encompassing the period in which the nest was active and a lagged mean SPEI value comprised of the period starting the previous September through June of the nesting year (Hansen et al., 2016; Vicente-Serrano et al., 2010). Negative SPEI values represent drought conditions; positive values indicate a net gain in moisture.

3 RESULTS

Of our 217 radio-marked females, data were obtained from the 107 (Table 3-1) sage-grouse nests observed within the study areas to complete our analyses. These nests were monitored during the 2012-2015 breeding seasons. Model derived estimates of nest survival over the study period were 32.5% (95% CI = 16-48.9%) and 17.9% (95% CI = 8.5-27.2%) for DLL and North Rich, respectively. However, estimates of sage-grouse nest survival did not differ ($P = 0.082$) between sites. Heights of perennial bunchgrasses (16.5 v 12.8 cm, $p<0.005$), forbs (7.5 v 5.1 cm, $p<0.001$), sagebrush (43.8 v 38.2 cm, $p=0.045$), and visual obstruction (56.4 v 48.3 cm, $p=0.018$) within nesting habitat were greater on DLL compared to North Rich (see Table 3-2). Nevertheless, these covariates were not identified as predictors of nest survival in our models (see Table 3-3).

The model sets that we tested failed to outperform (ΔAIC <2.0) the null model (Anderson, 2008; Burnham & Anderson, 1998). Only two of our models, lagged SPEI and rabbitbrush cover, from the climatic and habitat model sets, outperformed the null model. These parameters were then included in the final model set.

The best-supported model within our final model set included lagged SPEI ($\beta = -0.298$, 95% CI = -0.551 to -0.044) with an additive effect of total ground cover of rabbitbrush ($\beta = -0.310$, 95% CI = -0.568 to -0.053). This model predicts that as both rabbitbrush cover and SPEI values increased, DSR decreased (Figure 3-3).

4 DISCUSSION

Portions of DLL and North Rich serve as important wintering habitat for regional sage-grouse populations (Danvir, 2002; Danvir et al., 2005) and we experienced a high rate of emigration from the study areas. Of our 217 radio-marked females only 107 nests were located within the study area and appropriate for inclusion in our analysis. Our ability to detect an effect at a significant level (α = 0.05) may have been limited by the lower nest sample size (see Table 3-1) and relatively short study period.

While estimates of sage-grouse nest survival did not differ between sites, several habitat vegetation parameters previously reported as being linked to sage-grouse nest survival (Dinkins et al., 2016; Doherty et al., 2014; Kaczor et al., 2011; Knick & Connelly, 2011) were higher on DLL than North Rich. Our top model supported rabbitbrush cover and SPEI as the best predictors of sage-grouse nest survival for our populations. Despite the lack of model support for livestock grazing practices as a predictor of sage-grouse nest survival, four important sage-grouse habitat metrics (i.e., VOR, sagebrush height and cover, perennial bunchgrass height, and forb height) were greater in nesting habitat on DLL(Dinkins et al., 2016; Doherty et al., 2014; Kaczor et al., 2011; Knick & Connelly, 2011).

Other studies of sage-grouse nest survival have reported sagebrush height and cover as being important factors for explaining nest survival rates (Coates & Delehanty, 2010; Connelly et al., 1991; Gregg et al., 1994; Wallestad & Pyrah, 1974). Our models indicated that rabbitbrush cover had a negative effect on nest survival in our populations. While we were unable to determine the specific mechanisms through which rabbitbrush cover affected nest DSR, we hypothesized that it may be related to a metric of range condition not captured in our habitat surveys.

Rabbitbrush is a disturbance-adapted species and has been found to occur more frequently on degraded rangelands (Whisenant, 1987; Young & Evans, 1974). Beck et al., (2009) reported that increased rabbitbrush cover persisted in Wyoming sagebrush areas that had been burned 14 years previous to their study. Because rabbitbrush is a resprouter that can more easily withstand treatments, fires, etc., that affect shrubs, increases in its cover have been reported in historical vegetation treatments targeted at sagebrush cover reduction within our study area (Dahlgren et al., 2015; Danvir et al., 2005; Stringham, 2010). Thus, historic sagebrush treatments and land uses coupled with other biotic or abiotic legacy effects (Ripplinger, Franklin, & Edwards, 2015) may have been the more proximate cause affecting nest survival.

We tested the hypothesis that rabbitbrush was associated with indicators of rangeland degradation (bare ground, litter, days grazed) within our study areas using a cursory post-priori analysis of the available data. However, these models were not supported by available data and are not presented. Additional data would be required to more definitively determine the intricacies of the relationship between rabbitbrush cover and reductions in DSR and how they may be related to interactions with the soils, rangeland degradation and historical sagebrush treatments (Ripplinger et al., 2015).

We included the SPEI index in our models based on the findings of Hansen et al. (2016). In their study of sage-grouse nest survival in a Wyoming population, they reported a negative correlation between the lagged SPEI index and DSR. Their findings appear counterintuitive as they indicate that more xeric conditions have a positive effect on DSR. However, our models also supported SPEI as a predictor of DSR for our populations and demonstrated the same negative relationship between nest survival and areas with higher water balances.

Studies have reported increased nest depredation for sage-grouse and other gallinaceous birds following precipitation events (Herman-Brunson, Jensen, Kaczor, Swanson, & Rumble, 2009; Lehman, Rumble, Flake, & Thompson, 2008; Webb et al., 2012). This phenomenon, referred to as the moisture-facilitated nest depredation hypothesis, has also been linked to observed increases in predation of sage-grouse chicks (Guttery et al., 2013). However, our measures of SPEI represented means across a 10-month period (Sep-Jun) to encompass the most influential period of precipitation on sage-grouse habitat (Hansen et al., 2016) and were not specific to the nesting period. To address this, we isolated the nesting month SPEI in our analysis and found it was not supported in subsequent models. Another potential explanation for this finding is that it correlates with the previous winter snow fall which has the potential to limit access to food (Dahlgren et al., 2015; Remington & Braun, 1985) and affect hen condition in subsequent nesting season. However, models where SPEI values were restricted to the months of snowfall (Oct-Feb) in our study areas were not supported. In a study of annual counts of male sage-grouse across 734 leks in Wyoming, Monroe et al. (2017) found lagged NDVI values around leks along with timing and intensity of grazing were predictive of lek counts. NDVI was used by Monroe et al. as a proxy for vegetation production. In additional analyses of our data where NDVI values were included within the models, NDVI was not supported as a predictor of sage-grouse nest survival. Similar to our rabbitbrush cover results, we were unable to determine the specific mechanism through which SPEI influenced nest survival.

Smith et al. (2018) reported similar results for sage-grouse populations in central Montana where implementation of high-intensity rotational livestock grazing failed to have a detectable effect on survival (Smith et al., 2018). They suggested that because of the short temporal scales (i.e., ≤ 6 years), the desired habitat changes in vegetation composition and structure often attributed to improved grazing management were not detected (Ryerson & Parmenter, 2001). Grazing studies implemented to evaluate the effects on wildlife and their habitats, must also account for these legacy of land use effects when making comparisons between studies and drawing conclusions (Dettenmaier et al., 2017; Ripplinger et al., 2015). Because the livestock grazing treatments we studied were implemented >25 years prior to the start of our study, we anticipated that the lag effects suggested by Smith et al. (2018) were mitigated. However, Ripplinger et al., (2015) suggested that the legacy effects from historical land uses and management actions in our study area may persist well beyond 50 years.

Despite including the parameters identified by Dettenmaier et al. (2017) as important in evaluations regarding the effects of livestock grazing on grouse vital rates in our research, we did not detect a significant effect (i.e., at a 95% level of confidence), of livestock grazing on sage-grouse nest survival rates. Livestock grazing can be quantified in many ways and we accounted for factors most likely to affect sage-grouse vital rates including timing and frequency, duration, and stocking rate ($AUM \cdot ha^{-1}$) (Dettenmaier et al., 2017).

Concomitantly, differences in vegetation heights were evident despite disparities in precipitation and stocking rates ($AUM \cdot ha^{-1}$) between study areas. The DLL study area received 70 mm less annual precipitation on average and had stocking rates ($AUM \cdot ha^{-1}$) ~50% greater (0.76 vs. 0.46 ($AUM \cdot ha^{-1}$)) than North Rich. Differences in nesting habitat between our study sites might suggest a potential for targeted sagebrush treatments coupled with seeding efforts and supported by a prescriptive grazing plan to ameliorate some effects of xeric conditions in sagebrush landscapes where sage-grouse and livestock grazing co-occur. These results corroborate those of Dahlgren et al. (2015) who used a 25-year case study to compare sagebrush treatments with sage-grouse lek counts across study areas in northern Utah and Wyoming.

5 MANAGEMENT IMPLICATIONS

Our results suggest that implementation of a prescriptive grazing practice alone may not improve sage-grouse nest survival. However, when integrated as part of a more holistic management approach that may include carefully targeted sagebrush treatments, these grazing practices may support higher quality nesting habitat for sage-grouse in the form of increased nesting cover and greater economic return for the operators in terms of increased stocking rates. Rather than endorse a particular grazing management practice, we recommend that managers base appropriate grazing management plans upon sound rangeland management concepts that account for local conditions and sage-grouse population habitat-use. This includes the consideration of timing and deferment, duration, and stocking rates when developing grazing plans. Lastly, we recommend that sagebrush removal treatments proposed in lower elevation sage-grouse nesting habitats dominated by Wyoming sagebrush be rigorously reviewed prior to implementation and include a post-treatment seeding plan to reduce the potential for increases in rabbitbrush cover as this had a particularly negative effect on sage-grouse nest survival in our study areas.

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TABLES AND FIGURES

TABLE 3-1 Number and fate of sage-grouse (Centrocercus urophasianus) nests used to model sage-grouse nest survival within Deseret Land and Livestock (DLL) and North Rich study areas Rich County, Utah, USA, 2012-2015.

	Study Area	
	DLL	North Rich
Successful	20	26
Failed	19	42
Total	39	68

TABLE 3-2 Comparison of sage-grouse (*Centrocercus urophasianus*) nesting habitat (mean ± sd) in Deseret Land and Livestock (DLL) and North Rich study areas Rich County, Utah, USA, 2012-2015. Significance codes: '***' 0.001, '**' 0.01, ' ' 1.

	Study Area	
	DLL	North Rich
Height (cm)		
Sagebrush ***	45.5 ± 17.5 (n = 266)	37.2 ± 15.5 (n = 335)
Rabbitbrush	17.7 ± 5.6 (n = 76)	17.3 ± 5.9 (n = 130)
Perennial bunchgrasses ***	17.1 ± 8.4 (n = 271)	12.0 ± 4.7 (n = 332)
Forbs ***	7.5 ± 5.0 (n = 267)	5.1 ± 2.6 (n = 331)
Visual obstruction (VOR) **	56.4 ± 24.8 (n = 72)	48.3 ± 21.2 (n = 174)
% Cover		
Sagebrush **	15.5 ± 11.3 (n = 297)	19.8 ± 11.5 (n = 348)
Rabbitbrush	6.0 ± 5.8 (n=297)	5.5 ± 4.8 (n=348)
Perennial bunchgrasses	20.8 ± 16.5 (n = 297)	19.6 ± 15.0 (n = 348)
Forbs	14.5 ± 13.5 (n = 297)	14.1 ± 11.2 (n = 333)

TABLE 3-3 Example sets for top performing covariates within each candidate model set (temporal/spatial, climatic, predator, and habitat) for greater sage-grouse (*Centrocercus urophasianus*) nest survival in Rich County, Utah, USA, 2012-2015. Significant covariates within each model set were carried forward as the “Best models” set.

Model	ΔAIC_c[1]	k[2]	w[3]	Deviance
Temporal/Spatial models				
Study Area	0.00	2	0.29	408.04
Null	0.48	1	0.23	410.53
Year + Study Area	1.56	5	0.13	403.57
Climatic models				
SPEI w/ lag (Sep-Jun)	0.00	2	0.64	406.09
Null	2.44	1	0.19	410.53
Total precipitation Apr-Jun	3.80	2	0.10	409.89
Nesting period SPEI	4.44	2	0.07	410.53
Predator models				
Null	0.00	1	0.53	412.53
Coyote density	1.29	2	0.28	413.83
Total raven count	2.00	2	0.19	410.53
Habitat models*				
Rabbitbrush cover	0.00	2	0.29	406.43
Bare ground	1.46	2	0.14	407.90
Null	2.13	1	0.09	410.53
Rabbitbrush height	1.00	2	0.09	407.40
Litter	2.03	2	0.09	408.43
Grazing models				
Livestock density	0.00	2	0.37	406.98
Null	1.55	1	0.17	410.53
Annual days grazed	1.60	2	0.17	408.58
Growing season days grazed	3.01	2	0.08	409.99
Best models				
Rabbitbrush cover + SPEI w/ lag	0.00	3	0.66	401.21
SPEI w/ lag	2.87	2	0.16	406.09
Rabbitbrush cover	3.22	2	0.13	406.43
Null	5.31	1	0.05	410.53

[1] Akaike's Information Criterion adjusted for small sample sizes. Numbers are based on differences from the best approximating model within each model set.

[2] Number of parameters estimated.

[3] Akaike weight: strength of evidence given the data, normalized to sum to 1.

* Top 5 habitat models are presented here. Complete habitat results are available in Supporting Information.

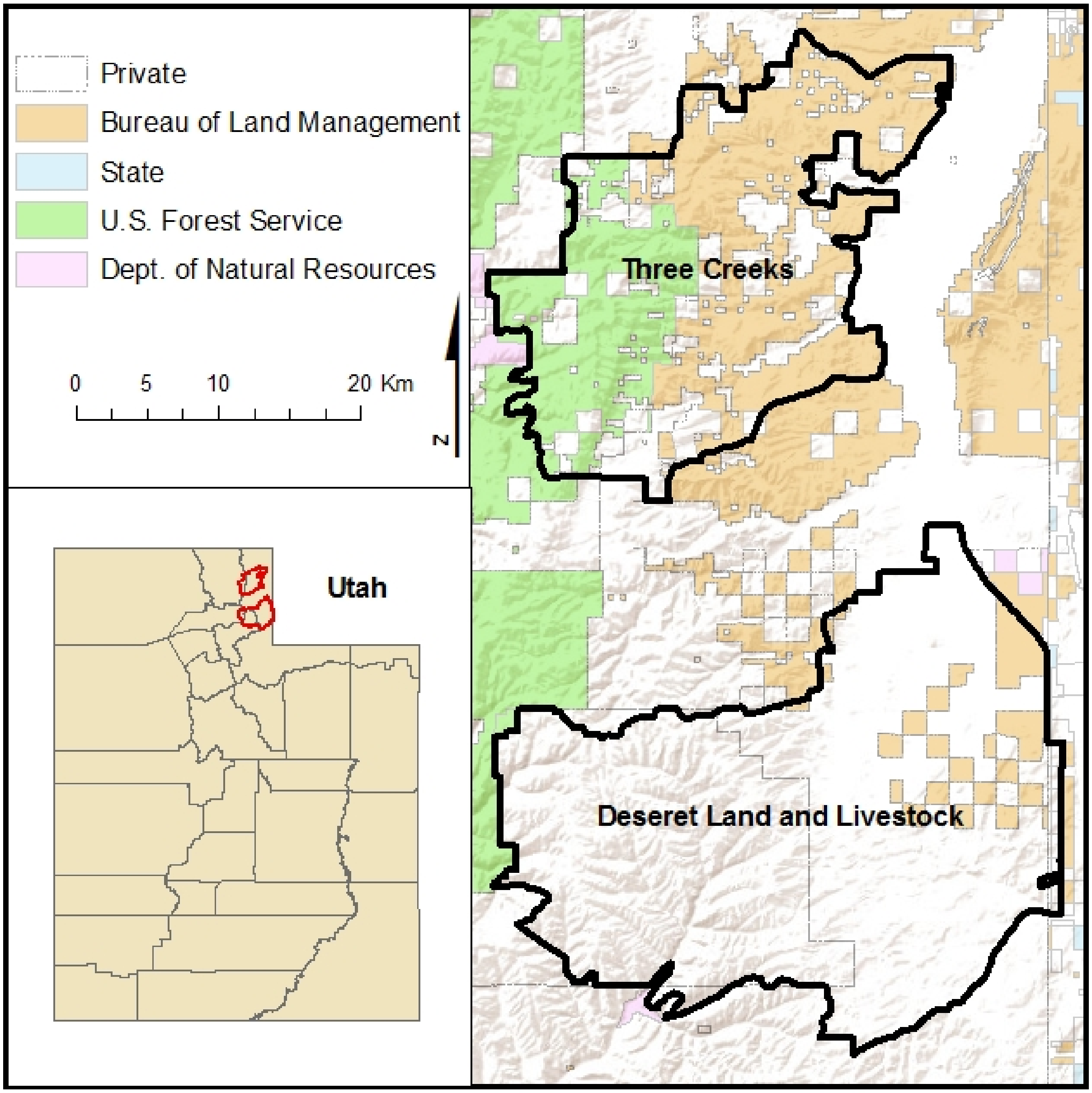

FIGURE 3-1 Greater sage-grouse (*Centrocercus urophasianus*) nest survival study area boundaries, Rich County, Utah, USA.

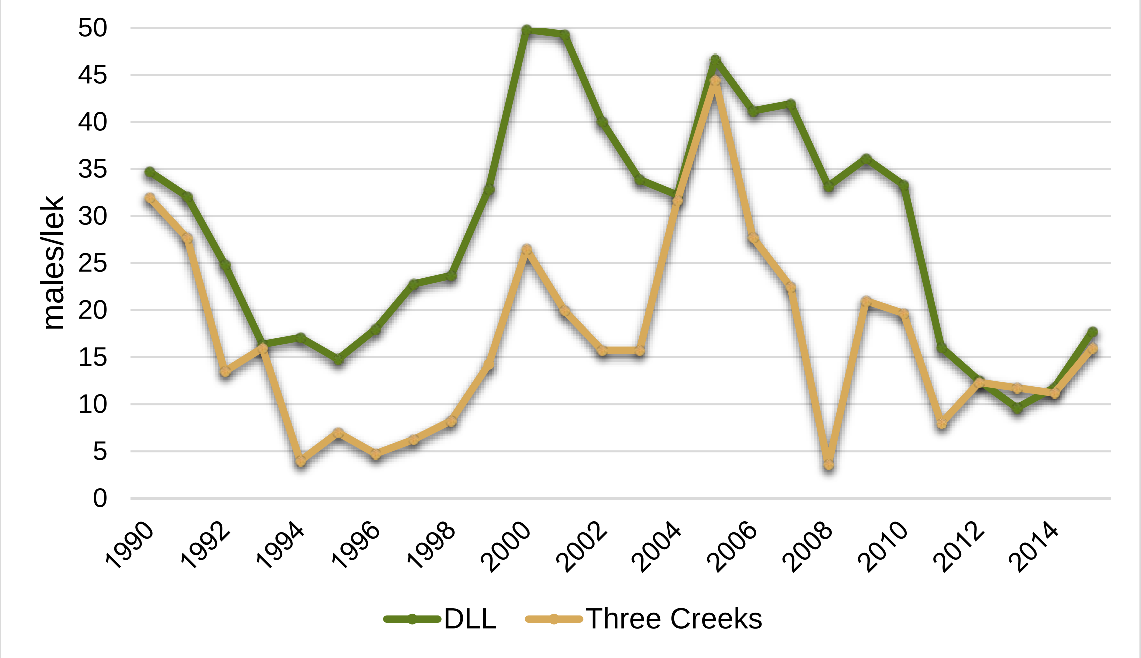

FIGURE 3-2 Greater sage-grouse (*Centrocercus urophasianus*) estimates of average males per lek 1990-2015 on Deseret Land and Livestock (DLL) and North Rich study areas, Rich County, Utah, USA. Estimates for North Rich in 2008 were lower due to missing data.

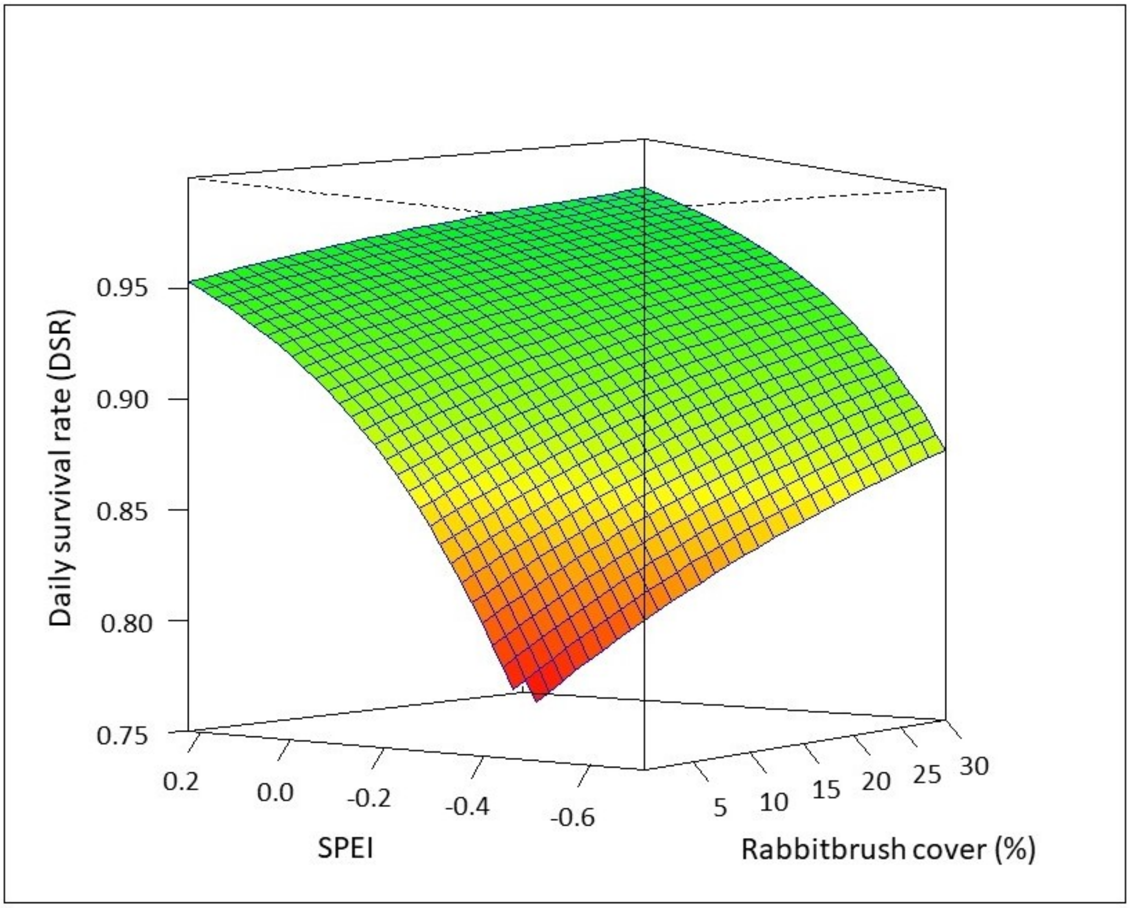

FIGURE 3-3 Effects of rabbitbrush (*Chrysothamnus viscidiflorus*) cover and landscape-scale water balance (standardized precipitation evapotranspiration index; SPEI) on greater sage-grouse (*Centrocercus urophasianus*) nest daily survival rates (DSR) in northeastern Utah, USA. Negative values of SPEI represent drought conditions (i.e. evapotranspiration > precipitation).

CHAPTER 4

SAGEBRUSH MANAGEMENT TO ENHANCE LIVESTOCK FORAGE AFFECTS GREATER SAGE-GROUSE FEMALE SURVIVAL

ABSTRACT

Declines in greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) populations across their range in North America have been attributed to the loss and fragmentation of sagebrush (*Artemisia* spp.) landscapes resulting from anthropogenic disturbances. Grazing by domestic livestock is the most widespread anthropogenic land-use of sagebrush landscapes. Although improper livestock grazing (i.e., grazing that alters plant species composition and structure in a manner that reduces sage-grouse food or cover) has been identified as having negative impacts on sagebrush landscapes and sage-grouse populations at local scales, it was considered a range-wide species conservation threat by the U.S. Fish and Wildlife Service. While research has investigated the effects of sagebrush cover reduction treatments implemented to increase livestock forage within sage-grouse habitats, information regarding the direct effects of livestock grazing management practices on sage-grouse population vital rates is limited. To address this information need, we used information theory (IT) and Akaike's information criterion (AIC) to model non-conditional parameter estimates for livestock grazing management covariates to determine their relative contribution to female sage-grouse survival in a sagebrush-steppe landscape in northeastern Utah, USA. Our study was conducted on an 870 km^2 privately-owned ranch (Deseret Land and Livestock; DLL) managed under a prescriptive grazing practice that included time-controlled grazing

practices (Dahlgren et al., 2015). Between 1992-2006, DLL used chemical and mechanical treatments on approximately 1-2 % of its sagebrush habitat per year to reduce the sagebrush canopy and increase livestock forage. For the model-averaged estimates, sagebrush height, sagebrush cover, and stocking rate (AUM · ha^{-1}) were informative parameters (85% CIs that did not overlap 0). The strength of evidence based on the variate weight was highest for sagebrush height, sagebrush cover, and stocking rate (AUM · ha^{-1}) respectively. Taller sagebrush height was associated with increased female survival rate estimates. Total sagebrush cover and stocking rates (AUM · ha^{-1}) were negatively correlated with taller sagebrush cover and stocking rates (AUM · ha^{-1}) were negatively associated with female survival rate estimates. However, models based on livestock grazing parameters were poor predictors of female survival and suggested that livestock grazing management actions were not a limiting female survival in our study population.

1 INTRODUCTION

The decline in greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) populations across western North America has been primarily attributed to loss and fragmentation of their sagebrush (*Artemisia* spp.) habitats (Connelly & Braun, 1997; Garton et al., 2011; Knick et al., 2003; M. A. Schroeder et al., 2004). Concomitantly, in 2010, the U.S. Fish and Wildlife Service (USFWS) designated sage-grouse as a candidate species for protection under the Endangered Species Act (USFWS 2010). Subsequent to the candidate species designation, state and federal agencies, industry, private landowners, and stakeholders initiated unprecedented efforts to mitigate species' range-wide conservation threats. Collectively, these efforts resulted in the 2015 decision by USFWS that the species no longer warranted consideration for ESA protection (USFWS 2015).

The loss and fragmentation of the sagebrush habitats on which sagebrush-obligate species such as sage-grouse depend has largely been attributed to increased anthropogenic activities (Connelly et al., 2004; M. A. Schroeder et al., 2004). Grazing by domestic livestock is the predominant anthropogenic land-use across the sagebrush ecosystem in North America (C. S. Boyd et al., 2014; Brussard et al., 1994; Crawford et al., 2004; Dettenmaier et al., 2017; Knick & Connelly, 2011; Noss, 1994). However, relative to other anthropogenic activities the impacts of livestock grazing are more diffuse across the landscape (C. S. Boyd et al., 2014; Knick et al., 2011). While the direct impacts of livestock grazing are largely unknown, the USFWS still identified improper livestock grazing a potentially local, but not range-wide, conservation threat for greater sage-grouse (USFWS 2010; 2015).

Research has demonstrated the potential effects of sagebrush treatments used to support livestock grazing on sage-grouse habitat (Beck & Mitchell, 2000; Connelly et al., 2004; Dahlgren, Chi, & Messmer, 2006; Dahlgren et al., 2015), however few studies have directly linked livestock grazing management practices to vital rates for ground-nesting grouse species such as the sage-grouse (Dettenmaier et al., 2017).

Danvir et al. (2005) and Dahlgren et al. (2015) reported that sage-grouse populations responded positively (i.e., increased numbers of males counted on leks, and number of broods observed) to sagebrush cover reduction treatments implemented on an 87,000 ha private ranch, where 1-2% of the total sagebrush area were treated annually.

Treatments were subsequently maintained using a prescriptive grazing practice that included time-controlled grazing (Dahlgren et al., 2015). Changes in the male-based lek counts were used to assess the response of sage-grouse populations to conservation actions such as vegetation treatments and prescribed grazing management (Dahlgren et al., 2016).

More recently, Smith et al. (2018) reported that contrary to their stated hypothesis, sage-grouse nest survival did not improve when U.S. Department of Agriculture Natural Resources Conservation Services (NRCS) recommended rotational grazing practices were implemented on multiple private ranches in central Montana, USA. However, the temporal scale of their study may have been inadequate for the rangeland habitats they studied to respond to the grazing treatment. Additionally, their Montana study site exhibited less sagebrush cover, greater perennial bunchgrass cover, was lower in elevation, and received more precipitation relative to the majority of sage-grouse habitat (Dahlgren et al., 2015; Smith et al., 2018). To better quantify the effects of livestock grazing management on wildlife in general and sage-grouse specifically, research studies should document; 1) livestock type, 2) timing and frequency of grazing, 3) duration of grazing or rest, and 4) stocking rates (Beck & Mitchell, 2000; Dettenmaier et al., 2017).

Using parameters associated with sagebrush cover reduction treatments, presence of livestock, grazing rest periods, and stocking rates ($AUM \cdot ha^{-1}$), we compared the relative direct and indirect effects associated with livestock grazing management practices on female sage-grouse survival during the nesting and brood rearing seasons from 2011 – 2015 (April-July). This time period coincides with livestock grazing of pastures within sage-grouse habitat in our study area and is considered the period of highest female sage-grouse mortality (Connelly, Apa, Smith, & Reese, 2000; Wik, 2002).

To determine the relative effects of our parameters, we developed a set of 18 *a priori* models from 4 continuous and 2 categorical grazing and sagebrush treatment variables commonly associated with the grazing practices on our study area and explain variation in female sage-grouse survival rate estimates. Models were limited to a small set of available predictors; therefore, we do not suggest that we captured the full range of all possible models. We used an all-subset, full-model averaging approach with multi-model inference (MMI) as a method to achieve robust inference for each of our derived parameters (Burnham & Anderson, 2001, 2002; Burnham, Anderson, & Huyvaert, 2011; Symonds & Moussalli, 2011). Based on previously published research (Dahlgren et al., 2015; Danvir et al., 2005), we expected that parameters involving sagebrush treatments would have a stronger weight of evidence as predictors of female sage-grouse survival than parameters of livestock grazing.

2 MATERIALS AND METHODS

2.1 Study Area

We conducted our study on Desert Land and Livestock (DLL), an 87,000 ha privately-owned domestic cattle (*Bos taurus*) ranch which occupies portions of Rich and Morgan counties in northeastern Utah, USA (41°18’46” N, 111°13’16” W; Figure 4-1). DLL was composed of mostly private (93%) lands with 7% administered by the Bureau of Land Management (BLM). The DLL is topographically diverse with high elevation (~2700 m) mountains transitioning to low (~1800 m), wide valleys. High elevations were characterized by steep canyons and broad ridges with large open valleys bottoms and meadows at lower elevations. Primary soil orders consisted of Mollisols, Inceptisols, Aridisols, and Alfisols (Natural Resources Conservation Service (NRCS), 2009).

Mid to low elevations were characterized predominantly by Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) with smaller inclusions of rabbitbrush (*Chrysothamnus spp.* and *Ericameria nauseosa*) and spineless horsebrush (*Tetradymia canescens*). Common grasses included bluebunch wheatgrass (*Pseudoroegeneria spicata*), western wheatgrass (*Pascopyrum smithii*), needle-and-thread (*Hesperostipa comata*), and Sandberg bluegrass (*Poa secunda*). Higher elevations were dominated by mountain big sagebrush (*A. t.* ssp. *vaseyana*) intermixed with stands of black sagebrush (*A. nova*), snowberry (*Symphoricarpos spp.*), and antelope bitterbrush (*Purshia tridentata*). At the highest elevations, mountain big sagebrush transitioned into stands of aspen (*Populus tremuloides*) and conifer (Danvir et al., 2005). Patches of basin big sagebrush (*A. t.* ssp. *tridentata*) were restricted to the relatively more mesic draws and valley floors.

From 1996-2015 the mean annual precipitation was 24.8 cm measured at the nearest (3 km) Cooperative Observer Program (COOP) weather station in Woodruff, Utah, USA (“Western Regional Climate Center,” 2016). Mean temperatures ranged from -12-3.5° C from November-May and 1.5-22.5° C from May-October.

In the late 1970’s, DLL implemented a prescriptive grazing strategy. This was accomplished using two or three herds of 1,500-3000 head of domestic cattle and 120 pastures of varying size (18-2,207 ha) (Danvir et al., 2005). Approximately 75% of these pastures are upland dry range where productivity is highest during the early spring and late fall (Payne, 2011). Irrigated meadows composed the remaining 25% of the ranch. From 2012-2015, the mean stocking rate (AUM · ha^{-1}) for pastures within sage-grouse habitat was 0.65 ± 0.26 AUM/ha^{-1}. On average, 90% of the cattle occur on only 10% of the landscape (Danvir et al., 2005) and mean grazing period was 10 days. A key objective of the prescriptive grazing management plan on DLL is to provide growing season rest for approximately 20% of the pastures annually (Danvir et al., 2005). Grazing deferment is scheduled to coincide with the growing season to provide recovery for bunchgrasses and preferred forage species during the critical growing period (Teague et al., 2011). Another grazing plan objective includes resting up to 25% of the landscape from livestock grazing annually. The annual rest period affords forage species opportunities to complete their life cycle without continuous grazing pressure from livestock. Implementation of similar grazing management plans in other studies have demonstrated reductions of the negative effects of selective grazing (Morris & Tainton, 1996; Norton, 1998; O'Connor, 1992; Provenza, 2008; Teague et al., 2011, 2004). These key characteristics included as part of DLL's grazing and overall holistic management plan are important components in sustaining wildlife habitat for sage-grouse (Teague et al. 2013; Boyd et al. 2014).

In 1993, DLL incorporated multiple vegetation treatments methods to reduce woody, primarily sagebrush, vegetation and increase forage. Treatments included prescribed burning, chemical (tebuthiron), and mechanical (aerators and disking) methods and have been implemented on 1-2% of DLL's sagebrush annually from 1992-2009 (Dahlgren et al., 2015). Treated areas were distributed across the landscape and ranged in size from <100 ha to > 400 ha. Sagebrush treatments were designed to have a high edge/area ratio, be irregular in shape, and simultaneously improve forage of livestock and habitat for elk (*Cervus canadensis)*, pronghorn (*Antilocapra americana*), and sage-grouse (Danvir et al., 2005).

While primarily managed for livestock production, DLL is the largest Cooperative Wildlife Management Unit (CWMU) in Utah and wildlife opportunities provide additional revenue for the ranch (Danvir et al., 2005). Sage-grouse lek densities on DLL were 0.02 km-2 (n=19) with a mean male/lek count of 25.3 (2006-2015; Utah Division of Wildlife Resources [UDWR] 2015, unpublished data).

2.2 Data Collection

We captured female sage-grouse during 2012-2015 on and near leks within the study area. To minimize capture effects on nest initiation, we concentrated captures to early spring (February-April) and concluded before the start of the nesting season (mid-April). Sage-grouse were captured at night using all-terrain vehicles, spotlights, binoculars, and long handled nets (Giesen et al., 1982; Wakkinen et al., 1992). We fit 116 female sage-grouse with 15–19 g necklace style radio-transmitters (Advanced Telemetry Systems, Isanti, MN, USA; Holohil Systems, Carp, Ontario, Canada) and released all radio-marked sage-grouse at the point of capture. Study protocols were approved by the Utah State University Institutional Animal Care and Use Committee (IACUC no. 2411) and the UDWR (COR no. 2BAND8744).

Locations of radio-marked females were recorded 2-3 times each week during the period April through June to detect nest initiation attempts. Nest initiation was confirmed using binoculars at a distance of ≥ 10 m to minimize the risk of flushing the female. Nest abandonment resulting from researchers flushing sage-grouse from nests has been documented as an issue in other sage-grouse studies (Baxter et al., 2008; Holloran et al., 2005). We continued to locate all non-nesting females 1-2 times each week until 01 August each year.

2.3 Habitat Surveys

We measured sage-grouse habitat characteristics (see Table 4-1) at nest and brood sites. Each site was then paired with randomly generated one within the same pasture. This allowed us to better quantify the sage-grouse habitat within each pasture. Habitat surveys were comprised of four 15 m or 25 m transects, for nest and brood locations respectively, oriented in the cardinal directions and converging at the nest bowl or proximate brood location (Connelly et al., 2003).

We recorded vegetation measurements that represented the cover and structure for all shrub species along each transect. Forb and grass cover was estimated using 0.1-m^2 quadrats (Daubenmire, 1959; BLM 1996) placed at 3, 6, 9, 12, and 15 m at nest sites, and additionally at 18 and 21 m at brood locations along each transect. We identified all forb and grass species within each quadrat and assigned them a cover category based on the estimated percent cover. We reduced observer estimation bias using Daubenmire’s class system: 1 (no cover-5%), 2 (5.1-25%), 3 (25.1-50%), 4 (50.1-75%), 5 (75.1-95%), and 6 (95.1-100%) (Daubenmire, 1959). Consistent with other vegetation studies with similar objectives, we measured heights for each species using the closest individual to a predetermined corner of the Daubenmire frame that was in contact with the transect tape.

We measured shrub canopy foliar cover for each species using the canopy line intercept method (Canfield, 1941; BLM 1996; Connelly et al., 2003). Because of the open nature of shrub canopies in sagebrush steppe, gaps in foliage that were <5 cm were considered continuous. The line intercept method was preferred for estimating shrub canopy because it converges on actual shrub cover at lower sample sizes when compared to Daubenmire plots (Hanley, 1978). We included measurements of shrub height along each transect and calculated the mean shrub height for each species at that site. Estimates of treatment were applied as the proportion of detection occasions that the hen was located in a treatment.

2.4 Predator Surveys

Predation has been reported as the largest contributing factor for sage-grouse mortality (Connelly, Apa, et al., 2000; Orning & Young, 2017). Because predation has also been reported as a limiting factor in some sage-grouse populations (Gregg et al., 1994; Nelson, 1955; M.A. Schroeder & Baydack, 2001), we estimated coyote (*Canis latrans*) densities across the study area using scat transects. We used 20, 1 km scat transects along unimproved dirt tracks to estimate coyote abundance (Henke & Knowlton, 1995). We cleared each transect of scat during June of each year following the denning season. We surveyed transects for new scats after a 14-day deposition period. To address potential bias associated with undetected scats, we surveyed transects in both directions (Knowlton & Gese, 1995). We followed the methods developed by Gese and Terletzky (2009) and calculated coyote abundance as:

$$\text{coyotes/km}^2 = 4.9052 * \text{scats/km/day}$$

Because common ravens (*Corvus corax*) have not been identified as predators of adult sage-grouse, they were excluded from our analysis (Conover & Roberts, 2016).

2.5 Grazing Data

We obtained livestock grazing schedules from DLL for 2012-2015. Grazing schedule data included pasture size, date in, date out, AUMs (Animal Unit Months), and herd size. We used this information to estimate all of the livestock management covariates in our models.

2.6 Analysis

We constructed weekly observation periods for each female detected >2d during that observation period. We defined time intervals by week for each year as t=0 starting week 1 on 01 April and concluding at week 18, t=18 on 01 August. We limited our analysis to April-July for each of the years. This time period represented the nesting and brood rearing seasons of our radio-collared females. We calculated grazing and habitat covariate values as the mean of all known locations for each female within each detection period. However, we were unable to match temporal scales for all of our covariates because sagebrush estimates were made annually and females were located weekly. The grazing schedule data allowed for the calculation of weekly values for our grazing covariates and coincided with the detection period. While habitat treatment covariates were collected on a longer temporal scale and could only be applied on a yearly scale to include the best estimates. Given the data available we applied covariates at the pasture level by pooling all habitat surveys from that pasture and estimating a mean value by year. We used the Anderson-Gill (A-G) formulation of the Cox proportional hazard

(CoxPH) in R 3.4.2 (R Development Core Team, 2015) using package SURVIVAL (Therneau, 2017) to model estimates for habitat and livestock grazing predictors of sage-grouse female survival.

The A-G model accommodates left- and right-censored data, with time-dependent covariates measured across a large number of time intervals (Fleming & Harrington, 1991; Therneau & Grambsch, 2013). Consistent with the Cox model, the primary assumption for the A-G method is that the risk ratio is considered to remain proportional over time (Hosmer & Lemeshow, 2000). We tested for violations of the proportional hazard assumption using the cox.zph function in package SURVIVAL. We calculated variance inflation factors (VIF) using package CAR (Fox et al., 2017) to identify predictors with high levels of multicollinearity (VIF > 5); no predictors were excluded because of violations of the proportional hazard assumption or as a result of high multicollinearity.

We developed a set of 18 *a priori* A-G models (see Table 4-1) from 4 continuous and 2 categorical grazing and habitat/treatment variables associated with HILF grazing practices on DLL and assumed to explain variation in survival of female sage-grouse (Table 4-1). Models were limited to this small set of available predictors and therefore we do not suggest that we captured the full range of all possible models. Because we recorded few mortalities (n=15) we used Akaike's information criterion with a correction for small sample sizes (AIC_c) (Burnham & Anderson, 2002). We used an all-subset, full-model averaging approach with multi-model inference (MMI) as a method to achieve robust inference for each of our derived parameters (Burnham & Anderson, 2001; Symonds & Moussalli, 2011). Model-averaged estimators across models (i.e. $\hat{\bar{\theta}} =$

$\sum w_i \hat{\theta}_i$) often have increased precision and reduced bias when compared to estimators of that parameter obtained from the best selected model (Burnham & Anderson, 2001). Model averaged parameter estimates were calculated (see Table 4-2) in package AICCMODAVG (Mazerolle, 2017) using the modavg function to obtain revised unconditional standard errors and a 85% confidence interval (CI) (Buckland, Burnham, & Augustin, 1997; Burnham & Anderson, 2002) for each parameter (Table 4-2). Comparisons among 20 predator survey sites across DLL to determine variations in predator density were done using a one way ANOVA.

3 RESULTS

Our analysis was based on 307 weekly observations of 65 female sage-grouse from 1 April to 31 July, effectively the nesting and brooding season, for the years 2012-2015. We recorded 15 mortalities which provided an estimated mean survival of 0.45 (Figure 4-2, SE = 0.1; 95% CI = 0.29 to 0.70).

Based on our candidate model set the most consistently supported parameters included sagebrush height and cover, both reported indicators of sage-grouse habitat quality. Vegetation treatments, stocking rates (AUM · ha^{-1}), and days rested were also represented in the models that constituted the 85% AIC_c weighted value subset of models. However, because of high model selection uncertainty, we employed MMI using AIC_c and based on full-model averaging for each of the parameters of interest to reduce issues of model selection bias.

For the model-averaged estimates, sagebrush height, sagebrush cover, and stocking rate (AUM · ha^{-1}) were all informative parameters (85% CIs that did not overlap

0; see Table 4-2). The strength of evidence based on the variate weight was highest for sagebrush height, sagebrush cover, and stocking rate (AUM · ha^{-1}) respectively. Both sagebrush height and sagebrush cover appeared in nine models in our set. As shown in Table 4-1, sagebrush height was present in the nine best explanatory models; sagebrush cover the five best; and stocking rate (AUM · ha^{-1}) in the best model. The remaining parameters were considered uninformative as they had 85% CIs that overlapped 0.

Based on the weighted aggregate coefficients, our model estimates of mortality risks were 1.7 ($5^{0.11}$) times higher for female sage-grouse in areas where sagebrush cover was increased by an additional 5% (i.e., 35% vs. 30%) (Table 4-2). Whereas sage-grouse in areas where sagebrush height was 5 cm taller had a 40% reduction in mortality risk. Increases of 50% in mean stocking rates (AUM · ha^{-1}) increased the risk of mortality by 1.1 times.

Tests of the Schoenfeld residuals for each model suggested that our data did not violate the proportional hazard assumption (maximum $\chi^2 = 3.52$, df = 6, $P = 0.74$). Based on calculations of VIF, multicollinearity was not identified as an issue between predictor covariates. Finally, our tests between predator survey sites found no support for significant differences in predator densities across the study area.

4 DISCUSSION

Decoupling management actions used to support livestock grazing such as sagebrush cover reduction treatments from the direct effects of livestock may help inform land managers regarding the importance of various management actions on wildlife, especially ground nesting birds such as the sage-grouse. In a 25-year case study, Dahlgren et al. (2015) concluded that annual treatments that were designed to reduce sagebrush cover and subsequently maintained by a prescriptive grazing management that included time-controlled grazing, were primarily responsible for observed increases in sage-grouse brooding success and populations in northeastern Utah, USA. Conversely, studies by Smith et al. (2018) and Dettenmaier et al. (unpublished) found that sage-grouse nest survival did not differ between managed under prescribed grazing practices compared to historical seasonal grazing.

Our comparisons of the relative contribution between sagebrush treatments used to increase livestock forage and the direct effects of livestock lend support to previous research findings. Our results indicated that within the models we tested, predictors associated with treatments, sagebrush cover, and sagebrush height (Watts & Wambolt, 1996) had the greatest weight of evidence as predictors of female survival.

Because our analysis was limited to few predictor variables related to sagebrush treatments and direct effects of livestock grazing management, we urge caution in drawing conclusions from our findings. It should also be noted that both of these predictors are likely associated with higher productivity sites that may be a confounding factor in our analysis. Our model set was produced a priori with the objective of determining relative contributions of our predictor covariates on female survival. Also, our estimates of sagebrush cover and sagebrush height were limited by spatial scale. Our data were limited to the pasture scale to include as many habitat surveys into our estimates as possible. While we acknowledge that spatial data layers of vegetation such as LANDFIRE exist, they were designed to be applied at large landscape scales with the recommendation against using small groups or individual cells (“LANDFIRE,” 2013).

While caution should be used when developing predictive models based on the results of MMI (Cade, 2015), this technique has merit, as it has been demonstrated to be a useful tool in extending knowledge within ecological applications (Burnham & Anderson, 2002; Burnham et al., 2011; Razgour, Hanmer, & Jones, 2011; Symonds & Moussalli, 2011). Our research remains an exploratory analysis with the objective of extending the current understanding of the effects of all aspects of livestock grazing management and sagebrush treatments on female sage-grouse survival.

These results viewed together with other research (Danvir et al. 2005, Dahlgren et al. 2015, Smith et al. 2018) lend support to sagebrush cover reduction treatments having a larger effect on sage-grouse population vital rates when compared to the more direct effects of livestock grazing management. While recent studies trended toward a focus on specific grazing management practices, we suggest taking a broader look at sagebrush treatments with the objective of supporting livestock grazing practices.

5 MANAGEMENT IMPLICATIONS

Our findings suggest that land manager’s may achieve increased species conservation results by first ensuring that sagebrush treatment objectives are within sage-grouse guidelines and supported by grazing practices that help maintain those treatments. There likely exists a variety of grazing management prescriptions that can support suitable habitat for sage-grouse. However, perhaps most importantly, we urge managers to use Best Management Practices (BMPs) in the context of local ecological conditions. We recommend that managers first consider the consequences of implementing sagebrush treatments within sage-grouse habitat before action is taken. We agree with previous studies that caution against sagebrush treatments occurring over large tracts of sagebrush and at low elevation. Most importantly, objectives should be consistent with meeting the guidelines for sagebrush height and cover in sage-grouse habitat.

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TABLES AND FIGURES

TABLE 4-1 Candidate Cox proportional hazard (CoxPH) survival models with Andersen-Gill parameterization, number of parameters (K), Akaike's Information Criterion (AIC_c) scores, differences among AIC_c scores (Δ), AIC_c weights (w_i), accumulated AICc weights (acc w_i), and evidence ratio (ER) for models of greater sage-grouse (*Centrocercus urophasianus*) female survival for Deseret Land and Livestock (DLL) in northeastern Utah, USA, 2012-2015.

	Candidate models	*K*	AIC_c	ΔAIC_c	w_i	acc w_i	ER
1	SH + SC + SR	3	69.43	0.00	0.346	0.346	
2	SH + SC	2	69.55	0.12	0.325	0.670	1.06
3	SH + SC + DR	3	71.31	1.88	0.135	0.805	2.56
4	SH + SC + TX	3	71.35	1.93	0.132	0.937	2.62
5	SH + SC + SR + DR + TX + LP	6	75.15	5.72	0.020	0.957	17.46
6	SH	1	75.76	6.33	0.015	0.971	23.74
7	SH + SR	2	76.16	6.73	0.012	0.983	28.96
8	SH + LP	2	76.62	7.19	0.009	0.993	36.40
9	SH + DR	2	77.22	7.80	0.007	1	49.28
10	SC	1	86.73	17.30	0.000	1	5720.54
11	SC + SR	2	87.60	18.17	0.000	1	8815.47
12	SC + LP	2	88.73	19.30	0.000	1	15525.51
13	SC + DR	2	88.73	19.31	0.000	1	15578.75
14	TX	1	92.02	22.60	0.000	1	80644.47
15	SR	1	93.01	23.59	0.000	1	132284.61
16	LP	1	93.31	23.88	0.000	1	153356.48
17	DR	1	93.38	23.95	0.000	1	158542.77
18	SR + DR	2	95.03	25.60	0.000	1	362171.70

SC sagebrush cover, *SH* sagebrush height, *SR* stocking rate (AUM · ha^{-1}), *DR* days rested, *TX* treatment, *LP* livestock present

TABLE 4-2 Model-averaged estimates for six factors of livestock grazing and habitat treatments on greater sage-grouse (*Centrocercus urophasianus*) female survival during the nest and brooding seasons in northeastern Utah, USA, 2012-2015.

	LP	SR	DR	TX	SC	SH
1		2.86 (1.84)			0.11 (0.04)	-0.11 (0.02)
2					0.11 (0.04)	-0.10 (0.02)
3			0		0.11 (0.04)	-0.10 (0.02)
4				0.30 (0.63)	0.11 (0.04)	-0.11 (0.03)
5	0.72 (1.44)	1.69 (2.78)	0	0.20 (0.65)	0.11 (0.04)	-0.11 (0.03)
6						-0.09 (0.02)
7		2.32 (1.59)				-0.10 (0.02)
8	1.01 (0.86)					-0.10 (0.02)
9			0			-0.10 (0.02)
10					0.10 (0.04)	
11		2.08 (1.71)			0.10 (0.04)	
12	-0.14 (0.81)				0.10 (0.04)	
13			0		0.10 (0.04)	
14				-.62 (0.52)		
15		1.13 (1.73)				
16	-0.20 (0.78)					
17			0			
18		1.14 (1.73)	0			
w	0.029	0.377	0.162	0.152	0.957	1
$\bar{\bar{\beta}}$	0.81	2.78	0	0.29	0.11	-0.10
$\widehat{se}(\bar{\bar{\beta}})$	1.29	1.91	0	0.63	0.04	0.02
85% CI	-1.71 to 3.34	-0.96 to 6.52	0 to 0	-0.95 to 1.52	0.04 to 0.19	0.15 to -0.06

LP livestock present, *SR* stocking rate (AUM · ha^{-1}), *DR* days rested, *TX* treatment, *SC* sagebrush cover, *SH* sagebrush height, *w* variate weight. Positive coefficient indicates increased hazard for variable. Estimates are based on an all-subset candidate set with full-model averaging. Parameter estimates include unconditional ± SE and 85% confidence intervals.

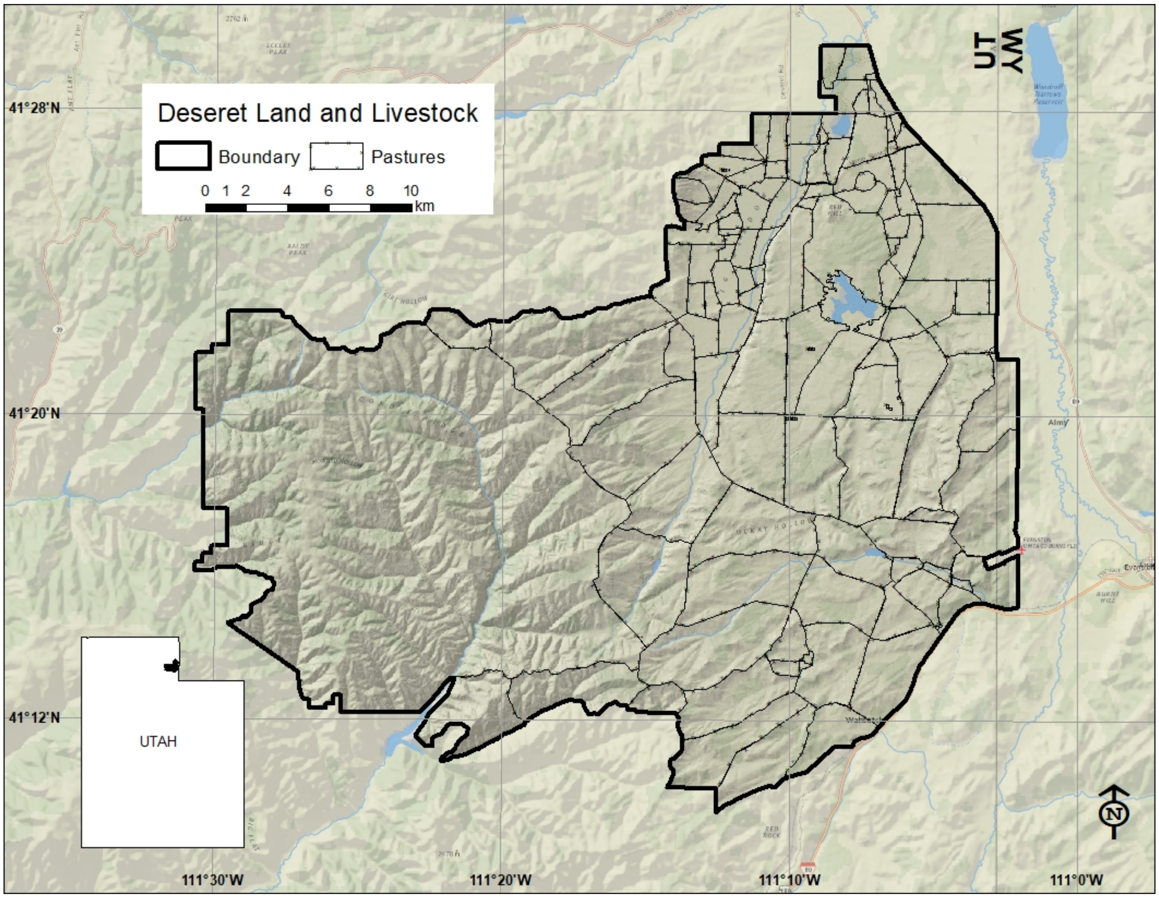

FIGURE 4-1 Location of Deseret Land and Livestock (DLL) ranch in northeastern Utah, USA.

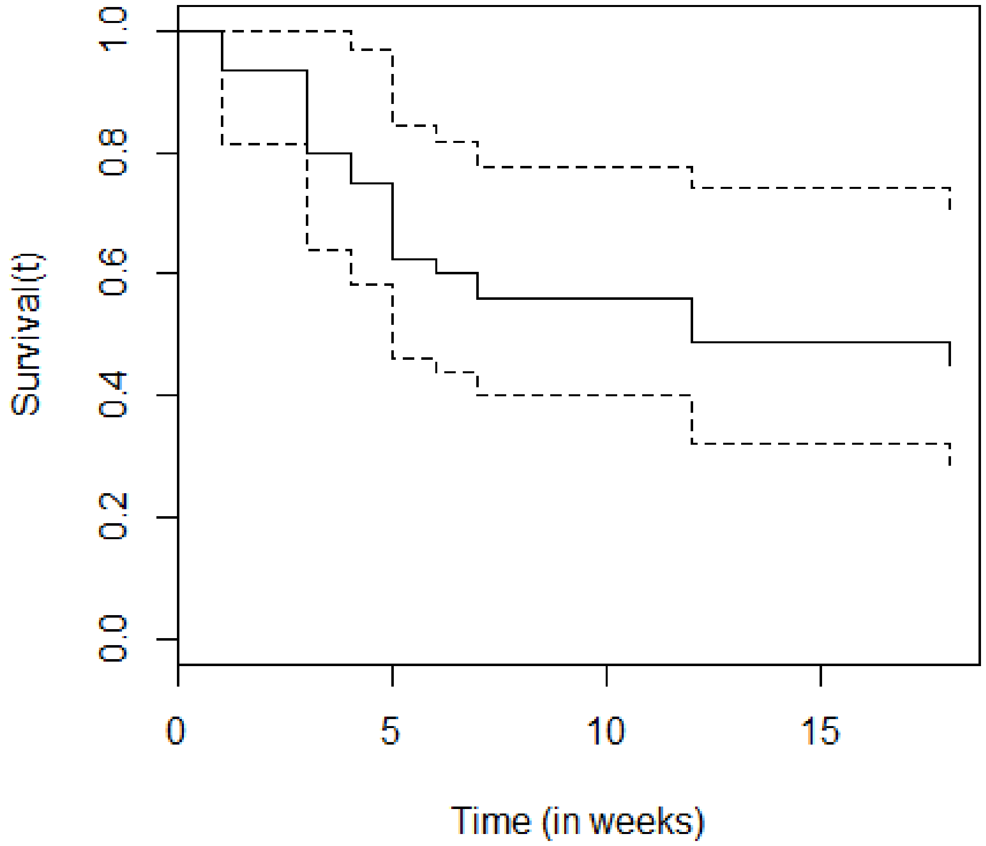

FIGURE 4-2 Female greater sage-grouse (*Centrocercus urophasianus*) survival estimates with 95% confidence intervals (dashed lines) for the period 01 April – 31 July on Deseret Land and Livestock, Rich County, Utah, USA , 2012-2015.

CHAPTER 5

CONCLUSIONS

There is an increasing amount of research investigating the habitat requirements and population demographics of greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) populations. However, to date, few studies have focused specifically on the potential effects that livestock grazing may have on these populations (Beck & Mitchell, 2000; Dettenmaier et al., 2017). While the US Fish and Wildlife Service (USFWS 2010) determined that livestock grazing has the potential to affect sage-grouse at local scales, effects at the landscape scale are largely unknown. To address this issue I began with a data-driven and systematic review of the peer-reviewed literature to determine the current knowledge of the effects of livestock grazing on grouse populations worldwide. I used meta-analytical methods to calculate unbiased estimates of *Hedges' g* (Hedges, 1981) as a measure of the direct effect of livestock grazing on grouse populations in addition to a quantifying the overall effects. To address sage-grouse populations more directly I analyzed models with parameters of habitat and livestock grazing to compare the relative effects of seasonal and prescribed grazing management practices on sage-grouse nest survival. Finally, I used information theory (IT) and Akaike's information criterion (AIC; Burnham and Anderson 2002; Burnham, Anderson & Huyvaert 2011; Razgour, Hanmer & Jones 2011; Symonds & Moussalli 2011) to model non-conditional parameter estimates for livestock grazing management covariates to determine their relative contribution to female sage-grouse survival.

To conduct the meta-analysis, I completed a literature search in May 2017. Of the initial 5,637 topic search results, only 4 studies met our inclusion criteria. I analyzed 6 measurements of grazing's effect on adult grouse numbers and 3 on chick production within our meta-analysis. I found that in these studies livestock grazing had a negative impact on adult grouse numbers (random effects $\bar{E}$= -1.28, d.f. = 5, 95% CI: -2.02, -0.85) and chick production (random effects $\bar{E}$= -0.84, d.f. = 2, 95% CI: -1.34, -0.59). There is also evidence supporting an overall moderate to high (Cohen, 1988) negative effect of livestock grazing on adult grouse numbers and chick production (random effects $\bar{\bar{E}}$= -1.12, d.f. = 8, 95% CI: -1.63, -0.59). However, our analysis was limited to studies of black (*Lyrurus tetrix*) and red (*Lagopus lagopus scotica*) grouse and lacked studies for North American prairie grouse. Also, the total number of papers meeting our criterion were limited. Finally, despite efforts to limit issues of publication bias within our meta-analysis we couldn't overcome the scarcity of appropriate studies in the published literature.

For the nest survival analyses, I developed sets of a priori models that incorporated livestock grazing management prescriptions (i.e., timing and frequency of grazing, duration of grazing or rest, stocking rates [AUM · ha^{-1}]) with micro-habitat vegetation characteristics, temporal, predator indices, and climatic conditions on sage-grouse nest survival. I tested these models using information theory (Anderson, 2008). Based on previously published research (C. S. Boyd et al., 2014), I predicted that sage-grouse nest survival rates and important habitat metrics would be higher under a combination of prescribed grazing management practices compared to seasonal grazing practices. Model derived estimates of DSR for the study period did not differ between

Deseret Land and Livestock (DLL) and the North Rich study area. However, heights of perennial bunchgrasses, forbs, sagebrush, and visual obstruction within nesting habitat were greater on DLL compared to North Rich. Still, these covariates were not identified as predictors of nest survival in my models. My analysis did not support my hypothesis that nest survival was higher in areas managed under prescribed grazing practices.

Only two of the nest survival models, lagged SPEI and rabbitbrush cover, outperformed the null model. The best-supported model within my final model set included lagged SPEI with an additive effect of total ground cover of rabbitbrush. This model predicts that as rabbitbrush cover increased, daily survival rate (DSR) decreased, but as SPEI values become more negative (xeric conditions), DSR increased. While I was unable to determine the specific mechanisms through which rabbitbrush cover affected nest DSR, I hypothesize that it may be related to a metric of range condition not captured in my habitat surveys. Rabbitbrush has been found to occur more frequently on degraded rangelands (Whisenant, 1987; Young & Evans, 1974). Beck et al., (2009) reported that increased rabbitbrush cover persisted in Wyoming sagebrush areas that had been burned 14 years previous to their study. Increased rabbitbrush has been reported in historical vegetation treatments targeted at sagebrush cover reduction within my study area (Dahlgren et al., 2015; Danvir et al., 2005; Stringham, 2010). Thus, historic sagebrush treatments and land uses coupled with other biotic or abiotic legacy effects (Ripplinger et al., 2015) may have been the more proximate cause affecting nest survival.

I included the SPEI index in my nest survival models based on the findings of Hansen et al. (2016). In their study of sage-grouse nest survival in a Wyoming population, they reported a negative correlation between the lagged SPEI index and DSR.

Their findings appear counterintuitive as they indicate that more xeric conditions have a positive effect on DSR. However, my models also supported SPEI as a predictor of DSR for my populations and demonstrated the same negative relationship between nest survival and areas with higher water balances.

Finally, I used information theory and AIC to model non-conditional parameter estimates for livestock grazing management covariates to determine their relative contribution to female sage-grouse survival in DLL. By identifying factors associated with livestock grazing management that have the greatest potential to affect sage-grouse populations we may provide managers a way to focus and maximize conservation efforts.

Deseret Land and Livestock between 1980-2000, has treated approximately 1-2 % of its sagebrush cover per year to enhance forage for livestock grazing. For the model-averaged estimates, sagebrush height, sagebrush cover, and stocking rate (AUM $\cdot$ ha^{-1}) were informative parameters (85% CIs that did not overlap 0). The strength of evidence based on the variate weight was highest for sagebrush height, sagebrush cover, and stocking rate respectively. Taller sagebrush height contributed to increased female survival rate estimates while total cover of sagebrush and stocking rates were negatively correlated to female survival rate estimates. However, this may have been the result of reduced herbaceous cover in these areas. Furthermore, the models based on livestock grazing parameters were poor predictors of female survival and suggested that livestock grazing management actions were not a limiting female survival in my study population.

The overall results from my research demonstrates the potential for prescriptive grazing practices that emphasizes rest to benefit sage-grouse populations. However, I identified some of the complexities in conducting research targeted at answering fundamental questions regarding the role of livestock grazing in managing sagebrush rangeland landscapes for multiple purposes. I also suggest that land manager’s may achieve increased species conservation results by focusing more on sagebrush treatments rather than specific grazing practices. There likely exists a variety of grazing management stratagems that can support suitable habitat for sage-grouse (Smith et al., 2018), however, I urge managers to use Best Management Practices (BMPs) in the context of local ecological conditions. I also recommend that managers consider the potential impacts of sagebrush treatments on sage-grouse populations when they are implemented in sage-grouse habitat. I agree with previous studies that caution against sagebrush treatments occurring over large tracts of sagebrush particularly in lower elevation Wyoming sagebrush communities. Most importantly, management objectives should be consistent with meeting the local guidelines for sagebrush height and cover in areas of sage-grouse habitat.

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CURRICULUM VITAE

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EDUCATION

Ph.D.

In Progress
Utah State University, Logan, UT
Major: Wildlife Ecology
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August 2004 - May 2006
Utah State University, Logan, UT
Major: Conservation, Restoration Ecology
SJ & Jessie E Quinney Scholar, graduated Cum Laude, dean's list. Member Undergraduate Student Council.

EXPERIENCE

InterWest Wildlife and Ecological Services, Inc., Richmond, UT — *Wildlife Biologist*

April 2017 – Present

Successfully ensured compliance with federal regulations including the Migratory Bird Treaty Act and the Bald and Golden Eagle Protection Act on large multi-year construction project. Identified and assessed risks to species and determined appropriate mitigation efforts for protection.

Utah State University, Logan, UT — *Graduate Research Assistant*

August 2011 - Present

Successfully oversaw and managed 5-year research project involving multiple stakeholders. Developed research objectives and field protocols using theoretical frameworks of ecosystems for practical application in the field. Used quantitative skills to analyze data in R, RMark, Program MARK, MetaWin, and SPSS. Developed database in MS Access to efficiently store and effectively retrieve +100,000 data records. Strengthened leadership and problem-solving while safely supervising 14 technicians. Used ArcGIS to create and analyze spatial data. Involved in trapping and radio-collaring efforts for research of greater sage-grouse across Utah. Successfully handled and processed hundreds of animals without injuries. Used radio telemetry to track movements and locations of radio-collared sage-grouse. Demonstrated strong oral and written communication through presentations and scientific publications.

Utah State University, Logan, UT — *Research Technician*

October 2010 - August 2011

Involved in trapping and radio-collaring efforts for research of greater sage-grouse across Utah. Provided expertise in database management to increase efficiency of Utah's Sage-Grouse Database. Conducted habitat surveys in sagebrush steppe ecosystem.

Bureau of Land Management, Twin Falls, ID — *Biological Technician*

May 2006 - October 2010

Demonstrated leadership as the interdisciplinary team leader on an Environmental Assessment involving a USFWS listed threatened species. Continued to develop management and leadership skills by successfully supervising BLM biological technicians. Responsibilities included training of proper protocols, data quality, scheduling, and field safety. Project was completed on time and included surveys of 144 sites across 600,000 acres. Successfully collected data of plant communities using a variety of protocols. Supervised technicians on livestock grazing mapping project. Processed field data using ArcGIS and created landscape scale maps of grazing use across pastures. Used Interpreting Indicators of Rangeland Health (IIRH) protocols to collect range condition and trend data. Developed Rangeland Health Indicator Evaluation Matrices for BLM field office. Conducted Ecological Site Inventories (ESI) and trained other technicians in ESI protocols. Inventoried BLM field office for USFWS listed species. Independently planned and conducted brush density maps using NAIP imagery and ArcGIS. Surveyed streams for presence of BLM listed imperiled species using electroshock techniques. Collected and maintained monitoring data on high priority allotments. Identified and inventoried noxious species populations for treatment.

Idaho Department of Fish and Game, Jerome, ID — *Volunteer Wildlife Technician*

May 2006 – October 2010

Worked with biologists trapping and radio-collaring greater sage-grouse. Helped track and monitor sage-grouse using radio telemetry. Conducted sage-grouse aerial surveys to estimate population numbers and identify new leks. Assisted with the capture and processing of Columbian sharp-tailed grouse using funnel traps. Trapped and processed mule deer using both drive nets and clover traps. Captured small mammals using Sherman traps to collect post-wildfire population data.

PUBLICATIONS

Dettenmaier SJ, Messmer TA, Hovick TJ, Dahlgren DK (2017). Effects of livestock grazing on rangeland biodiversity: a meta-analysis of grouse populations. *Ecology and Evolution*. 7, 7620-7627. doi:10.1002/ece3.3287.

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