CAN TARGETED CATTLE GRAZING INCREASE ABUNDANCE OF FORBS OR ARTHROPODS IN SAGE-GROUSE BROOD-REARING HABITAT?

by

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ABSTRACT

Suboptimal brood-rearing habitat often limits greater sage-grouse (*Centrocercus urophasianus*) populations in western North America. In mountain big sagebrush (*Artemisia tridentata* Nutt. ssp. *vaseyana* [Rydb.] Beetle) brood-rearing habitat, dense sagebrush canopy cover (> 25% cover) may limit the understory forbs and arthropods that sage-grouse prefer to eat during summer. Targeted cattle grazing is a potential habitat management tool to reduce dense sagebrush. This study evaluated targeted cattle grazing on a landscape scale to increase forbs and arthropods within core sage-grouse brood-rearing habitat. Objectives of this study were to evaluate how well targeted cattle grazing reduced mountain big sagebrush canopy cover, increased forb abundance and diversity, and increased arthropod abundance. Targeted cattle grazing was applied within two large, contiguous pastures (625 ha each) in the Beaverhead Mountains of southwestern Montana. The two pastures were grazed simultaneously at a light stocking rate (6.25 ha/AUM) for two weeks each year in mid-October 2015 and 2016. Vegetation and arthropod responses were measured during the following June-early July (2016 and 2017, respectively) within 32 microsites where mountain big sagebrush canopy cover exceeded 30% pre-treatment. Microsites were 0.008 ha to match the spatial scale at which sage-grouse broods select fine-scale habitat. One of two treatments was randomly assigned to each microsite: a low moisture block protein supplement or no supplement (unsupplemented). In the first summer after treatment, supplemented microsites averaged 78% less sagebrush canopy cover (8% vs. 36%; $P < 0.001$) and 25% more forb canopy cover (15% vs 12%; $P = 0.122$). Sage-grouse forb canopy cover was 50% greater in supplemented microsites (3% vs. 2%; $P = 0.003$). Forbs also comprised a greater proportion of the herbaceous understory in the supplemented vs. unsupplemented sites (48% vs. 36%; $P = 0.002$). Arthropod abundances were greater in supplemented than unsupplemented microsites only during the wet year of 2017 when arthropods were 1.7–1.8× more abundant in supplemented microsites. Sagebrush canopy cover was reduced by cattle trampling, not browsing. My results demonstrate that targeted cattle grazing can increase abundance of forbs and arthropods in mesic, dense stands of mountain big sagebrush in sage-grouse brood-rearing habitat.

CHAPTER ONE

INTRODUCTION

The greater sage-grouse (hereafter: sage-grouse) is a ground-dwelling bird that inhabits sagebrush rangelands (Patterson ,1952; Connelly et al., 2000b). Historically sage-grouse resided in portions of 16 western states and three Canadian provinces. However, due to habitat reduction, fragmentation and degradation and predation, hunting, and disease, sage-grouse occupy an estimated 56% of their historic range (Braun, 1998; Schroeder et al., 2004). Sage-grouse population declines within the last century have raised concerns about the future existence of sage-grouse on western rangelands (Connelly and Braun, 1997; Schroeder et al., 2004).

Declines of sage-grouse populations are partly attributed to the availability of brood-rearing habitat needed for juvenile sage-grouse chicks (Aldridge and Brigham, 2001; Crawford et al., 2004; Gregg, 2006; Atamian et al., 2010). During summer, sage-grouse females select areas with 10–25% sagebrush canopy cover, 10% forb canopy cover, and 15% grass canopy cover (Sveum et al., 1998; Connelly et al., 2000b) that provide arthropods and forbs important for juvenile sage-grouse diets (Klebenow and Gray, 1968; Crawford and Lutz, 1985; Barnett and Crawford, 1994; Drut et al., 1994b; Sveum et al., 1998; Thompson et al., 2006; Harju et al., 2013). Within the last century, sagebrush cover has increased in localized areas of western North America, which may have reduced the abundance of forbs and arthropods on sagebrush rangelands (Vale 1975; West, 1983; Miller et al., 1994; Jamison et al., 2002; Thompson et al., 2006).

Stands of mountain big sagebrush with >25% canopy cover can be treated with mechanical methods, fire, or herbicides to improve quality of sage-grouse brood-rearing habitat and improve brood survival (Pyle and Crawford, 1996; Dahlgren et al., 2006). However, these methods are costly and cannot be applied in some areas due to constraints imposed by topography or weather. Targeted livestock grazing, the application of livestock grazing and browsing to manipulate vegetation for habitat goals (Launchbaugh and Walker, 2006), is an alternative habitat management tool that can be applied in difficult terrain in most weather.

Previous studies have documented that sagebrush comprises a small proportion of cattle diets in mountain and foothill rangeland throughout all seasons (Ngugi et al., 1992; Torstenson et al., 2006), despite its high crude protein content (Wambolt, 2004). Cattle avoid consuming sagebrush because it contains post-secondary compounds, primarily terpenes (Johnson et al., 1976; Ngugi et al., 1995; Villalba et al., 2002). Terpenes in sagebrush are generally lower in late fall and winter than during spring or summer (Kelsey et al., 1982). Terpenes require biotransformation through digestion bio-chemical pathways to be excreted from ruminants (Foley et al., 1995). Protein supplementation can supply the additional energy and metabolites required for digestion and excretion of toxins (Illius and Jessop, 1996), including terpenes in sagebrush (Villalba et al., 2002). Given that protein supplement placed in dense sagebrush stands during late fall can attract cattle (Bailey and Welling, 1999), protein supplementation may enable cattle to reduce sagebrush canopy cover through browsing and trampling.

Recently, a targeted grazing study by Petersen et al. (2014) documented that protein-supplemented cattle reduced sagebrush canopy cover and increased forb and graminoid abundance in small, experimental pastures. However, additional research is needed to evaluate potential effects of this approach on a landscape scale. The purpose of this study was to evaluate protein-supplemented, targeted cattle grazing to increase sage-grouse food items within brood-rearing habitat. I had three primary objectives for this research. First, I evaluated the ability of cattle to reduce dense sagebrush canopy cover in supplemented microsites while grazing within large pastures. Second, I evaluated whether forb abundance and diversity increased in supplemented microsites. Lastly, I evaluated whether arthropod abundance increased in supplemented microsites.

CHAPTER TWO

LITERATURE REVIEW

It is important to define several important terms used throughout this thesis to avoid potentially unclear meanings (Hall et al., 1997; Krausman and Morrison, 2016). Habitat is defined as the environmental conditions (e.g., physical and biotic) that allows occupancy of an organism for survival and reproduction (Hall et al., 1997). Habitat type is defined as a unit of land that supports or is capable of supporting a specific climax plant community (Daubenmire, 1968). Vegetation type is defined as the current plant association that produces distinguishable characteristics that dominate the aspect or physiognomy of an area (Society for Range Management, 1998).

Sage-grouse Brood-Rearing Habitat

Brood-rearing habitat provides the necessary foraging resources and cover for sage-grouse chicks (Klebenow, 1969; Wallestad, 1971; Drut et al., 1994a; Gregg, 2006; Thompson et al., 2006; Hagen et al., 2007; Dahlgren, 2009; Kirol et al., 2012; Schreiber et al., 2015). Chick survival, an important sage-grouse population vital rate (Taylor et al., 2012), is highly influenced by the availability of food resources in brood-rearing habitat (Barnett and Crawford, 1994; Drut et al., 1994b; Gregg, 2006; Thompson et al., 2006; Dahlgren, 2009). Following hatching, sage-grouse broods transition from nesting habitat to early brood-rearing habitat, which is generally near nesting grounds in upland sagebrush plant communities (Gates, 1983; Connelly et al., 2000b). Broods may travel

between 1 and 18 km from nest sites to reach brood-rearing habitat (Wallestad, 1971; Holloran, 1999; Fedy et al., 2012). As summer progresses, sage-grouse broods transition to late summer brood-rearing habitat, which includes mesic uplands or mesic lowlands such as cropland, seeps, or irrigated pastures (Roscoe, 2002; Schreiber et al., 2015). Sage-grouse transition to late brood-rearing habitat as forbs mature and desiccate in early brood-rearing habitat (Klebenow, 1969). Sage-grouse broods often seek succulent, broad-leaved forbs and select mesic over xeric sites (Schreiber et al., 2015). Sage-grouse broods may remain in upland brood-rearing habitat throughout the summer if succulent forbs remain available (Wambolt et al., 2002b).

Sage-grouse broods benefit from a mosaic of vegetation structure, foraging species, and escape cover (Klebenow, 1985). Sage-grouse broods typically forage on the edges of large openings or meadows (Neel, 1980; Dunn and Braun, 1986; Klott and Lindzey, 1990) and avoid areas with dense sagebrush cover (Wambolt et al., 2002b). For example, sage-grouse in Wyoming avoided areas where total vegetation foliar canopy cover exceeded 75% (Schreiber et al., 2015). Sage-grouse use increases where habitat treatments (e.g., mowing or herbicide) create edge and openings in dense mountain big sagebrush (Dahlgren et al., 2006; Dahlgren et al., 2015; Baxter et al., 2017).

Sage-grouse prefer open shrub canopy for brood-rearing (Klebenow, 1969; Martin, 1970; Wallestad, 1971). Brood-rearing habitat has approximately 10–25% sagebrush canopy cover where sagebrush plants are 40–80 cm tall (Connelly et al., 2000b). Klebenow (1969) reported that sage-grouse brood-rearing habitat ranged from 9 to 25% sagebrush canopy cover in southeastern Idaho. Sage-grouse broods in

southwestern Montana used sites with 14% sagebrush canopy cover at six weeks of age and by late summer-early fall broods selected sites with 25% sagebrush canopy cover (Martin, 1970).

Sage-grouse brood-rearing habitat has a diverse herbaceous understory of graminoids and forbs that totals more than 15% canopy cover (Connelly et al., 2000b). Sage-grouse broods generally select areas with greater forb abundance than randomly available sites (Drut et al., 1994a; Sveum et al., 1998; Holloran, 1999; Hagen et al., 2007). Sage-grouse broods may also select areas with greater forb diversity than randomly available sites (Bunnell et al., 2004). In contrast, sage-grouse broods in xeric sagebrush habitats may select sites that provide greater shade to prevent chick heat stress rather than select sites with greater forb abundance (Kirol et al., 2012).

Sage-grouse Brood Diets

Arthropods are essential for satisfying the dietary protein requirements of sage-grouse chicks during the first three weeks after hatching (Klebenow, 1969; Johnson and Boyce, 1990). Important sage-grouse arthropod foods include Hymenoptera (e.g., ants), Coleoptera (e.g., beetles), larvae Lepidoptera (e.g., caterpillars), and Orthoptera (e.g., grasshoppers; Klebenow and Gray, 1968; Peterson, 1970; Drut et al., 1994b; Fischer et al., 1996; Gregg and Crawford, 2009; Thompson et al., 2006; Schreiber et al., 2015). Hymenoptera and Coleoptera comprise the majority of arthropods within sage-grouse chick diets (Klebenow and Gray, 1968; Peterson, 1970; Drut et al., 1994b). Orthoptera may comprise a larger portion of sage-grouse chick diets later during summer, after forbs

senesce (Klebenow and Gray, 1968; Peterson, 1970). Gregg and Crawford (2009) concluded that management of sage-grouse brood-rearing habitat should strive to favor arthropods, particularly Lepidoptera, to improve sage-grouse chick survival. Interestingly, Schreiber et al. (2015) noted that sage-grouse selected microsites in south-central Wyoming that provided more Diptera (e.g., flies) and fewer Coleoptera. However, the authors cautioned that this may have been because sage-grouse may have been selecting areas for cover rather than feeding.

Forbs generally begin to comprise a larger portion of sage-grouse diets after chicks reach one to two weeks of age (Klebenow and Gray, 1968; Thompson et al., 2006). Forbs are essential food items for sage-grouse (Klebenow and Gray 1968, Wallestad and Eng, 1975; Barnett and Crawford 1994, Drut et al., 1994b, Gregg et al., 2008). Drut et al. (1994b) observed 41 Families of arthropods and 34 genera of forbs were present in sage-grouse diets in Oregon. However, sage-grouse diets were dominated by only three Families of arthropods, 10 genera of forbs, and sagebrush. Asteraceae appears to be an important forb Family for sage-grouse diets in brood-rearing habitat (Girard, 1935; Pennington et al., 2016). When forbs and arthropods are limited, sage-grouse chicks will eat sagebrush leaves (Drut et al., 1994b).

During late September, sage-grouse transition from late summer brood-rearing habitat to winter habitat, which generally follows the desiccation of forbs (Wambolt et al., 2002b). Broods typically disperse and form large flocks that are gender-based during this transition (Braun et al., 2005). Sage-grouse will continue to forage on the last remaining succulent forbs such as buckwheat (*Eriogonum* Michx.; Braun et al., 2005).

Once the remaining forbs have desiccated, sage-grouse diets typically shift to sagebrush (Wallestad and Eng, 1975; Braun et al., 2005).

Regional differences in sage-grouse survival can be related to differences in arthropod and forb abundances (Drut et al., 1994a). The availability of certain food items such as Lepidoptera and slender phlox (*Microsteris gracilis* [Hook.] Greene) has been linked to the survival of sage-grouse chicks (Gregg and Crawford, 2009). Gregg (2006) documented that brood average daily movements tended to be greater in areas with lower forb abundances. The greater daily movements of foraging chicks may increase exposure risk to predators and subsequently decrease sage-grouse chick survival (Gregg 2006).

Habitat Variables Influencing Sage-grouse Forb and Arthropod Abundance

Moisture availability regulates perennial forb production in western North America (Miller et al., 2013). Therefore, vegetation treatments that reduce sagebrush canopy cover generally increase forb production on cool, moist sites, but not on sites with warmer soil temperatures (Miller et al., 2013; Bates et al., 2017). Annual forb production generally increases for two to five years after juniper (*Juniperus* L.) or sagebrush canopy is reduced, whereas perennial forb production generally remains greater for longer periods (Miller et al., 2013).

Arthropod abundance is positively related to forb abundance (Jamison et al., 2002; Thompson et al., 2006; Pennington et al., 2016). Habitat treatments such as fire can increase Orthoptera abundance due to increased forb availability (Evans, 1984; Porter and Redak, 1997). In Wyoming brood-rearing habitat, overall arthropod abundance was

negatively correlated to total sagebrush canopy cover (Thompson et al., 2006). In Montana, grazed pastures tend to have greater abundances of sage-grouse arthropods than non-grazed pastures (Goosey et al., 2017).

Ants are commonly one of the arthropods consumed most often by sage-grouse chicks (Klebenow and Gray, 1968; Peterson, 1970). In Wyoming big sagebrush habitat, western harvester ant (*Pogonomyrmex occidentalis*) abundance improved following sagebrush recovery from disking and mowing (Sneva, 1979; Hess, 2011). However, mesic sites may not promote ant availability due to ants preferring sandy, xeric sites over mesic locations (Kirkham and Fisser, 1972). Sage-grouse broods in Wyoming big sagebrush habitat selected sites with greater Hymenoptera availability and lower broad-leaf forb canopy cover (<20%), suggesting ants are likely more abundant in drier sites than mesic areas (Schreiber et al., 2015). Research on sage-grouse broods in western Wyoming noted that Hymenoptera and Coleoptera were positively correlated with total forb production (Thompson et al., 2006).

Sage-grouse and Livestock Grazing

Livestock grazing impacts on sage-grouse have been a contentious subject for many years (Smith et al., 2018). Livestock grazing can shape and influence wildlife habitat through altering plant composition, production of certain types of vegetation, forage nutritional quality, and vegetation diversity (Vavra, 2005). Livestock grazing can influence sage-grouse habitat quality positively and negatively (Beck and Mitchell, 2000; Crawford et al., 2004). A recent meta-analysis concluded that livestock grazing was

detrimental to grouse populations, however, the analysis included only four studies of European grouse populations and none from North America (Dettenmaier et al., 2017). The authors recommended additional research be conducted to evaluate the effects of livestock type, timing and frequency of grazing, duration, and stocking rate on grouse populations (Dettenmaier et al., 2017). Almost no studies are available that examine direct effects of livestock grazing on sage-grouse populations (Crawford et al., 2004; Boyd et al., 2014). Direct negative effects from livestock grazing may include nest abandonment and nest trampling; however, nest trampling is infrequent (Rasmussen and Griner, 1938; Patterson, 1952; Call, 1979).

The greatest indirect negative effect livestock may exert on sage-grouse is nesting and brood-rearing habitat quality (Beck and Mitchell, 2000; Boyd et al., 2014). Improperly managed livestock grazing can favor invasive weeds (Young and Longland, 1996) which may alter natural fire return intervals in sagebrush communities (Brooks et al., 2004). In addition, heavy livestock grazing in riparian meadows that decreases succulent forb availability may cause sage-grouse to avoid riparian meadows (Neel, 1980; Klebenow, 1982; Klebenow, 1985). Lastly, indirect negative effects from livestock grazing also include the conversion of sagebrush habitat to promote additional livestock forage (Braun et al., 1977).

Indirect positive effects from livestock grazing on sage-grouse may include increased abundances of forbs (Neel, 1980; Evans, 1986; Guttery, 2011). Hayfields and irrigated pastures also can provide sage-grouse additional foraging grounds for forbs and arthropods (Roscoe, 2002). A six-year study in central Montana recently concluded that

rest-rotation and rotational cattle grazing did not benefit sage-grouse nest survival rates compared with other grazing systems such as season-long grazing, and nest success did not limit sage-grouse in any areas moderately grazed by cattle, regardless of grazing system (Smith et al., 2018).

Sage-grouse Brood-rearing Habitat Treatments

Sagebrush treatments that create a mosaic of small openings within dense stands of sagebrush can produce more brood-rearing forbs (Dahlgren et al., 2006; Dahlgren et al., 2015). Herbicides, mechanical treatments, and prescribed fire can be used to reduce sagebrush cover, however, treatments are more likely to increase forbs in mountain big sagebrush plant communities that are more mesic than in Wyoming big sagebrush communities (*Artemisia tridentata* Nutt. ssp. *wyomingensis* Beetle & Young; Dahlgren et al., 2006; Thacker, 2010; Beck et al., 2012). Managers should insure that the treatment rate of dense sagebrush does not exceed the return interval of sagebrush (e.g., 15–25 years in mountain big sagebrush) to avoid removing too much sagebrush cover (Dahlgren et al., 2015).

Fire

Prescribed fire in mountain big sagebrush communities generally benefits sage-grouse. For example, small prescribed burns in mountain big sagebrush communities increased selection by sage-grouse on those sites (Thacker, 2010). Forb abundance typically increases following prescribed fire in mountain big sagebrush (Martin, 1990; Pyle and Crawford, 1996). In addition, Formicidae and total arthropod abundance also

typically increase following prescribed burns in mountain big sagebrush (Nelle et al., 2000; Davies et al., 2014). Mountain big sagebrush communities following fire generally recover within 15–25 years (Bunting et al., 1987; Moffet et al., 2015). However, in some mountain big sagebrush communities, sagebrush recovery following burning may require longer than 20 years (Lesica et al., 2007), which can impact local sage-grouse populations (Nelle et al., 2000).

Prescribed fire in Wyoming big sagebrush communities generally does not benefit sage-grouse. For example, loss of some sage-grouse breeding populations in southeastern Idaho was attributed to prescribed fire in Wyoming big sagebrush communities (Connelly et al., 2000a). Fischer et al. (1996) documented reduced abundance of insects following prescribed fire in Wyoming big sagebrush and three-tip sagebrush (*Artemisia tripartita* Rydb.) communities. Further, researchers have concluded no changes in long-term forb abundance (Wambolt and Payne, 1986) or forb nutritive quality following prescribed fire in Wyoming big sagebrush communities (Rhodes et al., 2010). In northeastern Wyoming, prescribed fire in sage-grouse nesting and early brood-rearing habitat did not meet habitat guidelines suggested by Connelly et al. (2000b) for sagebrush canopy cover, sagebrush height, or graminoid cover 8–19 years post fire in Wyoming big sagebrush (Hess and Beck, 2012).

Herbicide

Herbicide treatment is also a common method to improve livestock and wildlife forage resources in sagebrush communities (Vale, 1974). Applications of 2,4-dichlorophnoxyacetic acid (2,4-D) in the 1960s and 1970s negatively impacted sage-

grouse in central and southwestern Montana (Martin, 1970; Wallestad, 1975). Recovery of mountain big sagebrush canopy cover and density to pre-treatment levels following 2,4-D application may require > 20 years following application (Sturges, 1993). In Utah, small areas treated with a low rate of tebuthiuron in mountain big sagebrush stands during fall were favored by sage-grouse broods in the subsequent years following treatment (Dahlgren et al., 2006). The authors attributed sage-grouse selection of treated stands over untreated stands to the increase in available forbs and the remaining sagebrush skeletons that provided cover. In Wyoming big sagebrush stands, forbs decrease following fall applications of imazapic at high rates (Baker et al., 2009). However, forbs do not decrease when imazapic is applied at low rates during fall (Kyser et al., 2007). Because the impacts of chemical treatments on sagebrush and sage-grouse are quite variable, managers should consider factors such as application rate (low vs. high), timing (e.g., spring vs. summer), type of herbicide, and sagebrush sub-species when using herbicide to thin dense sagebrush cover to improve sage-grouse habitat quality.

Mechanical

Sage-grouse generally benefit from mechanical treatments that reduce, but do not eliminate, sagebrush cover in mountain big sagebrush communities (Dahlgren et al., 2006; Dahlgren et al., 2015; Baxter et al., 2017). Mountain big sagebrush distribution follows closely to mesic precipitation zones, compared to Wyoming big sagebrush which inhabits xeric sites (Wambolt et al., 2002a). Additional precipitation in mountain big sagebrush communities provides for additional herbaceous growth such as forbs when

sagebrush cover and resource competition are reduced (Bunting et al., 1987; Miller et al., 2013).

In Wyoming big sagebrush plant communities, Hess (2011) documented that arthropods such as ants can increase from 3.5 to 9.1 times in abundance following mowing treatments. However, nine years after mowing, only one of four sites had sufficient sagebrush canopy cover for sage-grouse nesting and brood-rearing (Hess and Beck 2012). Mowing of Wyoming big sagebrush in southeastern Oregon did not increase forbs or perennial grasses while invasive annual grasses increased (Davies et al., 2011).

Targeted Grazing Effects on Sagebrush and Decadent Herbaceous Vegetation

Targeted livestock grazing is the application of livestock grazing and/or browsing to manipulate vegetation for habitat goals (Launchbaugh and Walker, 2006), such as to increase habitat heterogeneity to benefit upland passerines (Derner et al., 2009). Beck and Mitchell (2000) suggested that moderate livestock grazing within sage-grouse brood-rearing habitat can benefit sage-grouse through increased forb abundance. Herbicide, mechanical, and prescribed fire treatments for manipulating habitat are expensive (Cleaves et al., 1999; Dahlgren et al., 2006; Sheley et al., 2014). Targeted grazing to reduce sagebrush cover may be more cost-effective and easier to apply in terrain and weather conditions that impede herbicide, mechanical, and prescribed fire treatments.

Sheep grazing has been suggested as the most effective tool to reduce sagebrush canopy via targeted grazing (Blaisdell et al., 1982). Research conducted by Dziba et al. (2007) indicated that sheep browsing can decrease sagebrush and increase biodiversity

when protein supplement is strategically located where sagebrush cover is dense. Guttery (2011) demonstrated that protein-supplemented sheep can reduce sagebrush cover by 68% in small experimental pastures (e.g., 3.2 ha). Sage-grouse also responded positively from the grazing effects and selected sheep-grazed pastures over ungrazed pastures. Guttery (2011) suggested that intensive sheep grazing is likely impractical to apply as a large-scale treatment due to the intensive management required. In southern Idaho, fall sheep grazing reduced three-tip sagebrush cover while increasing the abundance of forbs and grasses (Laycock, 1979). Grasses and forbs were dormant and tolerated grazing during fall, whereas heavy sheep grazing when grasses and forbs were actively growing during spring reduced their abundance and increased three-tip sagebrush density (Laycock, 1979).

Cattle typically consume grass-dominated diets (Rook et al., 2004) and avoid browsing sagebrush due to post-secondary compounds, primarily terpenes (Johnson et al., 1976). Sagebrush is a minor component of cattle diets throughout all seasons in the northern Rocky Mountain region (e.g., ≤ 1.0%; Ngugi et al., 1992; Torstenson et al., 2006). Cattle grazing during winter likely results in the greatest ingestion of sagebrush as monoterpenes are lowest during this period (Kelsey et al., 1982). Mountain big sagebrush is likely to be consumed the most due to its higher palatability compared with other big sagebrush subspecies (Wambolt, 1996).

In mixed stands of Wyoming big sagebrush and basin big sagebrush (*Artemisia tridentata* Nutt. spp. *tridentata*) in northeastern Nevada, targeted cattle grazing reduced sagebrush canopy cover by 34–39% (Petersen et al., 2014). During late fall and early

winter, high-density cattle grazing (62,501 kg/ha to 76,810 kg/ha live cattle weight) was applied in small experimental pastures (0.2 ha) for 5–7 days. Pastures were dominated by dense sagebrush. A protein supplement was made available to aid in the digestion of the sagebrush foliage during the grazing trials. Peterson et al. (2014) documented that forb and grass composition increased, while sagebrush composition decreased by as much as 69%. Cattle were reported to consume dormant herbaceous vegetation initially before consuming sagebrush (Petersen et al., 2014).

Targeted cattle grazing was examined in southwestern Montana to reduce dense Wyoming big sagebrush (Wambolt and Watts, 1996). Four treatments were applied in August of three consecutive years: a moderate stocking rate (1.6 ha/AUM), twice the moderate stocking rate (0.8 ha/AUM); four times the moderate stocking rate (0.4 ha/AUM), and eight times the moderate stocking rate (0.2 ha/AUM). After three consecutive years of treatment, Wyoming big sagebrush canopy cover was reduced from about 30–35% to 25% or 20% with 4× and 8× the moderate stocking rate, respectively. However, perennial grass production did not increase, and total herbaceous cover decreased (Wambolt and Watts, 1996).

In central New Mexico, researchers examined strategic supplement placement and low-stress cattle herding to improve pronghorn (*Antilocapra americana*) forage quality (Pollak, 2007). Cattle were herded to a 20% CP supplement in decadent, mature forage areas during June-July. Forb and grass regrowth was measured in August of the same year. Cattle supplement intake averaged 0.32 kg/hd/day. Annual forb cover trended higher in targeted grazing treatments, however, perennial forb canopy cover did not differ

in treated and untreated areas. Pronghorn use trended greater in treated areas, due to the formation of cattle trails and increased annual forb abundance within treated locations (Pollak, 2007).

Ralphs and Banks (2009) studied targeted cattle grazing of broom snakeweed (*Gutierrezia sarothrae* [Pursh] Britton & Rusby) in central Utah. High-intensity cattle grazing reduced broom snakeweed primarily through the trampling of seedlings and consumption without impacting the crested wheatgrass (*Agropyron cristatum* [L.] Gaertn.) stand (Ralphs and Banks, 2009). A pre-conditioning study noted that supplemented cattle consumed more boom snakeweed than non-supplemented cattle in a pen setting (Ralphs and Wiedmeier, 2004). However, free-ranging diets between supplemented and non-supplemented cattle did not differ.

In Texas, targeted cattle grazing is used to enhance habitat for bobwhite quail (*Colinus virginianus*; Hernández and Guthery, 2012). Like sage-grouse, bobwhite quail require diverse habitat to fulfill their life history (Guthery, 1997). Managers often use heavy cattle grazing in localized areas through placement of supplement, water, salt, or hay to create patches of disturbance, which increases the abundance of forbs that benefit bobwhite quail (Hernández and Guthery, 2012). An important characteristic of this management is the repositioning of heavy, spot grazing throughout a pasture as to avoid repeated overuse in certain locations. Additionally, it’s important to keep spot-grazing within 50 m of brush so that bobwhites can quickly access escape cover (Hernández and Guthery, 2012).

Effects of Supplementation on Sagebrush Intake

Domestic livestock limit intake of sagebrush because it contains post-secondary compounds, primarily terpenes (Johnson et al., 1976; Ngugi et al., 1995; Villalba et al., 2002). Terpenes must be eliminated and detoxified from mammals to maintain physiologic function and meet nutrient requirements (Sorensen et al., 2005; Dziba et al., 2006). Terpenes have antimicrobial properties and decrease digestibility within ruminants (Oh et al., 1968; Connolly et al., 1980). The specific mode of action from terpenes is believed to be the systematic disruption of cell membranes and liver damage following absorption (Foley and McArthur, 1994).

Terpenes require biotransformation through digestion bio-chemical pathways to be excreted (Foley et al., 1995). Livestock that consume large amounts of terpenes require additional macronutrients to detoxify the terpenes (Villalba et al., 2002). Terpenes conjugate with compounds including glutathione, glycine, and sulfate to increase water solubility (Cheeke and Shull, 1985; Cheeke, 1998), which disrupt the acid base balance through the addition of organic acids (Foley et al., 1995). Glucose and catabolized amino acids are depleted through conjugation (Illius and Jessop, 1995). Therefore, supplementing protein in animal diets should allow for greater intake of forages with post-secondary compounds (Illius and Jessop, 1996).

Villalba et al. (2002) documented that the protein to energy ratio in sheep diets affects sagebrush intake. Protein-supplemented sheep consumed more sagebrush than energy-supplemented sheep. Sheep fed both an energy and protein supplement had intake levels of sagebrush similar to the protein-supplemented sheep (Villalba et al., 2002). The

energy-supplemented sheep were believed to have lower overall sagebrush intake due to the potentiating effects of terpenes on cellulolytic actions on rumen microbes (Nagy and Tengerdy, 1968). Dziba et al. (2007) reported similar results, such that sagebrush ingestion increased in diets of sheep when fed both an energy and protein supplement when compared to unsupplemented sheep. Frequency of feeding on sagebrush was twice as great with supplemented than unsupplemented sheep. Dziba et al. (2007) concluded that supplementation improved sagebrush utilization, as greater uptake of nutrients from supplement allowed for an enhanced rate of terpene detoxification (Freeland and Janzen, 1974; Guglielmo et al., 1996).

CHAPTER THREE

METHODS

Study Area

The study was located in two contiguous pastures (each c.a., 625 ha) on mesic, upland rangeland within the Beaverhead Mountains in southwestern Montana. These pastures contained occupied sage-grouse brood-rearing habitat (Roscoe, 2002). The dominant shrub species in these pastures was mountain big sagebrush, with scattered plants of three-tip sagebrush also present. Dominant graminoids were Idaho fescue (*Festuca idahoensis* Elmer), bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) Á. Löve), prairie junegrass (*Koeleria macrantha* (Ledeb.) Schult.), timber oatgrass (*Danthonia intermedia* Vasey) and Liddon sedge (*Carex petasata* Dewey). Common forbs included silky lupine (*Lupinus sericeus* Pursh), western yarrow (*Achillea millefolium* L. var. *occidentalis* DC.), sulphur-flower buckwheat (*Eriogonum umbellatum* Torr.), common dandelion (*Taraxacum officinale* F.H. Wigg.); pale agoseris (*Agoseris glauca* [Pursh] Raf.), and lambstongue ragwort (*Senecio integerriums* Nutt.). The pastures were dominated by native vegetation and were unaffected by invasive vegetation (e.g., cheatgrass [*Bromus tectorum* {L.}]).

Within each of the two pastures, a 4-ha macroplot of dense sagebrush was selected within the sticky purple geranium (*Geranium viscosissimum* Fisch. & C.A. Mey, ex C.A. Mey) phase of the big sagebrush/Idaho fescue habitat type (Mueggler and Stewart, 1980). The ecological site was Loamy within the Central Rocky Mountains

Major Land Resource Area (USDA-NRCS, 2018a,b), and both macroplots had the same slope (2-10˚), aspect (northeastern), and elevation (2130 m). A 40-cm deep soil pit was dug near the center of each macroplot, and soils of both macroplots were classified in the field as Ustic Argicryolls (Soil Survey Staff, 2015).

The 30-year average annual precipitation was 475 mm (Montana Climate Office, 2018). Total precipitation was 9% below and 10% above the 30-year average in 2016 and 2017, respectively (National Centers for Environmental Information, 2018). Crop-year precipitation (Sneva and Hyder, 1962; Sneva and Britton, 1983) was 3% below and 18% above the 30-year average for 2015-2016 and 2016-2017, respectively (National Centers for Environmental Information, 2018). Spring precipitation (April-June; Sharp, 1970; Smart et al., 2007) was 26% below and 36% above the 30-year average for 2016 and 2017, respectively (National Centers for Environmental Information, 2018). Collectively, these data indicate that 2016 can be characterized as a dry year and 2017 can be characterized as a wet year.

Sage-grouse require more sagebrush canopy cover in nesting habitat than in brood-rearing habitat (Connelly et al., 2000b). Therefore, vegetation treatments to reduce sagebrush canopy cover in brood-rearing habitat should not occur within 5 km of sage-grouse nesting habitat (Manier et al., 2014). The dense sagebrush macroplots selected within my study area were located 7–9 km from documented nesting habitat. Sage-grouse commonly travel 1–18 km from nesting sites to reach brood-rearing habitat (Wallestad, 1971; Holloran, 1999; Fedy et al., 2012).

Experimental Design

Experimental design was a randomized complete block in a split-split plot arrangement. Each 4-ha block (i.e., macroplot) was split into four quadrants (NW, NE, SW, and SE). Each quadrant was split into two subplots for treatment in either October 2015 or October 2016 (n = 8 subplots per block). Years were assigned randomly to subplots. Each subplot was split into two sub-subplots for treatment with or without protein supplement (n = 16 sub-subplots per block). Treatments were assigned randomly to sub-subplots. Within each sub-subplot, a 78.5-m^2 microsite (with or without a LMB biobarrel) was identified where pre-treatment sagebrush canopy cover exceeded 30%. Thus, quadrant was the whole plot factor, year was the sub-plot factor, and treatment was the sub-subplot factor (Table 1).

Targeted Cattle Grazing

Targeted cattle grazing was applied in October 2015 and October 2016. No livestock grazing occurred within the pastures during any other time of year from November 2014 through July 2017. Microsites treated with or without protein supplement in October 2015 were temporarily fenced with 1.2-m high mesh wire to exclude cattle grazing during the October 2016 grazing period.

A fall grazing application was selected to coincide with lower terpenes in sagebrush that might encourage consumption by cattle. Fall grazing also coincided with grass and forb plant dormancy to limit potential negative impacts from cattle grazing and trampling. Each year cattle grazed both pastures simultaneously at a light stocking rate

Table 1. Sources of variation and degrees of freedom for the randomized complete block design in a split-split plot arrangement.

Source		*df*
Block	(r-1)	1
Quadrant	(a-1)	3
Error A	(r-1)(a-1)	3
Year (of treatment)	(b-1)	1
Quadrant x Year	(a-1)(b-1)	3
Error B	a(r-1)(b-1)	4
Treatment	(c-1)	1
Quadrant x Treatment	(a-1)(c-1)	3
Year x Treatment	(b-1)(c-1)	1
Quadrant x Year x Treatment	(a-1)(b-1)(c-1)	3
Error C	ab(r-1)(c-1)	8*
Total	rabc-1	31

* Less one *df* for covariate

(0.13 to 0.14 AUM/ha: 210 cows per pasture for 14 days in 2015 and 153 cows per pasture in 2016 for 17 days in 2016). Upon entering the pastures each fall, cattle were herded to the 4-ha macroplot in each pasture where protein supplement was available. Riders on horseback held the herd at the macroplot for 20 minutes to familiarize the cattle with supplement location. Subsequently, cattle were not herded at any time during the grazing period each year. Cattle obtained drinking water from stock tanks and streams available throughout each pasture.

Protein supplement was provided via 100-kg low-moisture block (LMB) biobarrels (Crystalyx® BGF-30). The supplement was molasses-based with 30% crude protein, formulated for cattle consuming moderate- to low-quality forages (Ridley Block Operations, 2015). LMB biobarrels were placed within each macroplot immediately prior to cattle entering the pastures with LMB biobarrels located 40–50 m apart (14 LMB biobarrels per macroplot in 2015 and 12 LMB biobarrels per macroplot in 2016 at a rate of 15 or 13 cows per barrel in 2015 and 2016, respectively). The LMB biobarrels did not contain salt therefore, per the manufacturer's recommendation, six salt blocks (27 kg, 99.99% NaCl) were also placed within each macroplot, with each salt block spaced 20 to 50 m away from neighboring LMB biobarrels and other salt blocks. At the end of each grazing period in 2015 and 2016, all LMB biobarrels and salt blocks were removed. All LMB biobarrels and salt blocks were weighed after the grazing periods to determine average daily intake of supplement and salt by cattle.

Data Collection and Laboratory Analyses

To evaluate the reduction of sagebrush canopy cover via grazing, trampling, or both at LMB biobarrel sites, botanical composition of cattle diets was sampled in October 2015 and October 2016 with two techniques: bite-count (Sanders et al., 1980) and microhistology (Sparks and Malechek, 1968). The bite-count technique quantified cattle diets while cattle were grazing/browsing within each macroplot, whereas microhistological analysis of fecal samples quantified diets while cattle were grazing throughout the pastures.

For both observation years, observers used focal animal sampling (Altmann, 1974) to watch individual cows for 10 minutes and record the number of herbaceous and sagebrush bites. After 10 minutes, observers randomly selected another cow. Individual cows were only observed once during a sampling period. In 2015, bite-count observations were assessed during three sampling periods over the 14-day grazing period: days 3–4, 8–9, 13–14. Within each of the three 2015 sampling periods, each macroplot was visited daily to observe cattle diets during morning (07.30–10.00h), mid-day (11.30–14.00h), and afternoon (15.30–16.00h). In 2016, bite-count observations were made on the 5th and 11th day of the 17-day grazing period, and two observers recorded bite counts in both macroplots simultaneously from 07.00–17.00h. The 2016 sampling protocol provided greater observation of cattle diets within the macroplot throughout the day.

I collected fecal samples for microhistological assessment of cattle diets outside the macroplots. In 2015, I collected 10 random, fresh fecal samples from throughout each pasture on the 5th, 10th, and 14th days of the grazing trial. In 2016, I collected 10 fresh,

fecal samples from throughout each pasture on the 5th and 11th days of the grazing trial. I composited each day's 10 fecal samples into one sample per day per pasture and then prepared microhistological slides following the procedures of Davitt and Nelson (1980). From each composite fecal sample, 6 slides were analyzed with 25 microscope views per slide (n = 150 views per sample). Slides were viewed with ×10 magnification; however, ×63 magnification was used when needed to identify some epidermal fragments. I identified plant epidermal fragments to life form (graminoid, forb, or shrub). However, sagebrush was identified to genus. Within each of the 25 views, the frequency of graminoid, forb, sagebrush, and other shrubs was recorded. Diet composition was determined through the frequency addition method as described by Holechek and Gross (1982).

Bunchgrass utilization within each macroplot was measured at the end of each grazing period in October 2015 and October 2016. Four 200-m transects radiating in the cardinal directions from the center of each macroplot were used to measure cattle utilization using the Grazed Class Method (Schmutz et al., 1963). The utilization of the nearest bunchgrass was measured every two meters along the transects (n = 400 bunchgrasses per macroplot per year).

Vegetation, soils, and arthropods were sampled within 5-m radius circular sampling units (78.5-m^2 microsites with or without a LMB biobarrel, where pretreatment sagebrush canopy cover exceeded 30%). These 78.5-m^2 microsites corresponded to the size of patches that sage-grouse select for fine-scale habitat (Drut et al., 1994a; Gregg et al., 1994; Sveum et al., 1998; Gregg and Crawford, 2009). Vegetation and soil

disturbance was sampled during late June – early July 2016 and 2017 to correspond when sage-grouse chicks within the study area shift from arthropods to herbaceous diets (Roscoe, 2002). Four 5-m transects radiated in the cardinal directions from the center of each microsite. Herbaceous canopy coverage and herbaceous composition were measured with the Daubenmire Canopy Coverage Method (Daubenmire, 1959) modified with seven cover classes (Bailey and Poulton, 1968). The 20 × 50-cm quadrats were spaced at 1-m intervals on each transect (n = 20 quadrats per microsite). Forb species richness was recorded through frequency within each Daubenmire quadrat (Coulloudon et al., 1999). Canopy cover of sage-grouse forbs (i.e., forbs documented in the literature in sage-grouse diets; Girard, 1935; Braun et al., 2005; Stiver et al., 2015) were quantified from the species-level Daubenmire data. Forb species richness and Shannon Diversity Index values were calculated within each microsite (Shannon, 1948). The natural or average droop height of the tallest overhanging forb, grass, and sagebrush plant was measured within each Daubenmire quadrat (Stiver et al., 2015). Sagebrush canopy cover was measured with line intercept as described by Stiver et al. (2015). Soil disturbance was assessed with the soil/site stability attribute of the Interpreting Indicators of Rangeland Health (Pellant et al., 2005).

Arthropods were sampled in mid-June to correspond when sage-grouse chick diets within the study area are dominated by arthropods (Roscoe, 2002). Sage-grouse adults and chicks forage for food resources such as arthropods on the ground (Girard, 1935; Schroeder et al., 1999). Ground-dwelling arthropod abundance was measured with four pitfall traps (each, 7-cm diameter × 6-cm depth) in each supplemented and

unsupplemented microsite (Greenslade, 1964; Luff, 1975; Melbourne, 1999; Standen, 2000). Pitfall samples were collected twice per year with a 10-day interval during mid-June in 2016 and 2017. Each of the four sampling transects had one pitfall trap randomly located along its 5-m length. Pitfall traps were dug into ground level and half-filled with propylene glycol (Preston Low Tox® antifreeze/coolant). Pitfall traps were collected after 24 hours following the procedures of Nelle et al. (2000). During collection, pitfall samples were placed in sealed containers with antifreeze/coolant. Following collection, arthropod samples were cleaned and stored in 70% ethyl alcohol. Arthropod samples were identified to the common Orders of arthropods consumed by sage-grouse chicks: Coleoptera, Hymenoptera, Orthoptera, and Lepidoptera (Klebenow and Gray, 1968; Peterson, 1970; Drut et al., 1994b; Gregg and Crawford 2009). Coleoptera, Hymenoptera, and Orthoptera samples were separated further into common arthropod Families consumed by sage-grouse chicks (i.e., Families comprising ≥1.0% of sage-grouse chick diets; Klebenow and Gray, 1968; Peterson, 1970; Drut et al., 1994b). Common arthropod Families consumed by sage-grouse chicks include Formicidae, Tenebrionidae (e.g., darkling beetles), Scarabeidae (e.g., scarab beetles), Chrysomelidae (e.g., leaf beetles), Coccinellidae (e.g., ladybugs), Curculionidae (e.g., true weevil beetles), and Acrididae (e.g., grasshoppers). The Family Carabidae (e.g., ground beetles) was also included in the Families commonly consumed by sage-grouse chicks as they are often misidentified as Tenebrionidae (Hayes B. Goosey, personal communication). Common arthropod Families consumed by sage-grouse were separated by life form, such that only ground-dwelling life stages (e.g., larvae) that are available to sage-grouse were counted. Winged

(i.e., volant) adults were not counted. Lepidoptera larvae were included in the total count of arthropods from Families consumed by sage-grouse chicks.

Statistical Analyses

Vegetation data were analyzed with analysis of covariance (ANCOVA; Table 1). The GLIMMIX procedure of SAS (SAS Institute, 2017) was used to examine the following response variables: mountain big sagebrush canopy cover, total sagebrush canopy cover, and total shrub canopy cover; total forb canopy cover, sage-grouse forb canopy cover, and grass canopy cover; forb and graminoid composition; forb species richness and forb Shannon Index diversity; and grass height, forb height, and sagebrush height. When percentage data were not distributed normally, I used the beta distribution as recommended by Eskelson et al. (2011). Distance from the center of each microsite to the nearest supplement biobarrel or salt block was included as a covariate to account for potential influences on cattle foraging behavior. Models were reduced when interactions were non-significant ($P > 0.15$). All interactions that included quadrant were pooled within the model as they provided no biological inference.

Arthropod count data were analyzed with generalized linear models in the GENMOD procedure of SAS (SAS Institute, 2017). The response variables examined were the count (*n*) of Formicidae, count (*n*) of Coleoptera (those consumed by sage-grouse), count (*n*) of total sage-grouse arthropods by Family (i.e., ground-dwelling arthropods from Families documented in the literature to be consumed by sage-grouse), and count (*n*) of total sage-grouse arthropods by Order (i.e., ground-dwelling arthropods

from Orders documented in the literature to be consumed by sage-grouse). A negative binomial distribution was used in the GENMOD procedure of SAS (SAS Institute, 2017) to appropriately model arthropod count data (Sileshi, 2006). When arthropod variables were overdispersed, a Poisson distribution corrected for overdispersion was utilized with the DSCALE option (Proc GENMOD; SAS Institute, 2017; Sileshi, 2006; Goosey, 2012). Distance from the center of each microsite to the nearest supplement biobarrel or salt block was included as a covariate to account for potential influences on cattle foraging behavior. Models were reduced when interactions were non-significant ($P > 0.15$). All interactions that included quadrant were pooled within the model as they provided no biological inference.

Null Hypotheses

1. Mountain big sagebrush canopy cover, total sagebrush canopy cover, total shrub canopy cover, and sagebrush height did not differ between supplemented or unsupplemented treatments.
2. Sage-grouse forb canopy cover, total forb canopy cover, graminoid canopy cover, forb composition, forb species richness, forb Shannon Index diversity, graminoid height, forb height, and soil/site stability did not differ between supplemented or unsupplemented treatments.
3. Density of Formicidae, Coleoptera, total sage-grouse arthropods by Family during ground-dwelling life stages, and total sage-grouse arthropods by Order did not differ between supplemented or unsupplemented treatments.

CHAPTER FOUR

RESULTS

Cattle Diets

Supplement consumption averaged 0.26 kg/day/cow (0.24 kg/day/cow in 2015 and 0.28 kg/day/cow in 2016). Cattle utilization of perennial bunchgrasses within pasture macroplots averaged 9% (10.5% in 2015 and 7.4% in 2016). In 2015 and 2016, cattle botanical diet composition was 100% herbaceous forage (e.g., perennial bunchgrass) in the macroplots (bite counts) and pastures (microhistology). Each year, sagebrush comprised only a trace amount (< 0.25%) within cattle diets in the macroplots and pastures.

Vegetation and Soil Response

Shrubs

Mountain big sagebrush canopy cover response to targeted cattle grazing varied by year (Year × Treatment, $P = 0.087$; Table 2). However, mountain big sagebrush canopy cover was reduced in supplemented versus unsupplemented 0.008-ha microsites in both years, decreasing from 33% to 6% in 2015 ($P < 0.001$) and from 38% to 10% in 2016 ($P < 0.001$).

Response of total sagebrush canopy and total shrub cover also varied by year (Year × Treatment, $P = 0.050$ and $P = 0.054$, respectively; Table 2). However, total sagebrush canopy cover and total shrub cover were reduced in supplemented microsites

Table 2. Vegetation response in supplemented and unsupplemented microsites after targeted cattle grazing during October 2015 or 2016 within sage-grouse brood-rearing habitat in southwestern Montana. Vegetation response was sampled the following summer in late June/early July 2016 or 2017, respectively (n = 8 microsites per treatment per year).

	Year														
	2015-2016					2016-2017					Mean				
	Supplemented		Unsupplemented			Supplemented		Unsupplemented			Supplemented		Unsupplemented		
Vegetation Variable	Mean	SE	Mean	SE	*P*	Mean	SE	Mean	SE	*P*	Mean	SE	Mean	SE	*P*
Canopy Cover (%)															
Mountain Sagebrush	6.00	0.99	33.38	3.13	<0.001	10.00	0.75	37.88	2.63	<0.001	8.00	2.00	35.63	2.25	<0.001*
Total Sagebrush	6.00	0.99	34.13	3.88	<0.001	10.25	1.00	37.88	2.63	<0.001	8.13	2.13	36.00	1.88	<0.001*
Total Shrub	6.13	0.88	34.38	4.13	<0.001	10.38	1.13	37.88	2.63	<0.001	8.25	2.13	36.13	1.88	<0.001*
Sage-grouse Forbs	2.50	0.50	1.13	0.13	0.009	38.75	1.38	23.75	1.13	0.099	3.19	0.69	1.75	0.63	0.003
Forbs	12.63	0.88	9.88	3.88	0.514	17.75	2.75	13.63	1.13	0.203	15.19	2.56	11.75	1.88	0.122
Graminoids	15.13	2.63	19.50	4.25	0.017	16.50	2.00	20.00	2.25	0.048	15.81	0.69	19.75	0.25	0.002
Herbacous Composition (%)															
Forbs	44.75	5.75	32.88	13.88	0.064	51.75	6.50	40.13	4.38	0.012	48.25	3.50	36.50	3.63	0.002
Graminoids	55.25	5.75	67.12	13.88	0.064	48.25	6.50	59.87	4.38	0.012	51.75	3.50	63.50	3.63	0.002
Forb Diversity															
Species Richness	3.55	0.15	2.74	0.61	0.062	3.89	0.11	3.48	0.06	0.224	3.72	0.17	3.11	0.37	0.017
Shannon Index	0.87	0.04	0.72	0.17	0.13	0.95	0.02	0.87	0.01	0.542	0.91	0.04	0.80	0.08	0.089
Height (cm)															
Forb Height	10.45	0.49	12.13	1.91	0.223	12.41	1.30	16.24	1.68	0.149	11.43	0.98	14.18	2.05	0.048
Grass Height	19.47	0.38	28.65	1.16	0.001	24.75	0.01	32.67	1.44	0.006	22.11	2.64	30.66	2.01	<0.001
Sagebrush Height	46.73	1.89	81.62	7.69	0.002	36.78	4.69	71.34	2.68	<0.001	41.76	4.98	76.48	5.14	<0.001

* Year × Treatment interaction significant ($P \leq 0.10$).

in both 2015 and 2016 (Table 2). Overall, in the first summer following targeted cattle grazing during the preceding fall, total sagebrush canopy cover across years averaged 8% in supplemented microsites versus 36% in unsupplemented microsites. Sagebrush height averaged 41.8 cm and 76.5 cm in supplemented and unsupplemented microsites, respectively ($P < 0.001$; Table 2).

Forbs and Graminoids

Sage-grouse forb canopy cover and total forb canopy cover increased from 1.8% to 3.2% and from 11.8% to 15.2%, respectively, in unsupplemented and supplemented microsites ($P = 0.003$ and $P = 0.122$, respectively; Table 2). Forb composition (i.e., the proportion of the understory comprised by forbs) increased from 36.5% to 48.2% in unsupplemented and supplemented microsites, respectively ($P = 0.002$; Table 2). Forb height decreased from 14.2 cm to 11.4 cm in unsupplemented and supplemented microsites, respectively ($P = 0.048$; Table 2). Forb species richness and diversity were greater in supplemented than unsupplemented microsites (Table 2). Forb species richness increased from 3.1 to 3.7 in unsupplemented and supplemented microsites, respectively ($P = 0.017$). Forb Shannon Diversity Index increased from 0.80 to 0.91 in unsupplemented and supplemented microsites, respectively ($P = 0.089$).

Grass canopy cover decreased from 19.8% to 15.8% in unsupplemented and supplemented microsites, respectively ($P = 0.002$; Table 2). Grass height was reduced from 30.7 cm to 22.1 cm in unsupplemented and supplemented microsites, respectively ($P < 0.001$).

Soil/Site Stability

Soil/site stability did not differ between supplemented and unsupplemented microsites in either 2016 and 2017, with departure from natural capability for soil/site stability rated none to slight on all microsites. Rills, water-flow patterns, pedestals and/or terracettes, gullies, wind-scouring/blowouts or deposition areas, litter movement, soil surface resistance to erosion, soil surface loss or degradation, and compaction layers were rated none to slight for departure from natural capability in all microsites. Bare ground was the only individual indicator affected by targeted cattle grazing. Bare ground in all supplemented microsites had slight to moderate departure from natural capability whereas departure for bare ground was none to slight in all unsupplemented microsites.

Arthropod Response

Arthropods were more numerous in supplemented versus unsupplemented microsites, but statistically significant differences ($P \leq 0.15$) were identified in 2017 only (Table 3). Overall densities of Formicidae, Coleoptera, and total sage-grouse arthropods by Family and Order were 43%, 17%, 42%, and 42% greater, respectively, in supplemented versus unsupplemented microsites. In 2017, densities of Formicidae and total sage-grouse arthropods by Family were 1.8× and 1.7× greater, respectively, in supplemented microsites ($P = 0.115$ and $P = 0.114$, respectively).

Table 3. Arthropod response in supplemented and unsupplemented microsites after targeted cattle grazing during October 2015 or 2016 within sage-grouse brood-rearing habitat in southwestern Montana. Arthropod response was sampled the following summer in mid- to late-June 2016 or 2017, respectively (n = 8 microsites per treatment per year).

	Year														
	2015-2016					2016-2017					Mean				
	Supplement		Unsupplemented			Supplement		Unsupplemented			Supplement		Unsupplemented		
Arthropod Density	Mean	SE	Mean	SE	*P*	Mean	SE	Mean	SE	*P*	Mean	SE	Mean	SE	*P*
Formicidae	35.08	17.47	38.91	3.05	0.323	42.10	35.81	15.22	3.47	0.115	38.59	3.51	27.07	11.85	0.796†
Coleoptera	0.16	0.00	0.10	0.04	0.846	0.11	0.05	0.13	0.03	0.289	0.14	0.03	0.12	0.01	0.541
Total Sage-grouse Arthropods (Family)	35.41	17.49	39.20	3.17	0.328	42.35	35.83	15.47	3.42	0.114	38.88	3.47	27.33	11.87	0.749*
Total Sage-grouse Arthropods (Order)	41.67	19.43	43.68	4.14	0.390	43.27	35.93	16.14	3.36	0.157	42.47	0.80	29.91	13.77	0.737

† Year × Treatment interaction (P = 0.130).

* Year × Treatment interaction (P = 0.135).

CHAPTER FIVE

DISCUSSION

Many sage-grouse populations are limited by the availability of brood-rearing habitat (Aldridge and Brigham, 2001; Crawford et al., 2004; Gregg, 2006; Atamian et al., 2010). Chick survival, an important sage-grouse population vital rate (Taylor et al., 2012), is linked to the abundance of important food items in brood-rearing habitat (Gregg, 2006; Dahlgren, 2009). Management that provides a productive sagebrush understory of important sage-grouse food items in brood-rearing habitat will likely benefit sage-grouse populations (Thompson et al., 2006). Fine-scale brood-rearing habitat selection by sage-grouse occurs in relatively small areas (0.008 ha; Dunn and Braun, 1986; Gregg and Crawford, 2009), and sage-grouse broods often forage along edges of habitat with greater cover (Neel, 1980; Dunn and Braun, 1986; Dahlgren et al., 2006). Previous targeted grazing research with domestic sheep reduced mountain big sagebrush cover, increased forb cover, and increased sage-grouse use within 3.2-ha pastures (Guttery, 2011). My results demonstrated that targeted cattle grazing in 625-ha pastures can provide a mosaic of thinned mountain big sagebrush on a fine-scale order (e.g., 0.008 ha; Johnson, 1980) and increase the availability and diversity of important sage-grouse brood-rearing food items.

Cattle Diets

Protein supplementation can attract cattle to underutilized sites within large pastures (Bailey and Welling, 1999). My research demonstrates that protein

supplementation was effective in attracting cattle into dense sagebrush. Cattle supplement intake during my study was similar to previous research that evaluated the use of protein supplement to attract cattle to underutilized sites within pastures (average consumption = 0.30 kg/day/cow; Bailey and Welling, 1999, 2007; Bailey et al., 2008; Bailey and Jensen, 2008). My results demonstrate herding is not necessary to attract cattle to use protein supplement in dense sagebrush. Perennial bunchgrass utilization by cattle was minimal within the macroplots. However, previous research has documented increased forage utilization near supplementation sites (Bailey and Welling, 1999). My field observations noted that the cattle preferred to graze where sagebrush canopy cover was < 25%, which was outside the dense sagebrush macroplots.

Vegetation and Soil Response

Shrubs

Mountain big sagebrush, total sagebrush, and total shrub canopy cover were reduced through cattle trampling rather than browsing, as indicated from botanical diet composition data. Similar results were attained with targeted cattle grazing to control broom snakeweed. Ralphs and Banks (2009) noted that density of juvenile broom snakeweed plants was reduced through trampling. Peterson et al. (2014) noted that cattle consumed herbaceous forage before consuming sagebrush when first introduced into small pastures (0.2 ha). As herbaceous forage became restricted, cattle subsequently increased browsing pressure on sagebrush (Peterson et al., 2014). My results differ from Petersen et al. (2014), where sagebrush reduction was attributed to browsing by cattle

rather than trampling. Given my study area is interspersed with dense sagebrush and open herbaceous sites, cattle were not restricted to foraging in dense sagebrush habitat only, likely explaining why cattle diets in my study contained only trace amounts of sagebrush.

Selective breeding, epigenetics, and early life experiences can potentially increase sagebrush intake by range livestock. For example, Snowder et al. (2001) demonstrated heritable differences in the propensity of sheep to consume mountain big sagebrush, and livestock with previous experience consuming sagebrush may eat more sagebrush than naïve livestock (Peterson et al., 2014). In my study, cattle were familiar with sagebrush, but they had not been selectively bred for high sagebrush intake.

Sage-grouse select brood-rearing habitat where sagebrush canopy cover is 10–25% (Connelly et al., 2000b). Sagebrush canopy cover in my unsupplemented microsites averaged 36%, well above the habitat guidelines for sage-grouse brood-rearing habitat. In contrast, sagebrush canopy cover averaged 8% in my supplemented microsites the first summer after treatment, slightly below the habitat guidelines for sage-grouse brood-rearing habitat. However, I anticipate that sagebrush canopy cover in my supplemented microsites would recover and average ≥ 10% the second summer after treatment. For example, in mountain big sagebrush in south-central Utah, total shrub cover increased at a rate of 4.1% per year during the two years after targeted sheep grazing treatments had reduced shrub cover from 27.6% to 8.8% (Guttery, 2011).

Sagebrush height is also an important habitat characteristic within sage-grouse brood-rearing habitat (Connelly et al., 2000b). Although sagebrush height in supplemented microsites was considerably lower than unsupplemented microsites (42 cm

vs. 76 cm, respectively), sagebrush height in both supplemented and unsupplemented microsites satisfied recommendations for sagebrush height (i.e., 40-80 cm) within sage-grouse brood-rearing habitat (Connelly et al., 2000b).

Forbs and Graminoids

In general, sage-grouse select sites with greater forb abundance (Klebenow and Gray, 1968; Peterson, 1970; Wallestad, 1975; Dunn and Braun, 1986; Drut et al., 1994a). Sage-grouse broods also select brood-rearing habitat with greater forb diversity (Bunnell et al., 2004). The availability of forbs in brood-rearing habitat has been linked to the recruitment and survival of sage-grouse chicks in some localized populations (Drut et al., 1994b). Targeted cattle grazing in my study increased total forb canopy cover, sage-grouse forb canopy cover, total forb diversity, and total forb composition in supplemented microsites. Forb abundance also was increased in a previous study that examined sheep browsing of mountain big sagebrush, and the sheep-browsed pastures were subsequently selected for by sage-grouse broods (Guttery, 2011). In addition, mechanical treatments increased forbs in mountain big sagebrush communities that were subsequently preferred by sage-grouse broods (Dahlgren et al., 2006; Dahlgren et al., 2015). However, cattle browsing in a mixed stand of Wyoming big sagebrush and basin big sagebrush did not increase forb abundance (Petersen et al., 2014). Wyoming big sagebrush is typically found in warm, xeric sites, and forb response following sagebrush management is generally lower or negligible in those environments compared with cool, mesic sites (Miller et al., 2013).

Graminoid cover may be an important vegetation attribute that sage-grouse select in brood-rearing habitat (Thompson et al., 2006). Graminoid canopy cover was less in supplemented than unsupplemented microsites (15.8% and 19.8%, respectively), but graminoid canopy cover in both the supplemented and unsupplemented microsites met sage-grouse brood-rearing habitat guidelines (≥ 15% graminoid canopy cover; Connelly et al., 2000b). Cattle likely reduced graminoid canopy area in treated microsites through trampling rather than grazing as perennial bunchgrass utilization was light within the macroplot across both years (9%). However, recovery of graminoid cover to pre-treatment levels or greater is likely to occur within two to three years (Cole, 1988). A meta-analysis of sage-grouse brood-rearing habitat concluded that sage-grouse often select areas with greater herbaceous composition, while selecting areas with less sagebrush cover (Hagen et al., 2007).

Soil/Site Stability Response

Ecological processes are compromised and not functioning acceptably wherever the soil/site stability attribute of rangeland health exhibits moderate or greater departure from its natural capability (Miller, 2008; Herrick et al., 2010). Departure from natural capability for soil/site stability was rated none to slight on all supplemented microsites, indicating that disturbance from cattle trampling did not decrease soil/site stability.

Arthropod Response

Arthropods are essential for the development and survival of sage-grouse chicks during the first three weeks following hatching (Klebenow, 1969; Johnson and Boyce,

1990). In my study, arthropod abundance increased in supplemented microsites during the wet year of 2017, but not during the dry year of 2016. The increase in arthropods during 2017 may be attributed to greater forb production, which is correlated with arthropod abundance (Jamison et al, 2002; Thompson et al., 2006). Previous research in southeastern Idaho and south-central Oregon documented arthropod densities increased in mountain big sagebrush habitat one year after fire reduced sagebrush canopy cover (Davies et al., 2014; Nelle et al., 2000). However, Pyle and Crawford (1996) noted Coleoptera abundance was not affected following prescribed burns in mountain big sagebrush, while forb abundance increased. My Coleoptera results are similar to Pyle and Crawford (1996). The authors attributed their results to the understory components associated with Coleoptera presence such as food and cover may not have supported greater abundance following fire (Pyle and Crawford, 1996). In Montana, arthropods consumed by sage-grouse are generally more abundant within pastures grazed by livestock than pastures without grazing (Goosey et al., 2017).

CHAPTER SIX

IMPLICATIONS

Sage-grouse populations throughout western North America are often limited by the availability of brood-rearing habitat (Aldridge and Brigham, 2001; Crawford et al., 2004; Gregg, 2006; Atamian et al., 2010), and sage-grouse chick survival is linked to the availability of brood-rearing food items (Gregg, 2006; Dahlgren, 2009). My study demonstrates that targeted cattle grazing in dense mountain big sagebrush can provide a mosaic of thinned sagebrush on a fine-scale order (e.g., 0.008 ha; Johnson, 1980) and increase the availability and diversity of important sage-grouse brood-rearing food items. However, further research is needed to evaluate how small-scale dense sagebrush thinnings and sage-grouse chick survival are linked (Baxter et al., 2017). Future research and application should also evaluate alternative forms of protein supplement that are easier to transport (e.g., 22.7-kg pressed blocks vs. 100-kg biobarrels) and may enable rangeland managers to reduce sagebrush canopy cover in more microsites with an equivalent amount of total supplement (e.g., 4.4 pressed blocks @ 22.7 kg/block = 100 kg of supplement in one biobarrel). In addition, research and application should also evaluate feeding hay to cattle within dense stands of mountain big sagebrush to concentrate cattle trampling, reduce sagebrush canopy cover, and increase sage-grouse brood-rearing food items.

Caution is advised if targeted cattle grazing is used to reduce sagebrush canopy cover in areas where annual grasses (e.g., cheatgrass) or noxious weeds present invasion

risks in supplemented microsites. Caution also is advised when applying this habitat manipulation tool in Wyoming big sagebrush habitat. The xeric nature of Wyoming big sagebrush habitat may inhibit positive forb responses (Beck et al., 2012; Miller et al., 2013). However, arthropods, especially Hymenoptera, may increase more when sagebrush cover is reduced in xeric, Wyoming big sagebrush habitat (Hess, 2011) than in mesic, mountain big sagebrush habitat (Kirkham and Fisser, 1972; Schreiber et al., 2015). Finally, targeted cattle grazing to reduce sagebrush canopy cover in sage-grouse brood-rearing habitat should not occur within 5 km of sage-grouse nesting habitat (Manier et al., 2014) as sage-grouse require more sagebrush canopy cover in nesting habitat than in brood-rearing habitat (Connelly et al., 2000b).

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