AN ABSTRACT OF THE THESIS OF

Tyler W. Thomas for the degree of Master of Science in Rangeland Ecology and Management presented on September 8, 2022.

Title: Grazing Effects on Fuels and Plant Community Characteristics across Three Community Types in Wyoming Big Sagebrush Steppe

Abstract approved:

______________________________________________________
Kirk W. Davies Ricardo Mata-Gonzalez

Livestock grazing is the prominent land use in Wyoming big sagebrush (Artemisia tridentata ssp. wyomingensis [Beetle & A. Young] S.L. Welsh) steppe and has been present since the late 1800’s. There have been calls to remove livestock grazing from rangelands as historic grazing practices resulted in the degradation of some native plant communities and wildlife habitat. However, the distinction between historic grazing and moderate contemporary grazing practices is often not made.

Contemporary grazing differs greatly from historic grazing because grazing frequency, intensity, and season of use are managed, and periodic adjustments are made to maintain ecological integrity. Contemporary grazing may be an ecologically responsible land use compared to historic grazing, but there’s still information lacking on its effects on different plant community types found within Wyoming big sagebrush steppe. Intact, degraded, and exotic annual grass dominated sites are three common community types found in Wyoming big sagebrush steppe that have experienced long-term contemporary grazing. As there have been calls to remove
contemporary grazing, it is important for land managers to understand the implications of removing contemporary grazing as it may affect plant community characteristics and fuels differently.

The effect of grazing exclusion on fuel characteristics was evaluated among three common Wyoming big sagebrush community types: intact, degraded, and exotic annual grass types. In this study, a randomized block design within each community type, repeated over two years, was utilized to determine the effects of contemporary grazing exclusion on fuel characteristics. In each community type, five long-term (+10 yrs.) grazing exclosures were established with grazed and ungrazed treatments at each site. Grazing altered fuel characteristics in a manner that decreased wildfire probability, intensity, and severity in each community type. Effects of contemporary grazing on several fuel characteristics varied among community types, suggesting that fuel management plans should distinguish community types across grazing allotments as the effect of grazing on fuels may vary. Also, as community type and year consistently had significant effects on differences found in fuel characteristics, the spatial and temporal variation across Wyoming big sagebrush steppe should be considered when utilizing contemporary grazing to manage fuels.

In addition to evaluating fuel characteristics, a study on plant community characteristics was also evaluated to determine if the removal of contemporary grazing affects intact plant communities and promotes plant community recovery in degraded and exotic annual grass invaded sites. Plant community characteristics were collected in the same sites and treatments as in the fuels study. Only two plant community characteristics were influenced by the interaction between grazing
treatment and community type, suggesting that the effects the contemporary grazing exclusion may vary slightly by community type. As there were very few differences between the grazed areas and grazing exclosures, it is likely that contemporary grazing exclusion may not affect intact communities nor promote recovery of degraded and exotic annual grass communities. In the exotic annual grass sites, because there were negligible differences in annual grass abundance between the grazed and ungrazed areas, heavier grazing pressure could be warranted to reduce exotic annual grasses depending on management goals. Variables that consistently explained differences in plant community characteristics were community type and year, indicating that spatial and temporal variation had an effect on plant communities and may better explain differences in plant community composition and diversity than the exclusion of contemporary grazing.
Grazing Effects on Fuels and Plant Community Characteristics across Three Community Types in Wyoming Big Sagebrush Steppe

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Tyler W. Thomas, Author
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CHAPTER 1: INTRODUCTION AND BACKGROUND

Overview of Western Rangelands

The presence of large hooved animals in the western United States has been apparent since bison migrated westward post Wisconsin glaciation (Mack and Thompson 1982). Records of large hooved mammals show that there were small herds of bison located throughout parts of the steppe west of the Rockies, but were in the few areas that had permanent water sources and grasslands that could support herds of these mammals (Mack and Thompson 1982). Native ungulates have continually been a presence in steppe regions of the west, but comparatively the resources needed for most wild ungulates to survive are less than that of ungulates like bison that need more prairie and meadow systems (Harvey and Fortin 2013).

Until European settlers began to move west, wild ungulates were the primary grazers of the sagebrush steppe region (Mack and Thompson 1982). The introduction of livestock created a disturbance that had not been present, especially at this scale (Davies et al. 2009). Since the Homestead Act of 1862, sagebrush steppe throughout the west has been settled and cultivated for agricultural and urban uses (Bell 2012). Sheep were introduced in the 1850’s to provide mutton and wool for the increasing number of mining operations in the Great Basin (Roselle et al. 2010, Feuz and Kim 2019). Subsequently, the introduction of cattle in the Great Basin began in the 1860’s to provide additional support for mining operations in the western part of the basin (Knapp 1996). The growing demand for meat and animal products led to increased grazing pressure that eventually spread throughout the region. Settlers were migrating into the Great Basin from areas of greater productivity and resilience, resulting in the overestimation of forage available, compounding the issue of increased grazing pressure even further (Young and Sparks
However, because there were no fence laws, overgrazing quickly became an issue that continued to worsen as more people and livestock flooded into the region (Knapp 1996).

Plant communities that did not evolve with large herbivore grazing are not expected to be able to tolerate livestock grazing (Fleischner 1994, Noss 1994, Belsky and Blumenthal 1997, Jones 2000). However, the influence of large herbivores on the composition and diversity of shrub-steppe communities likely vary depending on plant community type and grazing pressure (Manier and Hobbs 2006, Perryman et al. 2021). Before the establishment of the grazing service and land management agencies, the Tragedy of the Commons plagued rangelands with overgrazing and extreme degradation as the demand by livestock and the forage supplied by these lands were not compatible (Dittel et al. 2018). The condition of sagebrush steppe during this post-settlement era varied. Historic overgrazing that depleted the native vegetation opened a niche for exotic annual grasses like cheatgrass (*Bromus tectorum* L.) and medusahead (*Taeniatherum caput-medusae* (L.) Nevski) to invade and proliferate within these arid systems (Fleischner 1994).

Improvements in land management began with the Taylor Grazing Act and the formation of offices like the Grazing Service and eventually the Bureau of Land Management (Dittel et al. 2018), resulting in the recovery of many rangeland communities (Yorks et al. 1992). AUM’s (animal unit months) allotted for much of the grazing lands were historically higher than the amount of AUM’s allotted today. For example, since 1915, AUM’s (animal unit months) allotted in Fremont National Forest in southern Oregon went from 400,000 to less than 1,000 for sheep and from 95,000 to 60,000 for cattle (Miller and Rose 1999). However, because of historically overused grazing allotments, many areas remain degraded with depleted understories and dense sagebrush overstories (Dyksterhuis 1958, Daubenmire 1970, Mack 1981, Knapp 1996, Jones 1985).
2000), or are dominated by exotic annual grasses, preventing the recovery of native perennial vegetation and altering the successional trajectory of these sagebrush steppe communities (Mack 1981, Melgoza et al. 1990, Davies 2011, Davies et al. 2014, Chambers et al. 2014).

**Ecology of Sagebrush Steppe**

The sagebrush steppe is a major vegetation complex (Bates and Davies 2014) that spans across 11 western states and two provinces of southwestern Canada (Kuchler 1970). Of the 62 million hectares of sagebrush ecosystems, at least 44% is estimated to be degraded or lost (West 1983, West and Young 2000, Schroeder et al. 2004, Rowland and Wisdom 2005). Plant community characteristics of sagebrush ecosystems vary greatly throughout rangelands due to the variety of historical disturbance regimes and site characteristics (West et al. 1984). Wyoming big sagebrush steppe communities have historically had long fire return intervals (50-100 years) because of the climatic conditions of these sites and limited available fuels (Mensing et al. 2006). Historical ranges of Wyoming big sagebrush steppe described by as low elevation, arid ecosystems inherently have lower resiliency compared to other sagebrush steppe communities (Chambers et al. 2014). Ecological disturbances that occur in Wyoming big sagebrush steppe can be necessary to sustaining and improving ecological function of the site, but historic grazing practices and exotic annual grasses have created uncertainty in how these communities will respond to subsequent disturbances or cessation of disturbances.

In mountain big sagebrush steppe, fire was more common (Miller et al. 2011), with sites in southwestern Montana having fire return intervals averaging 32 years (Lesica et al. 2007). However, in southern Oregon and other regions of the west, fire in mountain big sagebrush steppe was even more prevalent as historic fire return intervals averaged 12-15 years (Houston 1973, Burkhardt and Tisdale 1976, Martin and Johnson 1979, Miller and Rose 1999).
Nonetheless, historical fire regimes in big sagebrush steppe created mosaic burn patterns (West 2000), increasing landscape diversity and edge habitat (Lesica et al. 2007). In addition, these historic fire regimes were also successful at promoting habitat for sagebrush obligate species as mosaic burning would increase spatial heterogeneity and promote biodiversity (Engle and Bidwell 2001, Fuhlendorf and Engle 2004, Collins and Smith 2006, Boakye et al. 2013), maintaining intact sagebrush communities while creating patches of perennial grasses and forbs. These patches were very important for brooding habitat of sage grouse and other sagebrush obligate species as the forbs and grasses attracted insects that were crucial for chick growth (Curran et al. 2015).

Historic fire regimes had an integral role in maintaining landscape diversity in sagebrush steppe communities by regulating overstory dominance of sagebrush and promoting new understory growth. However, the historical overuse by livestock in sagebrush steppe resulted in the degradation of understory vegetation, thus, increasing susceptibility to invasion of exotic annual grasses within these overgrazed plant communities (Reed-Dustin et al. 2016, Mata-Gonzalez et al. 2018). Exotic annual grasses can increase fine fuels, resulting in an increased probability of wildfire that can destroy sagebrush steppe (Knapp 1995, Brooks 2008, Davies and Nafus 2013) by creating a positive-feedback loop between annual grasses and fire (D’Antonio and Vitousek 1992, Brooks et al. 2004). Due to the strong presence of annual grasses in many former sagebrush steppe communities, and the unlikeliness of being able to establish perennial vegetation in them, it has been proposed to recognize some of these areas as annual grasslands (Davies et al. 2021c), rather than continue to invest money and resources into futile attempts to restore these back to native sagebrush steppe communities. In some situations, the use of nonnative species like crested wheatgrass (*Agropyron cristatum* [L.] Gaertn.) over large areas
have been used to stabilize disturbed sites, particularly post-fire, and limit cheatgrass and other exotic annual grasses from establishing and spreading (Young and Evans 1986, Heady H. F. 1988, D’Antonio and Vitousek 1992, Sheley and Carpinelli 2005).

In addition to the use of nonnative species, removal of livestock grazing has been another proposed tool to limit the spread of exotic annual grasses. However, livestock exclusion doesn’t always follow with the improvement of forage production or recovery of native perennial vegetation (Robertson 1971, Sneva 1982, West et al. 1984, Anderson and Inouye 2001, Courtois et al. 2004, Manier and Hobbs 2006, Davies et al. 2014). Long-term livestock grazing exclusion (13 yrs.) didn’t improve native perennial bunchgrasses, but instead resulted in further deterioration of the plant community as woody species and annual grasses became more dominant (West et al. 1984). In situations where overgrazing resulted in increased exotic annual grasses and plant community degradation, moderate contemporary grazing can be used as a tool to restore those sites (Schmelzer et al. 2014, Perryman et al. 2020, Davies et al. 2021d), but further study is needed to evaluate its long-term effects on these plant communities.

Historic overgrazing generally resulted in the reduced resilience and resistance of plant communities to disturbances such as wildfire and exotic annual grasses, and consequently there have been calls to remove grazing entirely from rangelands. However, the effects of the cessation of grazing, historic and contemporary grazing, may vary by site condition and thus need to be studied further. In northern New Mexico, the exclusion of grazing for 22 years within lowland and upland big sagebrush communities did not improve site conditions as sagebrush cover increased and understory vegetation decreased (Holechek and Stephenson 1983). It was then suggested that sagebrush control and reseeding of grasses, forbs and specific shrubs would be the best method to improving rangeland condition. In a long-term grazing study in northern Arizona,
grazing exclusion within intact sagebrush steppe increased sagebrush abundance 30-40%, whereas grass abundance decreased at a similar rate (Hughes 1980). Similarly, sagebrush steppe that had been railed and then seeded resulted in a 70% increase in sagebrush abundance and a decrease in grass abundance at the same rate (Hughes 1980), suggesting that large increases in sagebrush abundance will reduce native perennial bunchgrasses. The long-term exclusion of livestock grazing can maintain a more diverse species composition (Hughes 1980), but may also result in long-term reduction of soil carbon and nitrogen cycling as well as overall productivity of the system (Schuman et al. 1999).

Historic overgrazing and exotic annual grasses have altered sagebrush steppe plant communities in which the plant community characteristics are vastly different compared to intact plant communities. The understory dominance of native perennial bunchgrasses and perennial forbs will be disrupted, and the increased abundance of sagebrush and exotic annual grasses will influence how these communities respond to disturbances and how succession after disturbance will progress.

**Community Types**

*Exotic Annual Grass Wyoming Sagebrush Steppe*

The presence of exotic annual grasses in Wyoming big sagebrush communities can severely alter plant community structure and function (Davies et al. 2021c). Approximately one-third (210,000 km²) of the Great Basin has cheatgrass cover ≥ 15%, and has been expanding at an annual rate of >3700 km² within the last decade (Bradley et al. 2018, Smith et al. 2022). The increased presence and widespread distribution of cheatgrass throughout the Great Basin is a result of the plant’s ability to outcompete native plants, especially seedlings, for water, nutrients, and space (Melgoza et al. 1990, Nasri and Doescher 1995, Rafferty and Young 2002). The
growth cycle of winter annual grasses starts before many of the native bunchgrasses in the Great Basin, alluding to the occupation of a niche that hasn’t been previously filled (Allen and Meyer 2014, Brownsey et al. 2017, Monaco et al. 2017). This creates an opportunity for exotic annual grasses like cheatgrass and medusahead to establish (Miller et al. 2011) and build up seed banks until a disturbance (overgrazing, fire, etc.) occurs, resulting in the rapid proliferation of annual grasses (Scheffer et al. 2009). Consequently, the native perennial communities will likely not recover due to the increased competition from annual grasses and ensuing decrease in fire return intervals because of the positive feedback loop between fire and annual grasses (Davies 2008, Davies et al. 2009, Sheley and Svejcar 2009, Allen and Meyer 2014).

Wyoming big sagebrush steppe communities dominated by exotic annual grasses will have greatly altered forage quality and production (Dittel et al. 2018, Mata-Gonzalez et al. 2018). Medusahead is a winter annual that reaches its highest crude protein levels (~10%) for approximately 10-15 days (Brownsey et al. 2017). Mature dry cows can maintain body weight at about 6-7% crude protein, meaning that they can graze medusahead from the vegetative stage up to after the reproductive stage (Brownsey et al. 2017). However, once medusahead transitions from the vegetative stage to the reproductive stage, crude protein generally drops well below 8% (Bovey et al. 1961, Hamilton et al. 2015, Villalba and Burritt 2015), indicating limited animal production potential during that timeframe. Looking at the susceptibility of medusahead to grazing, denoting that the forage quality is sufficient for livestock, it is susceptible for on average 25 days with >90% of the tillers susceptible to grazing during the first 10-15 days (Brownsey et al. 2017). Like medusahead, cheatgrass is affected most by grazing when it is grazed to a height of 2.5 cm during the boot stage and then again approximately 2 weeks later (Hempy-Mayer and Pyke 2008). These timing treatments would greatly reduce plant abundance and seed banks for
both medusahead and cheatgrass as cheatgrass densities of < 20 plants per m$^2$ were associated with a 69% or greater survival rate of bluebunch wheatgrass ($Pseudoroegneria spicata$) seedlings (Hempy-Mayer and Pyke 2008). However, as medusahead can quickly dominate large expanses of sagebrush steppe following disturbances like fire, grazing these large areas in a timeframe of ~25 days would mean a significant and likely unfeasible change in current grazing strategies.

The exotic annual grass sites compared to the degraded and intact sagebrush steppe sites will have greater fine fuels, resulting in more frequent fires that can be detrimental to sagebrush and other native perennial plant species because of the reduced recovery time between disturbances (Whisenant 1990, D’Antonio and Vitousek 1992, Brooks et al. 2004, Davies et al. 2021a, 2021b, 2021d). Not only is fire frequency and fuel continuity influenced by exotic annual grasses, but plant diversity is also greatly reduced with exotic annual grass dominance, degrading habitat quality and affecting sagebrush obligate species because of the impacts it has on plant community structure (Davies 2011, Coates et al. 2016).

**Degraded Wyoming Big Sagebrush Steppe**

In the Intermountain West, at least 30% of the remaining sagebrush steppe was degraded from historical grazing practices characterized by heavy, repeated growing season use (LaRoe et al. 1995). Wyoming big sagebrush steppe communities that were historically overgrazed are largely comprised of an overabundant sagebrush overstory and an understory devoid of large native perennial bunchgrasses and perennial forbs (Davies et al. 2021a). The restoration of these communities can be difficult as the process of reducing sagebrush dominance generates little response from native vegetation and can increase susceptibility to exotic annual grass invasion (Beck et al. 2012, Davies et al. 2012, Pyke et al. 2014). To maintain community resistance to
exotic annual grasses, Wyoming big sagebrush communities need to maintain perennial native herbaceous cover of at least 20% (Chambers et al. 2014). As historic overgrazing resulted in the degradation of many plant communities, studies have looked at the effects of removing grazing (moderate, contemporary) from native plant communities to evaluate recovery trends (Hughes 1980, Courtois et al. 2004, Dittel et al. 2018). With the removal of moderate contemporary grazing on these degraded areas, few differences were usually found when comparing the grazed areas to grazing excluded areas (Courtois et al. 2004, Copeland et al. 2021). Generally, the removal of disturbances such as contemporary grazing did not stimulate recovery of plant communities and further intervention would be needed to restore the large native perennial bunchgrasses and forbs that were lost with historic overgrazing.

The loss of large native perennial bunchgrasses generally characterizes sagebrush steppe that has previously been overgrazed or has been invaded by exotic annual grasses. In areas where historic overgrazing has occurred, sagebrush has proliferated as competition for resources was greatly reduced. Once a sagebrush overstory reaches its upper limits, recovery of large native perennial bunchgrasses is unlikely without active management to reduce the dominant overstory (Robertson 1971, Sneva et al. 1980, West et al. 1984, Anderson and Inouye 2001, Boyd and Svejcar 2011, Davies et al. 2016). Passive restorative techniques like grazing exclusion have been used in attempts to promote perennial bunchgrass recovery, but there was usually no response as the overabundant sagebrush overstory wasn’t directly treated and continued dominance over the understory vegetation (Davies et al. 2016).

**Intact Wyoming Big Sagebrush Steppe**

Intact sagebrush steppe can be identified by its codominant structure consisting of Wyoming big sagebrush and large native perennial bunchgrasses. The prominent large native
perennial bunchgrasses include Idaho fescue (*Festuca idahoensis* Elmer), bluebunch wheatgrass, and Thurber’s needlegrass (*Achnatherum thurberianum* (Piper) Barkworth), with the overall cover of this functional group approx. 10-15% (Bates and Davies 2019). Sandberg bluegrass (*Poa secunda* J. Presl) is also a prominent bunchgrass found in these systems that will generally have canopy cover averaging 5% (Bates and Davies 2019). Perennial forbs and annual forbs are highly variable annually in response to precipitation and temperature (Sneva 1982, Bates et al. 2005) and have average canopy covers of approx. 4 and 1% (Bates and Davies 2019), respectively. Ground cover consists of a moderate amount of bare ground (~50%), with rock and litter making up approx. 10% and 15% (Bates and Davies 2019), respectively. Intact sagebrush steppe tends to have higher resistance and resilience to disturbances compared to sites that have been invaded by exotic annual grasses or historically overgrazed (Davies et al. 2014, Chambers et al. 2014). Historic fire-return intervals in these intact communities indicate that the plant communities are not fire tolerant and any increase in fire frequency could result in plant community deterioration and change in community type (Mensing et al. 2006). Also, the responses of these intact communities to fire are dependent on many factors (precipitation, temperature, pre-fire condition, etc.), so changes in the natural fire regime could be complex issue comprised of several different factors (Chambers et al. 2014, Murphy et al. 2013).

**Ecology of Major Functional Groups**

**Exotic Annual Grasses**

Exotic annual grasses like cheatgrass and medusahead are increasing dominance in rangelands throughout the western United States (Knapp 1996, Davies 2008, Davies and Svejcar 2008, Bradley et al. 2018). The spread of these grasses throughout the Great Basin have resulted in increased fire frequencies (Torell et al. 1961, Young 1992), increasing number of megafires,
and millions of dollars being spent on wildland fire suppression (Roberts 1999, Calkin et al. 2005). In addition, it is also predicted that the wildfire season will be extended by more than 3 weeks and that the total area burned annually will at least double due to the increase in fine fuels and fuel continuity (Yue et al. 2013, Stewart and Hull 1949, Whisenant 1990, D’Antonio and Vitousek 1992, Knapp 1995, Brooks 2008).

When examining the effects of cheatgrass on sagebrush steppe communities, 10.7% of the land in the Great Basin with cheatgrass cover >15% had burned between 2000 and 2014 (Bradley et al. 2018). This is compared to only 5.2% of land with cheatgrass cover <15% burning during the same period (Bradley et al. 2018). The increase in total burned area and reduced fire return intervals perpetuates the continued spread and dominance of exotic annual grasses in sagebrush steppe, further displacing native perennial grasses and forbs (Knapp 1996). The spread of cheatgrass in sagebrush steppe is a consequence of several different disturbances and ecological factors. Fire is a disturbance that has been positively correlated with elevated probabilities of cheatgrass occurrence (Williamson et al. 2020, Smith et al. 2022). Fire is also likely to induce greater dispersal and abundance of cheatgrass as fire frequencies in cheatgrass dominated areas continue to increase (Williamson et al. 2020, Smith et al. 2022). In addition to the influence of fire on cheatgrass, historic grazing practices also increased the probability of cheatgrass occurrence and prevalence (Stewart and Hull 1949, Laycock 1967, Reisner et al. 2013) as it reduced competition for native perennial vegetation. However, disturbances such as contemporary grazing can now be used as a tool to manage cheatgrass and other exotic annual grasses by utilizing adaptive grazing strategies to reduce competition on native plant communities. Cheatgrass distribution has also been linked to elevation and solar exposure as cheatgrass is more prevalent in south-facing slopes and lower elevations (Williamson et al.
Furthermore, the spread of cheatgrass and other exotic annual grasses can be correlated with many ecological and anthropogenic disturbances, suggesting that management plans dealing with exotic annual grasses will likely need to incorporate several treatments to manage these problematic grasses.

The management of medusahead can also be problematic as it shares the same positive feedback loop with fire as cheatgrass, increasing its establishment rates and out-competing perennial plants (Davies and Svejcar 2008). Another consequence of medusahead is the high silica content in the plant’s post-reproductive stage, meaning that grazing it consistently during this stage can pose problems for animal production and health (Torell et al. 1961). However, many producers still utilize exotic annual grass dominated rangelands with limited issues. When utilizing mechanical and grazing treatments to control medusahead, it was found that defoliation of medusahead at any phenological state was effective in reducing seed head production (Brownsey et al. 2017). However, from a nutritional standpoint, the boot stage provided highest crude protein (9.95%), increasing animal production potential (Brownsey et al. 2017). As medusahead plants transition towards full reproductive growth, grazing/clipping at any height virtually suppressed all seed production (Brownsey et al. 2017). In addition to grazing timing treatments, tall tussock bunchgrasses are also critical to preventing medusahead invasion (Davies 2008). Seed dispersal of medusahead primarily occurs only a short distance from the parent plant in the absence of a vector (Davies 2008) and relatively short distances by wind (Furbush 1953, Davies and Sheley 2007). However, medusahead seeds are well adapted for dispersal by adhesion to moving objects (Monaco et al. 2005), and unlike desirable species where increased seeding rates lead to decreased establishment rates (Launchbaugh and Owensby 1969, Casler et
increased seeding rates of medusahead resulted in increased establishment rates (Davies 2008).

Abundant established perennial vegetation is crucial for limiting exotic annual grasses (Davies and Johnson 2017). Perennial bunchgrasses are the most important functional group for limiting exotic annual grasses in sagebrush steppe communities as an established perennial bunchgrass community can outcompete exotic annual grasses and has high resilience to disturbances like fire that would otherwise promote the spread of exotic annual grasses (Chambers et al. 2007, Davies 2008).

**Perennial Bunchgrasses**

Perennial bunchgrasses are a major component in sagebrush steppe communities as they are a dominant herbaceous functional group within intact systems (Davies et al. 2006). This functional group serves an important role in the production and stability of sagebrush steppe communities. Ecosystem services such as forage production and carbon sequestration are a result of an intact perennial bunchgrass understory (Davies et al. 2011). Another reason that maintaining perennial bunchgrasses is important is that this functional group serves an important role in limiting annual grass expansion (Chambers et al. 2007, Davies 2008). This is due to the substantial overlap in resource use between mature large perennial bunchgrasses and exotic annual grasses (James et al. 2008).

Large perennial bunchgrasses are particularly important because they can be used as an indicator for areas with high resiliency to disturbance (Davies et al. 2006). The resilience comes in the form of both resilience to fire and resilience to exotic annual grasses (Chambers et al. 2007, 2014). However, once large bunchgrasses are lost, it is difficult to successfully restore them (Svejcar et al. 2017, Davies et al. 2021a). Attempts to improve the probability of
restoration success include excluding livestock, which has generally been unsuccessful in promoting community recovery, especially when sagebrush cover is high (Sneva et al. 1980, West et al. 1984, Davies et al. 2016). This is because competition from sagebrush is likely limiting the recovery of these key understory species (Davies et al. 2021a).

As large native perennial bunchgrasses often recovery slowly following disturbance, introduced perennial bunchgrasses like crested wheatgrass are often seeded after fire because of its ability to establish quickly and compete well with exotic annual grasses (Miller 1956, Arredondo et al. 1998, Davies et al. 2010, McAdoo et al. 2017). Though crested wheatgrass is an introduced species, it can be successful in filling the void niche post-disturbance, but due to quick establishment and use of resources, it often competes with native perennial grasses (Marlette and Anderson 1986, D’Antonio and Vitousek 1992, Christian and Wilson 1999, Krzic et al. 2000, Fansler and Mangold 2011). However, regardless of native status, the importance of perennial bunchgrasses in sagebrush steppe communities is why most restoration plans will focus on the recovery and restoration of this functional group.

**Sagebrush**

Big sagebrush communities are a major vegetation complex in the western United States and southwestern Canada and at one point occupied over 62 million hectares (Tisdale et al. 1969, Kuchler 1970, McArthur and Plummer 1978, Miller et al. 1994, West and Young 2000). In the expansive sagebrush complex, Wyoming big sagebrush occupies the largest area and provides critical habitat for sagebrush obligate species and forage for livestock as over 70% of western rangelands are grazed (Jones 2000, Davies et al. 2006). Historically, big sagebrush fire regimes consisted of long fire-return intervals because the role of fire was to periodically reduce overabundant sagebrush overstories that would limit understory growth and diversity. However,
even though fire was an important historic disturbance in these communities, similar
disturbances today in big sagebrush communities can have largely variable effects.

When comparing big sagebrush communities, Wyoming big sagebrush generally has the
lowest resilience and resistance to disturbance since it primarily occupies lowland arid sites with
higher temperatures and dry conditions, favorable to plants like exotic annual grasses (Chambers et al. 2014). In addition, there are differences in plant community characteristics when
comparing Wyoming big sagebrush to other sagebrush communities like mountain big
sagebrush. Native perennial forbs are an important component of these communities as they
provide forage for wildlife such as sage grouse (Barnett and Crawford 1994, Gregg et al. 2008),
mule deer (Willms et al. 1979, Collins and Urness 1983), and elk (Kufeld 1973). However,
native perennial forb abundance is consistently greater in mountain big sagebrush than Wyoming big sagebrush, suggesting the need to distinguish between sagebrush communities when
managing for wildlife habitat and monitoring forb abundance (Davies and Bates 2010). In
addition to differences between big sagebrush communities, understory characteristics can vary
greatly within a single community depending on site characteristics and other factors. Within
intact Wyoming big sagebrush steppe in just southeastern Oregon, at least six plant associations
have been identified based on dominant/codominant perennial bunchgrasses with each
association having distinct plant community characteristics (Bates and Davies 2019). This
suggests that intact Wyoming big sagebrush steppe may not be a homogenous community and
that land managers should consider understory characteristics in their management plans (Bates and Davies 2019).

Sagebrush provides critical habitat for sagebrush obligate species and is a key
characteristic of rangelands across the west. However, due to disturbances reducing competition
for sagebrush, many areas have overabundant sagebrush overstories that greatly reduce 
understory production and habitat quality (Boyd and Svejcar 2011). Treatments such as 
sagebrush mowing have been implemented to restore understory vegetation, but with exotic 
annual grasses becoming prevalent across rangelands, these disturbances can increase the 
community’s susceptibility to exotic annual grass invasion (Davies et al. 2012, Davies and Bates 
2014, Swanson et al. 2016). In southeastern Oregon, mowing treatments resulted in substantial 
increases in exotic annual grasses (Davies et al. 2021). The combination of mowing with other 
treatments such as seeding was successful at increasing perennial bunchgrasses, but exotic 
annual grasses still substantially increased (Davies et al. 2021), suggesting that a combination 
of several treatments might be needed to promote perennial bunchgrasses while also limiting 
exotic annual grasses.

**Grazing Exclusion**

It has been a longstanding debate on whether grazing exclusion on rangelands stimulates 
community improvement, further degrades landscapes that were historically overgrazed, or has a 
similar effect to moderate contemporary grazing (30-50% utilization, use alternated between 
growing season and post-growing season with periodic years of rest). In eastern Oregon and 
Nevada, long-term livestock exclosures had similar vegetation characteristics compared to areas 
that were moderately grazed (Davies et al. 2014, Copeland et al. 2021). Many species in the 
Great Basin may not be expected to be highly grazing tolerant, however few indications of 
herbaceous community divergence associated with contemporary cattle grazing have been found 
grazed areas were associated with higher native perennial species abundance compared to 
which is also supported by grazing exclosure comparisons in Nevada (Courtois et al. 2004). This result may be due to grazing increasing the amount of bare ground, creating microsite conditions favorable for recruitment (Oesterheld and Sala 1990, Bullock et al. 1994, Kladivova and Munzbergova 2016). The cessation of grazing can increase shrub cover and reduce forb cover (Stohlgren et al. 1999, Manier and Hobbs 2006). However, other studies have shown increases in both shrub and forb cover while exerting no effect on net herbaceous cover (Schultz and Leininger 1999, Coughenour 1991, Singer 1996, Anderson and Inouye 2001).

Furthermore, the effects of contemporary grazing and grazing exclusion on plant community characteristics varies between studies and the impact of grazing is likely based on several ecological and anthropogenic factors (Davies et al. 2018, 2022, Copeland et al. 2021).

The effect of grazing and grazing exclusion on sagebrush steppe may be dependent on prior ecological condition and land use. It is possible that the negligible effects of grazing exclusion on plant community characteristics are because of the limited disturbances on the landscape prior to livestock exclusion (Manier and Hobbs 2006). In intact sagebrush communities, negligible effects on plant community characteristics are reported with grazing exclusion because these communities already have high resilience to disturbances (Davies et al. 2014). In areas where historic grazing in the early 1900’s created a shrub-dominated plant community, the effects are still prevalent as the native plant communities are still recovering (Manier and Hobbs 2006). The removal of moderate contemporary grazing in these degraded communities may have little influence on the understory vegetation because once sagebrush reaches its upper limit in abundance and cover, the recovery of perennial herbaceous vegetation is unlikely (Robertson 1971, Anderson and Inouye 2001). Also, the influence of sagebrush overstories on understory vegetation may be greater than the influence of contemporary grazing
within these degraded communities. Similarly, it is likely that the dominance of exotic annual grasses in annual grass invaded communities may hinder any native community response to grazing exclusion as exotic annual grasses will inhibit the recovery of native perennials (Davies et al. 2014). Furthermore, the effects of contemporary grazing exclusion on Wyoming big sagebrush plant community types may vary, and other factors such as community type may also influence differences found in plant community characteristics.

**Historic compared to Contemporary Grazing**

Grazing has been scrutinized by numerous groups and organizations because of the negative impact historic heavy, repeated growing season use had on vegetation and ecosystems. However, to compare historic grazing practices to moderate, contemporary grazing practices would be illogical as it would ignore the progress made in grazing management and the recovery of historically overgrazed rangelands as a result of moderate, contemporary grazing (Borman 2005, Davies and Boyd 2020). Historic overgrazing occurred because grazing on rangelands back in the 1800’s and early 1900’s was unrestricted free reign of livestock with limited understanding of the potential ecological impacts (Borman 2005, Davies and Boyd 2020). From 1905 to 1935, the majority (93%) of rangelands in public domain were depleted and were continuing to decline from unrestricted grazing (Box 1990). In Arizona, it was reported that large livestock numbers in the late 1800’s substantially reduced grass production and cover and contributed to the encroachment of woodland species (Leopold 1924). The Zion National Park area in southwestern Utah experienced similar changes as heavy grazing during the early 1900’s resulted in an increase in woody vegetation with reduced perennial grasses (Borman 2005). Along with woody vegetation encroachment, heavy grazing can promote exotic annual grasses by depleting competition from native perennial vegetation (Davies and Boyd 2020). Season-long
grazing can result in the increase of species that avoid grazing as the palatable native vegetation are continuously grazed without rest (Davies and Boyd 2020). Nevertheless, grazing is a term that is too often used in a generic sense, without regard to other factors like timing, frequency, intensity, and species of grazing animal (Heady and Child 1994, Borman 2005, Davies and Boyd 2020).

Grazing management has substantially improved over time as sites that were historically overgrazed reported similar recovery trends between grazing exclosures and areas with moderate contemporary grazing (Copeland et al. 2021), suggesting that current grazing practices do not inhibit recovery of degraded plant communities. Contemporary grazing can have positive effects on rangelands as it can encourage native vegetation recruitment in rangelands that were seeded with competitive introduced grasses post-disturbance (Pyke and Marty 2005). Moderate grazing can also reduce exotic annual grass abundance and cover by reducing litter accumulation and safe sites for exotic annual grasses (Perryman et al. 2020, Davies et al. 2021b). Grazing can also improve the habitat for some wildlife species and increase overall landscape diversity (Fuhlendorf et al. 2006). The effect of grazing on wildlife varies as some species may be favored with livestock grazing while others may be negatively impacted (Davies and Boyd 2020). Moderate contemporary grazing can maintain and/or restore native plant communities while historic grazing regimes favor exotic annual grasses and result in further deterioration of native sagebrush steppe plant communities (Box 1990, Fuhlendorf et al. 2006, Davies et al. 2009, Davies and Boyd 2020).
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CHAPTER 2:  
GRAZING EFFECTS ON FUELS VARY BY COMMUNITY STATE IN WYOMING BIG SAGEBRUSH STEPPE

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ABSTRACT

Limiting fire in Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis* [Beetle & A. Young] S.L. Welsh) steppe is often a management priority as fires threatens its ecological integrity and rural economies that dependent upon it. However, the Wyoming big sagebrush steppe is vast and occurs in different community states from intact (sagebrush-bunchgrass dominated) to exotic annual grass dominated. Grazing has been suggested as the only tool that is likely feasible to apply across such large landscapes to manage fine fuels, but there is concern that over time grazing may induce undesirable shifts in plant community composition (e.g. increases in exotic annuals) that increase fire risk. Therefore, we evaluated the longer-term (+10 yrs.) effects of contemporary, moderate grazing by cattle compared to grazing exclusion on fuel characteristics in three community states: intact, degraded, and exotic annual grass states. We accomplished this by measuring fuel characteristics in five grazed and ungrazed areas in each community state in 2020 and 2021. Grazing generally decreased fine fuel continuity and biomass and increased the live to dead ratio. These fuel alterations are consistent with decreasing the probability of fire ignition and, if ignited, producing a slower spreading fire with shorter flame lengths. The response of several fine fuel characteristics to grazing varied by community state. Fine fuel characteristics also commonly varied among community states and between years. These results suggest that fuel management plans need to recognize that grazing effects will vary by community state and be flexible because fuel characteristics vary spatially and temporally. Overall, our results suggest that contemporary grazing in the Wyoming big sagebrush steppe reduces the probability of wildfire and likely increases the effectiveness and safety of fire suppression. Consequently, grazing exclusion in these communities increases the probability of frequent, large wildfires that are difficult and dangerous to suppress.
KEYWORDS: fuel management; fire prevention; fire probability; grazing-fire interaction; proactive management
INTRODUCTION

Wyoming big sagebrush (Artemisia tridentata ssp. wyomingensis [Beetle & A. Young] S.L. Welsh) steppe is critical habitat for sagebrush-associated wildlife, many of which are species of conservation concern, and an important forage base for livestock in the western United States. These rangelands are facing unprecedented threats from mega-fires and more frequent fire, putting rural economies and sagebrush-associated wildlife in jeopardy (Davies et al. 2011; USFWS 2013; Bates et al. 2020). Fire was historically infrequent in these communities and shifted dominance from sagebrush to perennial bunchgrasses (Wright and Bailey 1982; Mensing et al. 2006), but exotic annual grass invasion has supplanted succession of native vegetation post-fire. Exotic annual grasses often increase after fire in Wyoming big sagebrush communities at the expense of native perennial vegetation (Steward and Hull 1949; Melgoza et al. 1990; Mahood and Balch 2019) and increase the probability of more frequent fire because of an increase in flammable fine fuel (Brooks et al. 2004; Balch et al. 2013), leading to the development of an annual grass-fire cycle (D’Antonio and Vitousek 1992). This, combined with the wide-spread loss of sagebrush habitat from multiple factors (Davies et al. 2011), has led to a general management objective of limiting fire in Wyoming big sagebrush steppe (USFWS 2013; Mahood and Balch 2019; Davies et al. 2021).

Fuel management is critically needed to reduce fire in the sagebrush steppe and other rangelands around the world (Nader et al. 2007). Management to limit fire, however, is challenging as the Wyoming big sagebrush steppe is extensive and occupies rugged, remote terrain that is difficult to access. Strategic placement of fuel breaks and green strips are commonly suggested for this effort. Fuel breaks and green strips may provide opportunities to limit the scope of wildfires and provide areas to stage suppression efforts (Pellant 1994; Agee et
al. 2000), but ecological effects of fuel breaks are uncertain (Shinneman et al. 2019, *this issue*). Additionally, these methods do not decrease the risk of ignition nor limit fire activity between them. Fuel also needs managed across the vast rangelands between fuel breaks and green strips. Grazing is likely the only method feasible to manage fuels across large sagebrush landscapes.

Grazing by livestock has been suggested as a tool to modify fuel characteristics to decrease fire probability and severity (Conard et al. 2001; Diamond et al. 2009; Davies et al. 2015; Starns et al. 2019; Rouet-Leduc et al. 2021), but longer-term (~10 yrs) grazing effects on fuels are less well known. Short-term, moderate grazing by cattle compared to short-term grazing exclusion greatly decreased the probability of ignition and fire spread in sagebrush-bunchgrass communities by decreasing fine fuel amount and continuity and increasing fuel moisture content (Davies et al. 2017; Orr et al. *this issue*). Grazing increases the live to dead fuel ratio by preventing the accumulation of prior years’ growth, thereby increasing the moisture content of fine fuels. Similar effects are likely with longer-term grazing, but if grazing results in plant community compositional shifts that affect fuels, then outcomes could vary. Grazing in forests (Zimmerman and Neuenschwander 1984), savannas (Waldram et al. 2008), shrublands (Grupenhoff and Molinari 2021) and prairies (Derner and Whitman 2009) caused compositional changes that altered fuel characteristics and subsequently fire probability and severity. Heavy, repeated grazing during the growing season also depleted perennial bunchgrasses and favored exotic annual grasses leading to increased fire frequency and size (D’Antonio and Vitousek 1992; Balch et al. 2013; Davies et al. 2021). However, compositional shifts from grazing are more likely with historic heavy, repeated used during the growing season compared to contemporary grazing practices (Borman 2005; Davies and Boyd 2020). Therefore, it is imperative to determine the effects of longer-term, contemporary grazing on fuels.
Grazing effects on fuels may vary among community states because of differences in vegetation compositional. Wyoming big sagebrush steppe exist in three general community states: 1) intact, 2) degraded, and 3) exotic annual grass states. In the intact community state, the understory is dominated by large native perennial bunchgrasses and perennial forbs (Davies et al. 2006; Bates and Davies 2019). The degraded community state is characterized by an understory where perennial bunchgrasses, excluding Sandberg bluegrass (*Poa secunda* J. Presl), and perennial forbs have been greatly reduced compared to the intact state, often from historic heavy, repeated growing season grazing and other mismanagement (Davies et al. 2011; Morris et al. 2011; Davies and Bates 2014). The exotic annual grass community state is a near monoculture of exotic annual grasses with few perennial grasses and a loss of the sagebrush overstory (Chambers et al. 2014). The vegetational compositional differences among these community states may result in differing responses of fuel characteristics to grazing. In addition, these community states vary in their fine fuel characteristics before grazing. Exotic annual grass community states have greater fine fuel biomass and continuity compared to intact community states (Davies and Nafus 2013). Though it is likely that contemporary grazing effects vary among these community states, it has not been investigated. As efforts to limit wildfire across the Wyoming big sagebrush steppe intensify, it is critical for managers to know the effects of grazing on fuel characteristics across community states.

The purpose of this study was to evaluate the effects of grazing on fuel characteristics across community states in Wyoming big sagebrush steppe. Our objective was to determine if contemporary grazing effects on fuels vary among community states and if grazing modifies fuel characteristics in a manner consistent with decreasing fire probability (reduced fine fuel biomass and continuity, and greater live to dead fine fuel ratio). We hypothesized that grazing effects
would vary among community states, but that grazing would alter fine fuel characteristics in the
three community states in a manner consistent with decreasing fire probability.

METHODS

Study Area

The study was conducted in Wyoming big sagebrush steppe in southeastern Oregon from west of
Riley, OR to east of Juntura, OR. Distance between study sites was up to 134 km. Historically
these communities were dominated by Wyoming big sagebrush with an understory dominated by
perennial bunchgrasses, predominantly Thurber needlegrass \textit{(Achnatherum thurberianum} (Piper)
Barkworth) and bluebunch wheatgrass \textit{(Pseudoroegneria spicata} (Pursh) A. Löve). Study sites
were intact, degraded, and exotic annual grass community states. The intact community state
was characterized by an understory dominated by large native perennial bunchgrasses, excluding
Sandberg bluegrass, and perennial forbs; large perennial bunchgrass and perennial forb cover
were 8.2\% and 2.2\%, respectively. The understory in the degraded community state was
depleted with very few perennial forbs and greatly reduced large perennial bunchgrass
abundance and cover; large perennial bunchgrass and perennial forb cover were 2.4\% and 1.0\%,
respectively. The exotic annual grass community state was a near monoculture of exotic annual
grasses, predominantly medusahead \textit{(Taeniatherum caput-medusae} (L.) Nevski) and cheatgrass
\textit{(Bromus tectorum} L.). In the annual grass communities, large perennial bunchgrass and native
perennial forb cover were < 1.0\% and < 0.1\%, respectively. Climate for this region is cool, wet
winters and hot, dry summers. Long-term (1981-2010) average annual precipitation ranged from
244 and 263 mm across the study sites (PRISM 2021). Crop year precipitation (Oct.-Sept.)
across the study sites was 124-134\%, 65-84\%, and 56-71\% of the long-term average in 2018-19,
2019-20, and 2020-21, respectively (PRISM 2021). Elevation of study sites ranged from 972 to 1469 m above sea level. Slopes ranged from 0 to 12° with varying aspects. Historical fire return intervals for Wyoming big sagebrush steppe communities were 50 to 100+ years (Mensing et al. 2006). Study sites were moderately grazed for the past last +40 years with use altering between spring and summer with periodic years of rest.

Experimental Design and Measurements

To determine the effects of grazing on fuel characteristics across community states we used a randomized block design in each community state. Treatments were grazed or ungrazed for the past +10 yrs. In each community state, we established five grazing exclosures to apply the ungrazed treatment. Grazing exclosures (50 X 80 m) were established for the intact and degraded community states in 2009 and in the exotic annual grass community state in 2010 in large pastures (>500 ha). Grazing was applied at the pasture level as part of normal management (i.e., contemporary grazing). Grazing was applied with cattle (cow-calf pairs) alternating between spring (growing season) and summer (post-growing season) use with infrequent years of grazing rest. Management objectives for these pastures was moderate utilization (40-50% consumption of available forage). However, we observed lower levels of utilization (<30%) in high plant production years. Utilization was estimated using the method described in Anderson and Curreir (1973). The grazing treatment replicates were placed adjacent to the grazing exclosures with a >5 m buffer between them and located on the same soil, topography, and vegetation community.

Fuel characteristics were measured in late July and early August of 2020 and 2021 after annual grazing treatments had been applied. Fuel continuity by group (erect herbaceous
vegetation, litter, fuel gap (no fuel), and shrub) were measured along two 20-m transects using the line-intercept method (Canfield 1941) in each treatment replicate. Fuel continuity by group was assessed every 1-cm along each transect. Total cover, average patch length (size) and number of patches of each group was determined along each transect. Fine fuel biomass was harvested in 15 randomly placed 1-m² quadrats per treatment replicate. Fine fuel was harvested as standing crop (erect herbaceous vegetation) and litter. Harvested biomass was oven dried at for 72 hours and then weighed. Total fine fuel was determined by combining standing crop with litter. Live to dead ratio of standing crop was determined by separating current year’s growth from prior years’ growth.

Statistical Analyses
We used repeated-measures ANOVAs using the mixed model method in SAS (SAS v. 9.4, SAS Institute, Cary, NC) to investigate grazing effects on fuel characteristics among Wyoming big sagebrush community states. Year was the repeated variable in all analyses. Random variables were block and block by treatment interactions in analyses. Treatment (grazing or ungrazed) and community state were treated as fixed variables in analyses. The treatment by community state interaction was included in all models to determine if the response of fuel characteristics to grazing varied by community state. Three-way interactions were included in the error term to improve sensitivity of analyses. Response variables were log-transformed prior to analyses to reduce issues with deviance from ANOVA assumptions. Covariance structure for the repeated-measures ANOVAs was selected using the Akaike’s Information Criterion (Littell et al. 1996). Figures and text present original, non-transformed data. Means were reported with standard errors in figures and results section and statistical significance was set at $P \leq 0.05$. 
RESULTS

Herbaceous fuel cover decreased with grazing (Fig. 1A; \( P < 0.009 \)), differed between years (\( P < 0.001 \)), and among community states (\( P < 0.001 \)). Herbaceous fuel cover was 1.2, 1.3, and 1.7-fold greater in ungrazed compared to grazed areas in the annual grass, degraded, and intact community states, respectively. Number of patches of herbaceous fuel was greater in the ungrazed than grazed areas (Fig. 1B; \( P = 0.050 \)) and varied among community states (\( P < 0.001 \)), but not between years (\( P = 0.073 \)). We did not find evidence that the size of herbaceous patches was affected by grazing (Fig. 1C; \( P = 0.104 \)). Size of herbaceous patches differed between years and among community states (\( P < 0.001 \)). Litter cover did not differ between treatments (Fig. 2A; \( P = 0.320 \)) or years (\( P = 0.434 \)), but varied among community states (\( P = 0.004 \)). The effect of grazing on number of litter patches varied by community state (Fig. 2B; \( P = 0.037 \)). In general, grazing reduced the number of litter patches in the intact community and annual grass community states, but increased litter patches in the degraded community state. The size of litter patches was not influenced by grazing (Fig. 2C; \( P = 0.488 \)) or year (\( P = 0.702 \)), but varied by community state (\( P = 0.015 \)). The effect of grazing on fuel gap (no fuel) cover was influenced by community state (Fig. 3A; \( P = 0.036 \)). Grazing increased fuel gap cover in the intact and annual grass community states, but not the degraded community state. Grazing effect on number of fuel gaps varied by community state (Fig. 3B; \( P = 0.034 \)). Number of fuel gaps was generally greater in grazed compared to ungrazed areas, but the magnitude of difference was much greater in the annual grass community state relative to the other community states. The size of fuel gaps was not influenced by grazing (Fig. 3C; \( P = 0.286 \)) or year (\( P = 0.864 \)), but varied among community states (\( P < 0.001 \)). Shrub cover and number of shrub patches were not
influenced by treatment (Fig. 4A-B; \( P = 0.187 \) and 0.182) or year (\( P = 0.058 \) and 0.257), but varied among community states (\( P < 0.001 \)).

The effect of grazing on fine fuel biomass varied by community state (Fig. 5A; \( P = 0.045 \)). The magnitude of the grazing effect on fine fuel biomass was greatest in the intact and least in the annual grass community state. Fine fuel biomass was 2.5, 1.8, and 1.5-fold greater in the ungrazed compared to the grazed treatment in the intact, degraded, and annual grass community states, respectively. Litter biomass differed between treatments and years, and varied among community states (Fig. 5B; \( P = 0.005, < 0.001, \) and \( < 0.001 \), respectively). Litter biomass was 2.6, 1.6, and 2.2-fold greater in the ungrazed than grazed treatment in the intact, degraded, and annual grass community states, respectively. The effect of grazing on standing crop biomass varied by community state (Fig. 5C; \( P = 0.001 \)). Grazing effect was much more pronounced in the intact and degraded community states compared to the annual grass community state. Standing crop biomass was 2.5, 1.9, and 1.1-fold greater in the ungrazed compared to the grazed treatment in the intact, degraded, and annual grass community states, respectively. Standing crop biomass also varied between years (\( P < 0.001 \)). The ratio of live to dead in the standing crop biomass differed between treatments and years (Fig. 5D; \( P = 0.008 \) and \( < 0.001 \), respectively), but did not vary among community types (\( P = 0.262 \)). The ratio of live to dead in the standing crop biomass was 2.5, 3.6, and 1.6-fold greater in the grazed compared to the ungrazed in the intact, degraded, and annual grass community states, respectively.

**DISCUSSION**

The effect of contemporary grazing on the response of several fine fuel variables in the Wyoming big sagebrush steppe varied by community state, suggesting that grazing plans for fuel
management will need to recognize that grazing effects will vary by community state. The interaction between grazing and community state was likely caused by differences in fine fuel characteristics among community states. These dissimilarities in fuel characteristics were likely largely driven by plant community compositional differences. In a synthesis of the literature, Davies et al. (2014) similarly concluded that the effects of long-term cessation of grazing varies by plant community composition. For example, in our current study, grazing had the least effect on standing crop in the annual grass community state, because little annual grass growth from prior years was still erect compared to bunchgrass-dominated communities where prior years’ growth contributes substantially to standing crop (Davies et al. 2016a). Thus, grazing effects in intact and degraded community states were the combination of current and prior years’ grazing reducing standing crop, but in the annual grass state grazing was largely only impacting the current year’s growth. Grazing effect on fuel gap cover also varied by community state, where it increased fuel gap cover in intact and annual grass community states, but not in the degraded state. This was likely because fine fuels (herbaceous and litter cover) were much less in the degraded state and thus, grazing did not increase fuel gap cover because most fuel cover was unpalatable woody shrubs. These results suggest that grazing management plans, especially for fuel management, need to acknowledge that grazing effects will vary based on plant community composition.

Though longer-term contemporary grazing effects on fuels varied by community state, grazing generally decreased fine fuel biomass and continuity and increased the live to dead ratio in all three community states. Other studies, though shorter-term, have also found that grazing reduces fuel biomass and continuity (Blackmore and Vitousek 2000; Briggs et al. 2002; Davies et al. 2017; Starns et al. 2019). Additionally, several studies have found that grazing increases
fine fuel moisture content (Davies et al. 2015, 2017; Rouet-Leduc et al. 2021; Orr et al. this issue), which is likely caused by grazing reducing the amount of prior years’ growth (dead) and thereby increasing the live to dead ratio. Grazing is undoubtedly influencing fine fuel characteristics across the sagebrush steppe, suggesting it has broad application for fine fuel management.

Results from our current study provide strong evidence that contemporary grazing reduced the probability of fire, regardless of community state. Reductions in fine fuel biomass and continuity and increased moisture content decreased the probability of fire in intact Wyoming big sagebrush communities (Davies et al. 2017; Orr et al. this issue). Grazing by livestock also creates refugia for fire sensitive species such as sagebrush in fire-dependent ecosystems (Dornbush et al. 2022). Similarly, large herbivore grazing in the tropics (Bernardi et al. 2019) and savannas (Trauernicht et al. 2013) decreased fire probability. Further supporting that grazing can decrease fire probability, declines in livestock in Greece resulted in greater wildfire risk (Colantoni et al. 2020). The effects of grazing on the above-mentioned fuel characteristics, leads us to conclude that grazing can be an effective tool to reduce wildfire probability. In agreement, Rouet-Leduc et al. (2021) concluded from a review of the literature that grazing is a cost-effective tool to mitigate wildfire risk. The fuel alterations from grazing we observed could also decrease wildfire size, continuity, and severity. Large fire years in the Great Basin are largely driven by fine fuels (Smith et al. this issue), thus grazing can potentially mediate this risk. Grazing, by reducing fine fuels and increasing fuel moisture content, decreased the area burned, the completeness of the burn, and fire severity in Wyoming big sagebrush communities in Oregon (Davies et al. 2016b). Grazing also reduced fire severity in other ecosystems (van Langeveld et al. 2003; Kimuyu et al. 2014). The effects of contemporary
grazing on fine fuels, and subsequently wildfire, in the Wyoming big sagebrush steppe has broad implications to the sustainability of rural grazing-based economies and the conservation of wildlife that depend on these plant communities.

Wildfires are likely easier and safer to suppress in contemporary grazed compared to ungrazed areas in the sagebrush steppe. Decreased fuel biomass and continuity and increased live to dead ratio with grazing would reduce flame lengths and rate of fire spread. Less fine fuels produce slower moving fires with decreased flame lengths (Bradstock and Gill 1993; Blackmore and Vitousek 2000). Greater live to dead ratio (i.e. greater fuel moisture) also decreases the rate of spread because as fuel moisture increases, more energy is required to cause ignition (Rothermel 1972; Thonicke et al. 2001; Chuvieco et al. 2004). Cattle grazing reduced flame lengths and fire spread in mesquite savannas in Arizona (Bruegger et al. 2016) and sagebrush steppe in Oregon (Davies et al. 2016b). Even with shrub dominated overstories, herbaceous fuel determined how engaged and complete shrubs burn, and thereby influenced fire behavior (Davies et al. 2016b). Fire suppression efforts are less dangerous and more effective with decreased flame lengths and rate of fire spread (Fried et al. 2004; Moghaddas and Craggs 2007). Thus, contemporary grazing by cattle in the Wyoming big sagebrush steppe increases the effectiveness of suppression and reduces the risk to wildland firefighters.

Additionally, our results strongly suggest that grazing management needs to be temporally and spatially flexible to meet fuel management objectives. Most measured fuel characteristics varied among community states and between years. In agreement with our findings, fine fuel continuity and biomass were greater and moisture content less in exotic annual grass compared to intact community states of the Wyoming big sagebrush steppe (Davies and Nafus 2013). Similarly, fine fuel continuity and biomass varies among years across the Great
Basin, often in response to precipitation in the current and prior year (Smith et al. *this issue*). Thus, to achieve fuel management goals, grazing management needs to be responsive to the spatial and temporal dynamics of fine fuels.

**MANAGEMENT IMPLICATIONS**

Contemporary grazing by cattle modified fine fuel characteristics across Wyoming big sagebrush community states. Grazing altered fuel characteristics in a manner that decreases fire probability, severity, and intensity. Grazing is, thereby, decreasing the likelihood of frequent wildfire and increasing the effectiveness and safety of fire suppression efforts. Consequently, exclusion of grazing in Wyoming big sagebrush steppe would increase the probability of wildfire and decrease suppression effectiveness. The effects of grazing on several fine fuel response variables varied by community state, suggesting the importance of adapting grazing management to community composition. For instance, heavier grazing pressure may be warranted in the annual grass community state to achieve desired fuel alterations (see Diamond et al. 2009; Stephenson et al. *this issue*). This may be achieved with fall grazing as this has limited impacts on perennial bunchgrasses (Schmelzer et al. 2014). Differences in grazing effects on fuel characteristics among community states needs to be recognized in fuel management plans.

Grazing plans to reduce fuels also need to be developed with fire managers to improve effectiveness. Our results suggest that grazing is a promising tool for managing fine fuel to decrease the probability of fire and improve suppression efforts. However, flexibility in the application of grazing is needed to match grazing pressure to fuel characteristics as they vary across space and time.
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LITERATURE CITED


Shinneman et al., this issue


Stephenson, M.B., Perryman, B.L., Boyd, C.S., Schultz, B.W., Svejcar, T., Davies, K.W., (this issue) Strategic supplementation to manage fine fuels in cheatgrass (Bromus tectorum) invaded system. Rangeland Ecology & Management


Figure 1.1. Herbaceous fuel cover, number of patches, and patch size (mean + S.E.) in the annual grass, degraded, and intact community states in 2020 and 2021.
Figure 1.2. Litter cover, number of patches, and patch size (mean + S.E.) in the annual grass, degraded, and intact community states in 2020 and 2021.
Figure 1.3. Fuel gap cover, number of patches, and patch size (mean + S.E.) in the annual grass, degraded, and intact community states in 2020 and 2021.
Figure 1.4. Shrub cover and patch size (mean + S.E.) in the annual grass, degraded, and intact community states in 2020 and 2021.
Figure 1.5. Fine fuel, litter, and standing crop biomass and live to dead ratio of standing crop (mean + S.E.) in the annual grass, degraded, and intact community states in 2020 and 2021.
CHAPTER 3:
EFFECTS OF A DECADE OF GRAZING EXCLUSION ON THREE WYOMING BIG SAGEBRUSH COMMUNITY TYPES

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IN REVIEW
ABSTRACT

Livestock grazing is the most extensive land use in Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis* [Beetle & A. Young] S.L. Welsh) steppe and its effects on plant community characteristics have been greatly debated. There have been calls to remove livestock grazing from public rangelands due to the negative impacts of historic overgrazing (heavy, repeated use during the growing season). However, most of the studies used to support grazing removal evaluated the impacts of excluding historic grazing, rather than the impacts of excluding moderate contemporary grazing (40-50% utilization, altering season of use) which has vastly different effects on plant communities. Thus, to understand the effects of removing contemporary grazing, we compared contemporary grazed areas to long-term (+10 yrs.) grazing exclusion areas in three common Wyoming big sagebrush community types: intact, degraded, and exotic annual grass-dominated types. Plant community characteristics (cover, density, diversity) were measured in 2020 and 2021 in five grazed and grazing excluded areas within each community type. The effect of grazing exclusion on Sandberg bluegrass (*Poa secunda* J. Presl) abundance and litter cover varied among community types, suggesting that grazing exclusion effects slightly varied among community types. However, most plant community characteristics were not influenced by grazing exclusion, suggesting that the removal of contemporary grazing has little effect on Wyoming big sagebrush plant communities. In contrast, most plant community characteristics varied among community types and between years, suggesting that grazing management plans need to account for the spatial and temporal variability among Wyoming big sagebrush communities. Furthermore, our results suggest that contemporary grazing exclusion has negligible effects compared to contemporary grazing on
plant communities, and that exclusion of contemporary grazing (passive restoration) does not promote the recovery of degraded and annual grass invaded plant communities.
KEYWORDS: exotic annual grass; defoliation; grazing management; passive restoration; plant community recovery; sagebrush steppe
INTRODUCTION

Historic overgrazing of the late 1800’s and early 1900’s resulted in the degradation of many ecosystems in the western US (Daubenmire 1970, Box 1990). Semi-arid ecosystems, such as Wyoming big sagebrush steppe, were particularly susceptible to native plant community degradation (Daubenmire 1970, Mack 1981, Box 1990, Knapp 1996). In the Wyoming big sagebrush steppe, historic grazing practices depleted native bunchgrass understories, thus contributing to the spread of exotic annual grasses like cheatgrass (*Bromus tectorum* L.) and medusahead (*Taeniatherum caput-medusae* (L.) Nevski), and subsequent loss of diversity (Mack 1981, Young and Allen 1997, Chambers et al. 2007). However, contemporary grazing practices are vastly different from historic grazing practices (Borman 2005, Davies and Boyd 2020). When done correctly, contemporary grazing management utilizes an adaptive approach where factors such as season of use, frequency, and intensity of grazing are evaluated and adjusted periodically to maintain ecological integrity (Davies and Boyd 2020). In contrast, historic grazing was often heavy, repeated use during the growing season with little thought of the ecological implications or long-term sustainability of the practice (Davies and Boyd 2020). Subsequently, the effects of grazing exclusion in areas with contemporary grazing practices are poorly known.

The effects of grazing exclusion on Wyoming big sagebrush steppe likely vary among community types because of differences in plant community composition (Davies et al. 2014). Disturbances such as historic overgrazing and the introduction of exotic annual grasses have altered vast areas of Wyoming big sagebrush steppe, resulting in distinct plant community types, all originally Wyoming big sagebrush-bunchgrass communities. Thus, Wyoming big sagebrush steppe can be grouped into three common community types: 1) intact, 2) degraded, and 3) exotic annual grass-dominated types associated with past management effects and invasion. The intact
community type is comprised of a sagebrush overstory and an understory dominated by native perennial bunchgrasses and perennial forbs (Davies et al. 2006, Bates and Davies 2014, 2019). The degraded community type is comprised of abundant sagebrush and an understory depleted of large native perennial bunchgrasses and perennial forbs with Sandberg bluegrass (*Poa secunda* J. Presl) being the dominant perennial bunchgrass (Davies et al. 2016a, Thomas and Davies IN PRESS). The degradation of these communities is likely the result of historic overgrazing and other anthropogenic disturbances such as altered fire regimes and energy development (Braun et al. 2002, Lyon and Anderson 2003, Bergquist et al. 2007, Davies et al. 2011, Morris et al. 2011, Naugle et al. 2011, Davies and Bates 2014). The exotic annual grass-dominated community type is a near monoculture of exotic annual grasses, nearly devoid of perennial bunchgrasses and sagebrush (Chambers et al. 2014), a result of exotic annual grass invasion, overgrazing, and fire (Whisenant 1990, D’Antonio and Vitousek 1992, Brooks et al. 2004, Reed-Dustin et al. 2016). These differences likely influence the plant community response to grazing exclusion, however, little information is available to assist land managers in determining if grazing exclusion effects vary by community type.

Improvement in public rangeland condition is largely attributed to a movement from historic overgrazing practices to contemporary moderate grazing practices (Box 1990). Exclusion of historic grazing compared to replacing historic with contemporary grazing practices has generally resulted in similar plant communities characteristics (Gardner 1950, Smeins et al. 1976, Norton 1978, Rice and Westoby 1978, Anderson and Holte 1980, Hughes 1980, Holechek and Stephenson 1983, Copeland et al. 2021). However, research comparing contemporary grazing practices with complete grazing exclusion as influenced by plant community differences is lacking. To understand the interaction between contemporary grazing and plant community
type in Wyoming big sagebrush steppe, more information is needed on the effects of contemporary grazing exclusion in intact, degraded, and exotic annual grass-dominated community types. Information regarding the effect of grazing exclusion in exotic annual grass-dominated community types is especially scarce as there are few grazing exclosure studies in these communities. In exotic annual grass-dominated communities, excluding fall-grazing increased the cheatgrass seedbanks and maintained exotic annual grass dominance (Schmelzer et al. 2014, Perryman et al. 2020), but grazing treatments were not during the typical grazing season (late spring-summer). Also, the predominant perennial bunchgrass was crested wheatgrass (*Agropyron cristatum* L. Gaertn), a competitive introduced bunchgrass (Schmelzer et al. 2014), so effects may differ in areas comprised of native perennial bunchgrasses. Shorter-term studies (< 10 yrs.) might not capture the full effect of contemporary grazing exclusion (West et al. 1984, Davies et al. 2016a, Davies et al. 2021b), especially since native perennial vegetation can be slow to respond to changes in management and treatments (Davies et al. 2016a). To assist land management decisions, further evaluations of grazing exclusion are needed in all three community types (exotic annual grass, degraded, intact), and to determine if recovery of degraded and exotic annual grass invaded plant communities is inhibited by contemporary grazing.

The purpose of this study was to evaluate the effects of contemporary grazing exclusion on plant community characteristics and if these effects vary among three common community types found in Wyoming big sagebrush steppe. We hypothesized that grazing exclusion effects would vary among community types, and that grazing exclusion would result in increases in native perennial bunchgrass abundance and plant diversity and decreases in exotic annual grass abundance and cover.
METHODS

Study Area

Our study was conducted in Wyoming big sagebrush steppe in southeastern Oregon from west of Riley, OR to east of Juntura, OR. Prior to European settlement, understories were co-dominated by the native perennial bunchgrasses Thurber’s needlegrass (Achnatherum thurberianum (Piper) Barkworth) and bluebunch wheatgrass (Pseudoroegneria spicata (Pursh) A. Löve). Past disturbances and invasion by exotic annual grasses have shifted some of these sagebrush-bunchgrass communities to different community types. For this study, we selected three community types commonly found within Wyoming big sagebrush steppe: intact, degraded, and exotic annual grass-dominated community types. At the beginning of the study, large native perennial bunchgrass and perennial forb cover were 8.2% and 2.2% in the intact community type, respectively. In the degraded community type, large native perennial bunchgrass and perennial forb cover was 2.4% and 1.0%, respectively. Poa secunda and annual forbs were the dominant functional groups in the degraded community type (Davies et al. 2016a, Thomas and Davies In review). The exotic annual grass-dominated community type had high exotic annual grass cover (~ 19%) and low cover of large native perennial bunchgrasses and forbs, < 1.0% and < 0.1% cover at the start of the study, respectively. The exotic annual grasses were predominantly medusahead (Taeniatherum caput-medusae (L.) Nevski) and cheatgrass (Bromus tectorum L.). The climate of this region consists of cold, wet winters and hot, dry summers with long-term (1991-2020) average annual precipitation ranging from 242-mm and 264-mm across study sites (PRISM 2022). The range in crop year precipitation (Oct. – Sept.) across study sites was 133-144%, 77-88% and 67-80% of the long-term average in 2018-19, 2019-20, and 2020-
The elevation range across the study sites was 1027 to 1478-m above sea level and slopes ranged from 0° to 12° with varying aspects. For Wyoming big sagebrush steppe communities, the historic fire return intervals are estimated to range from 50 to 100+ years (Mensing et al. 2006). Moderate grazing (see below) with spring and summer rotation was conducted at the study sites for the last +40 years with periodic years of rest.

**Experimental Design and Measurements**

Within each community type, five 30 × 50-m grazing exclosures (ungrazed treatment) with adjacent grazing treatments were established. Treatments were applied for +10 years with the grazing exclosures for the intact and degraded community types established in 2009 and the exotic annual grass community type exclosures established in 2010. Contemporary grazing was applied with cow-calf pairs alternating between spring and summer seasons with periodic year-long rest. Moderate grazing (40-50% utilization of available forage) was the management objectives for these sites with lower levels of utilization (< 30%) observed in high forage production years. Forage utilization was evaluated using the method described in Anderson and Curreir (1973). Grazing intensity was 0.20 to 0.38 animal unit months (AUMs) per ha with an average pressure of 0.23 AUMs per ha. Grazing pastures ranged in size from 200 ha to >1000 ha. Grazing treatment replicates were established adjacent to grazing exclosures with a > 5-m buffer between treatments. Blocked grazing and grazing exclusion treatments were placed in areas that shared similar topography, aspect, slope, and plant community. A randomized block design within each community type was used to investigate the effects of contemporary grazing exclusion on plant community characteristics across community types. With three community
types, five sites within each community type, and two grazing treatments per site, we had 30 plots that were measured once a year for two years.

Plant community characteristics were measured in late July and early August of 2020 and 2021 after grazing for the year was finished. Herbaceous canopy cover by species, ground cover (litter, bare ground, rock, moss, crust), and density by species measurements were made inside 40 × 50-cm frames (0.2-m²) located at 3-m intervals along four 50-m transects (starting at 3-m and ending at 45-m), resulting in 15 frames per transect and 60 frames per treatment. Herbaceous cover estimates were aided by markings painted on the frames that delineated 5, 10, 25, and 50% sections. Herbaceous density was determined by counting all individuals rooted in the frames. Shrub canopy cover by species was measured by line intercept (Canfield 1941) on each of the four 50-m transects. Canopy gaps less than 5-cm were included in shrub canopy cover measurements. Shrub density by species was determined by counting all individuals rooted in 2 x 50-m belt transects along each of the four 50-m transects at each site. Plant species diversity (Shannon diversity index) was calculated from species density measurements (Krebs 1998). Exotic plants were included in estimates of diversity.

Statistical Analyses

We used repeated-measures ANOVA’s using the mixed effects model method (nlme) in R (R Studio v. 4.1.2, RStudio Team, 2022) to determine grazing effects on measured plant community characteristics (herbaceous cover and density, shrub cover and density, and species diversity) among the three Wyoming big sagebrush community types. Year was the repeated measure variable, treatment was the fixed-effect variable, and block by community type interactions were the random-effect variables in all analyses. An interaction between grazing treatment and
community type was included in all models to determine if the response of plant cover, density, and diversity to grazing varied by community type. Response variables that violated ANOVA assumptions were log-transformed or incorporated weighted variances between community types prior to analyses to reduce issues with ANOVA assumptions. Covariance structure for the repeated-measures ANOVA’s was selected using the Akaike’s Information Criterion (RStudio Team 2022). Non-transformed data were presented in figures and text. Species were grouped by functional group for cover and density analyses. *Poa secunda* was analyzed separate from the other perennial bunchgrasses because it differs phenologically (James et al. 2008) and responds

Figure 2.1. Perennial grass density, *Poa secunda* density, and annual grass density in the annual grass, degraded, and intact community types in 2020 and 2021. The 25th and 75th percentiles are represented by upper and lower ends of the box. The line inside the box represents the median. The whisker ends represent the highest and lowest values within 1.5 * the interquartile range and the outliers are represented by the dots plotted past the whiskers.
differently to disturbances (McLean and Tisdale 1972, Yensen et al. 1992). Exotic perennial forbs such as whitetop (*Cardaria draba* [L.] Desv.) and field bindweed (*Convolvulus arvensis* L.) were analyzed separate from native perennial forbs. The annual forb group was comprised of both native and non-native species. Statistical significance was set at $P \leq 0.05$.

RESULTS

*Herbaceous plants: cover, density, diversity*

Perennial grass density was not influenced by grazing exclusion (Fig. 1A; $P = 0.138$) or year ($P = 0.150$), but was greatest in the intact community type and lowest in the annual grass community type ($P < 0.001$). The effect of grazing exclusion on *P. secunda* density was influenced by community type (Fig. 1B; $P < 0.001$) and differed between years ($P = 0.001$). *Poa secunda* density was generally less with grazing exclusion, but this effect was more evident in intact and annual grass invaded communities. Annual grass, native perennial forb, and exotic perennial forb density was not influenced by grazing exclusion (Fig. 1C, 2A, & 2B; $P = 0.761$, 0.966, and 0.778), but differed among community types ($P = 0.001$, 0.030, and 0.026). Annual forb density was not influenced by grazing exclusion (Fig. 2C; $P = 0.680$) or community type ($P = 0.103$), but differed between years ($P = 0.001$). Plant diversity was not influenced by grazing exclusion (Fig. 2D; $P = 0.465$), but differed among community types ($P = 0.028$) and between years ($P = 0.035$).

Perennial grass cover increased with grazing exclusion (Fig. 3A; $P < 0.001$) and differed among community types ($P < 0.001$), but not between years ($P = 0.700$). Perennial grass cover was 2.3, 3.2, and 2.8-fold greater in the ungrazed compared to the grazed areas in the annual grass, degraded, and intact community types, respectively. *Poa secunda* and annual grass cover
were not affected by grazing exclusion (Fig. 3B and 3C; \( P = 0.384 \) and 0.400), but differed between

Figure 2.2. Native perennial forb (PF) density, exotic perennial forb (PF) density, annual forb density and Shannon diversity index in the annual grass, degraded, and intact community types in 2020 and 2021. The 25\(^{th}\) and 75\(^{th}\) percentiles are represented by upper and lower ends of the box. The line inside the box represents the median. The whisker ends represent the highest and lowest values within 1.5 * the interquartile range and the outliers are represented by the dots plotted past the whiskers.
Figure 2.3. Perennial grass cover, Poa secunda cover, annual grass cover, and native perennial forb (PF) cover in the annual grass, degraded, and intact community types in 2020 and 2021. The 25th and 75th percentiles are represented by upper and lower ends of the box. The line inside the box represents the median. The whisker ends represent the highest and lowest values within 1.5 * the interquartile range and the outliers are represented by the dots plotted past the whiskers.

Native perennial, exotic perennial, and annual forb cover was not influenced by grazing exclusion (Fig. 3D, 4A, and 4B; \( P = 0.775, 0.614, \) and 0.897) and had varying responses to year and community...
type. We did not find evidence that bare ground cover was influenced by grazing exclusion (Fig. 4C; P = 0.059), but it differed between years (P = 0.048) and among community types (P < 0.001).

![Figure 2.4](image)

**Figure 2.4.** Exotic perennial forb (PF) cover, annual forb cover, bare ground cover, and litter cover in the annual grass, degraded, and intact community types in 2020 and 2021. The 25th and 75th percentiles are represented by upper and lower ends of the box. The line inside the box represents the median. The whisker ends represent the highest and lowest values within 1.5 * the interquartile range and the outliers are represented by the dots plotted past the whiskers.
Litter cover appeared to increase with grazing exclusion in the exotic annual grass community type, but was unaffected by grazing exclusion in the degraded and intact community types (Fig. 4D; \( P = 0.002 \)), and did not differ between years (\( P = 0.363 \)). Crust and moss cover were not influenced by grazing exclusion (Fig. 5A-B; \( P = 0.412 \) and 0.108), but differed among community types (\( P = 0.002 \) and < 0.001) and varied between years (\( P < 0.001 \) and 0.001). The amount of visible rock was influenced by grazing exclusion (Fig. 5C; \( P = 0.032 \)) and year (\( P = 0.003 \)), but not by community type (\( P = 0.157 \)).

Figure 2.5. Crust cover, moss cover, and rock cover in the annual grass, degraded, and intact community types in 2020 and 2021. The 25\textsuperscript{th} and 75\textsuperscript{th} percentiles are represented by upper and lower ends of the box. The line inside the box represents the median. The whisker ends represent the highest and lowest values within 1.5 * the interquartile range and the outliers are represented by the dots plotted past the whiskers.
Shrubs: cover and density

Sagebrush cover and density were not influenced by grazing exclusion (Fig. 6A & 6D; $P = 0.215$ and 0.692) or year ($P = 0.910$ and 0.216), but differed among community types ($P < 0.001$ and < 0.001). Other shrubs (yellow rabbitbrush (*Chrysothamnus viscidiflorus* [Hook.] Nutt.); spineless horsebrush (*Tetradymia canescens* DC.)) cover decreased with grazing exclusion (Fig. 6B; $P = 0.019$), but did not differ among community types ($P = 0.244$) or between years ($P = 0.767$). Other shrub density was not influenced by grazing exclusion (Fig. 6D; $P = 0.667$), community type ($P = 0.174$), or year ($P = 0.286$).
DISCUSSION

Our results suggest the exclusion of contemporary grazing has negligible impacts on plant community characteristics. In addition, the effect of grazing exclusion on plant community characteristics seldom varied by community type. Degraded and annual grass-invaded sagebrush communities are expected to change little without reduction in sagebrush and annual grasses, respectively (Davies et al. 2014), thus are likely resilient to contemporary grazing, hence the general lack of response to grazing exclusion. Similarly, intact communities are likely resilient to contemporary grazing, which may be a product of grazing management focusing on sustainability by adjusting stocking rates, intensity, and timing of use (Borman 2005; Davies and Boyd 2020). In contrast, community type consistently explained differences in community characteristics, suggesting that community type has a greater influence than contemporary grazing. Grazing is a major land use on rangelands throughout the western US and understanding the impacts of contemporary grazing and grazing removal is important for land managers in decision making processes, maintaining ecological stability, and promoting the recovery of degraded and exotic annual grass-dominated communities.

Only *P. secunda* density and litter cover were influenced by the interaction between grazing treatment and community type. *Poa secunda* density was higher in grazed areas in the exotic annual grass-dominated and intact community types relative to the degraded community type. Greater *P. secunda* density in grazed areas within the annual grass community type is likely explained by the reduction in litter in grazed areas. Grazing likely reduced shading as dense litter
layers typically produced by exotic annual grasses can cover the short-statured *P. secunda* plants (Davies et al. 2021b), and subsequently increased the area in which *P. secunda* is able to establish. Similar to the exotic annual grass-dominated community type, the greater *P. secunda* density with grazing in the intact community type is likely explained by the reduction in perennial bunchgrass cover, thereby also reducing shading of *P. secunda* plants. Litter was greater in the ungrazed areas within the exotic annual grass community type but showed no response in either the degraded or intact community types. This is in agreement with a study in Oregon that found grazing significantly reduced litter within exotic annual grass sites (Davies et al. 2021b). Similar to our litter cover results from the intact community, Veblen et al. (2015) also reported grazing to have no impact on litter cover within intact sagebrush communities. As only two variables were influenced by the interaction between grazing treatment and community type, grazing exclusion effects largely do not differ among community types. This is likely because contemporary grazing had minimal effects on the plant communities and subsequently, grazing exclusion did not produce many changes in the community characteristics.

One of the few differences found with grazing exclusion was greater perennial bunchgrass cover (excluding *P. secunda*), however, it is likely not consequential as bunchgrass density remained similar between grazed and ungrazed areas. In addition, increases in native perennial bunchgrass cover within grazing exclosures was expected as grazing removes previous year’s growth, a major contributor to total perennial bunchgrass cover (Davies et al. 2016b) and current year’s growth. Other studies have similarly reported that grazing exclusion increases perennial bunchgrass cover but does not affect perennial bunchgrass abundance (Davies et al. 2016a, Davies et al. 2021b). Furthermore, a difference in perennial bunchgrass cover is likely a response to annual precipitation and short-term management, contrary to an increase in
abundance that would represent long-term community trends (Copeland et al. 2021). Greater perennial bunchgrass biomass associated with greater cover from grazing exclusion can increase the risk of fire-induced mortality of bunchgrasses (Davies et al. 2009, Davies et al. 2016), and as a result, grazing exclosures may be more susceptible to post-fire exotic annual grass invasion and further degradation of native plant communities (Davies et al. 2016, Davies et al. 2021a). Regardless, reductions in perennial bunchgrass cover with grazing was not an indication of a shift in the plant community, but its implications will vary depending on management priorities (fuel management, wildlife habitat, etc.).

The minimal differences in plant density found between grazed areas and grazing exclosures indicates that grazing exclusion does not promote faster recovery of degraded plant communities compared to contemporary grazing. In support of our conclusion, several other authors reported moderate, contemporary grazing does not hinder the recovery of sagebrush steppe plant communities compared to grazing exclusion (Sneva et al. 1984, West et al. 1984, Courtois et al. 2004, Manier and Hobbs 2006, Copeland et al. 2021). Our results combined with these prior studies suggest that contemporary grazing in sagebrush steppe communities is compatible with the sustainability of these communities and provides no evidence that grazing exclusion would be advantageous. These communities appear relatively stable and resilient to contemporary grazing. This is likely because contemporary grazing, with its moderate levels of use and altering timing of use, does not favor one plant functional group over another.

Prior plant community characteristics likely have a more significant role in community recovery than the exclusion of contemporary grazing. In sagebrush-dominated plant communities, the recovery of perennial bunchgrasses with the cessation of grazing was unlikely once sagebrush cover reached its upper limit (Robertson 1971, Sneva et al. 1980, West et al.
1984, Anderson and Inouye 2001, Boyd and Svejcar 2011, Davies et al. 2016a), suggesting that the influence of an overabundant sagebrush overstory is likely greater than the effect of contemporary grazing on plant community characteristics. Our results from the degraded community type further support this idea as sagebrush abundance was greater in the degraded community type than the intact community type, but perennial bunchgrass abundance was significantly less in the degraded community compared the intact community. It is also unlikely that the exclusion of contemporary grazing will benefit intact plant communities as these sites already have established native perennial vegetation with high resilience to disturbance and resistance to exotic annual grasses (Chambers et al. 2014, Davies et al. 2014). Our results support this idea as abundance of native perennial bunchgrasses and forbs were not affected by a decade of grazing exclusion in the intact community type. Excluding contemporary grazing in annual grass dominated communities will likely not facilitate conversion back to a native perennial-dominated plant community as annual grass competition and increased fire frequency associated with annual grass invasion prevents native perennial bunchgrass establishment (D’Antonio and Vitousek 1992, Mack et al. 2000, Brooks et al. 2004, Eiswerth et al. 2009, Davies et al. 2021c). Our results suggest that the exclusion of contemporary grazing in Wyoming big sagebrush communities has little effect on plant community characteristics and community recovery, likely because moderate contemporary grazing has limited effect on these plant communities.

**MANAGEMENT IMPLICATIONS**

The exclusion of contemporary grazing resulted in minute differences in plant community characteristics in three common Wyoming big sagebrush community types. Only *P. secunda*
density and litter cover were influenced by interactions between grazing treatment and community type, suggesting that the effects of contemporary grazing exclusion may vary slightly among community types. The lack of difference between contemporary grazing and grazing excluded treatments on community characteristics is consistent with other studies (e.g., Copeland et al., 2021; Davies et al., 2022; Davies et al., 2018). Our results suggest that passive restoration (cessation of grazing) will not promote recovery of degraded and annual grass community types, thus restoration of these communities will require active management. In exotic annual grass-dominated rangelands, contemporary grazing had negligible impacts on exotic annual grasses. Therefore, in these communities, if the management goal is to reduce exotic annual grasses, heavier grazing pressure may be warranted (Hempy-Mayer and Pyke 2020), but outcomes will also depend on timing, intensity, and frequency of grazing. Community type and year consistently explained plant community differences, implying that the use of adaptive management in grazing plans would be recommended to account for spatial and temporal variability found in Wyoming big sagebrush steppe. Our results suggest that grazing exclusion compared with moderate contemporary grazing in three common Wyoming big sagebrush community types does not impact intact community types nor promote recovery of degraded and exotic annual grass community types. Though grazing exclusion and contemporary grazing do not differ substantially in their effects on plant community characteristics, applications of contemporary grazing should continue to be evaluated periodically to maintain ecological integrity. Additionally, care should be taken when extrapolating the results found in this study to other ecosystems.
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Chapter 4: OVERARCHING CONCLUSIONS AND FUTURE RESEARCH

Contemporary grazing on rangelands is apparent throughout the western United States and can be used as an effective tool for managing fuel buildup (Davies et al. 2017, Orr et al. this issue), exotic annual grasses (Schmelzer et al. 2014, Perryman et al. 2020, Davies et al. 2021c, b), and maintaining plant communities (Sneva et al. 1984, West et al. 1984, Courtois et al. 2004, Manier and Hobbs 2006, Copeland et al. 2021). Grazing has been referred to as an irresponsible use of public rangelands as historical grazing practices resulted in the degradation of many native plant communities and helped propagate the spread of exotic annual grasses (Laycock 1967, Mack 1981, Young and Allen 1997, Reisner et al. 2013). The effect of moderate contemporary grazing is often convoluted with historic grazing, even though it is vastly different in its impacts on plant communities (Davies and Boyd 2020). Contemporary grazing integrates ecological integrity into grazing practices as grazing frequency, intensity, and timing are controlled and evaluated periodically to maintain plant community health and diversity. Long-term studies have shown that contemporary grazing can be utilized as a tool in management, however, its effects on plant community composition can vary (Davies et al. 2014, Thomas et al. In review).

Moderate contemporary grazing is significantly different than historical or improper grazing and it is inappropriate to not distinguish between them when making conclusions about the effects of grazing (Davies and Boyd 2020). Historic grazing largely differs from moderate contemporary grazing as it was the unrestricted free reign of livestock on rangelands with little knowledge or concern about the ecological implications (Borman 2005, Davies and Boyd 2020). Long-term degradation of plant communities from historic grazing in sagebrush steppe is still apparent as it led to significant reductions in native perennial bunchgrasses and forbs, created overabundant sagebrush stands, and resulted in communities being vulnerable to exotic annual
grasses (Daubenmire 1970, Mack 1981, Box 1990, Knapp 1996). Grazing has also been linked to the spread and dominance of exotic annual grasses (Mack 1981, Rosentreter 1994, Knapp 1996, Belsky and Blumenthal 1997, Olff and Ritchie 1998, Chambers et al. 2007, 2014a, Reisner et al. 2013). However, type of grazing wasn’t typically specified, as moderate contemporary grazing can reduce annual grass litter accumulation and abundance of exotic annual grasses (Perryman et al. 2020, Davies et al. 2021b). The reduction in fuels, especially in annual grass invaded communities, can lead to decreased risk of plant mortality following fire and reduced litter cover, supporting native perennial seedlings trying to reestablish in these areas (Davies et al. 2009, 2016, 2021a). *Poa secunda* is a native perennial bunchgrass that can increase in abundance with contemporary grazing in annual grass invaded areas as the reduction in litter accumulation likely reduces shading of these short-statured plants (Davies et al. 2021b). In communities other than sagebrush steppe, historic overgrazing has been linked to dense, disease-susceptible forests with reduced fire frequencies because of decreased herbaceous understories (Borman 2005). In three Colorado national forests that experienced historic overgrazing, the implementation and continuation of moderate contemporary grazing resulted in dramatic improvements in forest condition (Bradford et al. 2003, Borman 2005). Furthermore, distinguishing between types of grazing is critical in management as historic grazing, characterized by heavy, repeated growing season use, is greatly different than moderate contemporary grazing that uses an adaptive approach to grazing plans and is periodically adjusted to maintain ecological integrity.

In this study, the interaction between contemporary grazing exclusion and the three plant communities was negligible as *Poa secunda* abundance and litter cover were the only variables that reported significant differences with treatment. The increase in *Poa secunda* abundance in the annual grass and intact community types coincides with similar studies where grazing
increased abundance (Yeo 2005, Veblen et al. 2015, Copeland et al. 2021). This is likely because of the reduction in litter and foliar cover from annual grasses and perennial bunchgrasses that would have otherwise shaded the small-statured Poa secunda plants (Davies et al. 2021b). The reduction in litter with grazing was only apparent in the exotic annual grass sites, in agreement with a study in Oregon where grazing significantly reduced exotic annual grass litter accumulation (Davies et al. 2021b). In addition to the interaction of grazing treatment and community type having little effect on plant community characteristics, few differences were found between contemporary grazing and grazing exclusion. Except for Poa secunda, abundances of native and annual vegetation were not affected by grazing treatment, indicating that exclusion of contemporary grazing likely does not promote plant recovery in annual grass invaded and degraded plant communities (Davies et al. 2018, 2021c, Thomas et al. In review). In addition, grazing exclusion likely has little effect on intact communities as the established native perennial vegetation provides high resilience to disturbance and high resistance to exotic annual grasses (Chambers et al. 2014b, Davies et al. 2014). Contemporary grazed areas often have similar plant community characteristics to grazing excluded areas (Courtois et al. 2004, Copeland et al. 2021, Thomas et al. In review), indicative of the minimal effects of contemporary grazing in Wyoming big sagebrush steppe.

Fine fuel management is a major issue in Wyoming big sagebrush steppe, especially in annual grass invaded communities as fire regimes are greatly altered from historic regimes. Contemporary grazing can be a tool to manage fine fuel load, continuity, and composition as risk of fire is lower in grazed areas compared to grazing exclosures. The interaction between grazing and community type influenced some fuel characteristics, suggesting that grazing management plans should incorporate community type when managing fuels in Wyoming big sagebrush
steppe. Grazing decreased standing crop herbaceous material and litter biomass, while also increasing the live-to-dead ratio of herbaceous vegetation, thereby, reducing the risk of fire, and likely increasing suppression effectiveness. Consequently, the exclusion of grazing increased risk of fire, especially in exotic annual grass sites, greatly reducing the chance for native perennial vegetation to recover. When managing fine fuels in exotic annual grass sites, heavier grazing may be warranted to achieve desired management goals.

In Wyoming big sagebrush steppe, community type and year consistently explained variation in fine fuel and plant community characteristics, indicating the need to include spatial and temporal variation when developing grazing management plans. Also, community type may have a greater influence than contemporary grazing in Wyoming big sagebrush steppe as grazing had minimal impacts on plant community characteristics. This is likely because contemporary grazing generally does not affect intact communities or inhibit the recovery of degraded or annual grass invaded communities.

Future research on contemporary grazing in Wyoming big sagebrush steppe has several avenues that it can go down that would greatly benefit grazing management. Investigating the effects of contemporary grazing in other sagebrush steppe community types would provide a more extensive understanding of how contemporary grazing affects fine fuels and plant community characteristics across the sagebrush ecosystem. The variability in the temporal scale across the sagebrush steppe is another factor that should be addressed in future research. Longer-term studies on contemporary grazing and grazing exclusion would record annual and seasonal trends in plant community responses, which may indicate when the application of grazing or other management tools would be most beneficial. Long-term studies could also provide a better understanding of native perennial vegetation responses to disturbances like fire and exotic annual
grasses that may not be captured in shorter studies. In addition to expanding the length and scope of these studies to provide a more holistic understanding of these communities, future research, especially in annual grass invaded communities, should incorporate other grazing treatments like different intensities, frequencies, and season of use to understand its impact on exotic annual grasses and native perennial vegetation. The manipulation of season of use was utilized by Davies et al. (2021b) to evaluate how the adjustment of timing of grazing would affect exotic annual grasses and native perennial vegetation one-year post-fire. They found grazing to greatly reduce exotic annual grasses and forbs with no effect on native perennial bunchgrass abundance (Davies et al. 2021b). This was likely attributed to the short duration of the study since a longer post-fire evaluation of grazing treatments on annual grass invaded communities was suggested to capture changes in perennial grasses that may take longer to manifest (Davies et al. 2021b). As heavier grazing pressure has been suggested as a tool to control exotic annual grasses and reduce fire risk, long-term studies are warranted to determine how grazing treatments would affect native perennial vegetation and soil characteristics in these exotic annual grass communities.

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