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Effects of Dormant Season and Contemporary Spring-Summer Grazing on Plant Community Composition in the Sagebrush Ecosystem☆,☆☆,★

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ABSTRACT

Livestock grazing is the primary land use across sagebrush ecosystems in the western US and its effects have been subject to extensive research and debate. Historical overgrazing, annual grass invasion and associated increase in fire frequency, conifer encroachment, climate change, and human modification have resulted in the loss or degradation of 86% of sagebrush ecosystems, leading to intensified interest in how remaining intact rangelands are managed. Unlike historical, continuous grazing, contemporary practices generally incorporate planned periods of rest and recovery from grazing during the growing season. Dormant season grazing is one such practice that shows promise for improving degraded rangelands and reducing wildfire risk. However, no studies have compared moderate intensity dormant season grazing to contemporary spring-summer grazing and grazing exclusion in sagebrush rangelands dominated by perennial bunchgrasses. We evaluated the effects of contemporary spring-summer grazing, dormant season grazing, and grazing exclusion on plant community characteristics in a Wyoming big sagebrush ecosystem. We expected the effects of dormant season grazing to be comparable to grazing exclusion. Deep-rooted perennial bunchgrass cover and density and shallow-rooted perennial bunchgrass cover in grazed areas did not differ from grazing exclusion (control) sites, and we found no support that grazing altered the deep-rooted perennial bunchgrass community through time. Dormant season grazing reduced native annual forb and sagebrush cover, but increased density of the shallow-rooted perennial bunchgrass. Our results suggest contemporary spring-summer or dormant season grazing are unlikely to lead to a decline in desirable perennial bunchgrasses.

Introduction

Livestock grazing occurs on over 25% of lands globally (Asner et al., 2004), and is the primary land use across the desert and sagebrush ecosystems of the western United States (Lubowski et al., 2005; Chambers et al., 2008). Overgrazing during the late 19th and early 20th centuries led to degradation of millions of acres of rangelands across the western US (Griffiths, 1902; Borman, 2005; Davies et al., 2011). Grazing management practices improved with the passage of the Taylor Grazing Act in 1934, the creation of the Federal Grazing Service (later to become the Bureau of Land Management) and Forest Service, and the development of rangeland science (Ross, 1984; Box, 1990; Svejcar, 2015). Contemporary grazing practices differ vastly from early, "tragedy of the commons" grazing when rangelands were subjected to heavy, unmanaged use by domesticated ungulates. Contemporary grazing practices involve controlling the timing, intensity, season, and duration of use, allowing for periods of no grazing (deferment via rotational use or short-term rest) and adaptive grazing management to improve forage availability (Borman, 2005; Davies and Boyd, 2020). Historical overgrazing, expansion of conifers, invasion by exotic

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weeds, increased fire frequency, climate change, and conversion of rangeland for other uses has led to extensive loss and degradation of sagebrush ecosystems (Crist et al., 2023; Davies et al., 2011; Doherty et al., 2022; Harris et al., 2024). Currently less than 14% of sagebrush ecosystems are designated as healthy core sagebrush areas – defined as being those with abundant sagebrush, native understories, and minimal threats (i.e., invasive annual grasses, expanding conifers, and human modification) – with a continued loss of an estimated 526,000 hectares per year (1.3 million acres per year; Doherty et al., 2022). This continued loss has led to an intensified interest in maintaining core tracts of rangeland with high ecological integrity (Doherty et al., 2022). While funding agencies continue to direct resources towards restoration of degraded sagebrush rangelands (Svejcar et al., 2017), sustaining existing habitat through effective management may be of equal or greater importance (Davies et al., 2011; Pyke, 2011; Johnson et al., 2022; Maestas et al., 2022). In the face of multifaceted, landscape scale threats to the sagebrush ecosystem, research that improves our understanding of management strategies that contribute to maintaining the productivity and resiliency of healthy sagebrush rangeland will be vital for protecting the core sagebrush rangelands that remain (Davies et al., 2011; Maestas et al., 2022).

Managers are implementing dormant season (fall or winter) grazing to maintain the resiliency of intact rangelands or to improve marginal, or degraded rangelands, as an alternative to grazing exclusion (Davies et al., 2014; Perryman et al., 2018). Dormant season grazing is also being incorporated into rangeland management planning to decrease fine fuels and wildfire risk (Davies et al., 2015, 2016a, 2021a) and to decrease abundance of cheatgrass, while increasing perennials (Davies et al., 2022b, 2021b; Mosley and Roselle, 2000; Vermeire et al., 2023). Dormant season grazing has been shown to decrease annual grasses and promote existing perennial bunchgrasses, due to the phenological offset of their growing seasons (Smith et al., 2012; Schmelzer et al., 2014; Davies et al., 2021b) and through a reduction in ground litter, which favors annual grasses over native bunchgrasses (Evans and Young, 1970; Facelli and Pickett, 1991; Newingham et al., 2007; Adair et al., 2008; Wolkovich et al., 2009). By grazing during the dormant season, bunchgrasses can produce seed each year, increasing the likelihood that seeds will be available when conditions are conducive to bunchgrass establishment. Unlike spring-summer rotational grazing, which can impact seed production and availability (Bates et al., 2009), dormant season grazing occurs when deep-rooted perennial bunchgrasses experience limited to no new above-ground growth. It has generally been assumed that dormant season grazing does not harm bunchgrasses after the seed ripening stage because they begin to become photosynthetically inactive during this time (Cook and Child, 1971; Davies et al., 2014, 2016b, 2022a). However, during wet and warm falls, bunchgrasses can resume growth, and if interrupted by defoliation, the grasses could experience a reduction in stored carbohydrate reserves, reducing future potential reproduction or growth (Benot et al., 2019; McShane and Sauer, 1985). Yet, most recent research examining dormant season grazing suggests beneficial effects (Davies et al., 2016b, 2021b, 2022b; Schmelzer et al., 2014) or limited effect (Price et al. 2023).

Contemporary spring-summer grazing has also been shown to be sustainable for rangelands (Holechek et al., 1999; Courtois et al., 2004; Copeland et al., 2021). The shift from historical continuous grazing and unmanaged levels of defoliation to contemporary grazing is a primary reason for rangeland improvement across public lands throughout the west (Box, 1990). Contemporary spring-summer grazing can also help prevent the post-fire loss of native perennial bunchgrasses and conversion to invasive annual grasses by reducing fine fuel accumulation near their growth points, lessening the probability of fire-induced mortality (Davies et al., 2009b). Dormant season grazing is increasingly being used in addition to or as an alternative to growing season grazing to not only reduce fire risk and decrease fire severity through the reduction of fine fuels, but also to reduce the cost of feeding hay to livestock by prolonging the grazing season. However, most studies of dormant season grazing have focused on rangelands invaded by annual grasses, and no studies compare contemporary spring-summer rotational grazing, dormant grazing, and grazing exclusion in rangelands dominated by perennial bunchgrasses under moderate grazing intensity.

The purpose of this study was to evaluate the effects of contemporary spring-summer, and dormant season grazing on plant community characteristics in a Wyoming big sagebrush ecosystem. We asked the following two questions: (1) What is the change in the functional group cover and density across grazing treatments? and (2) How does the perennial bunchgrass community change over time under different grazing regimes? We hypothesized that bunchgrass recruitment under dormant season grazing compared to contemporary spring-summer grazing would lead to higher densities of deep-rooted perennial bunchgrasses in dormant season-grazed sites. We also expected a reduction in herbaceous cover, but not density, of bunchgrasses in grazed sites relative to ungrazed controls. We hypothesized minimal change in the composition of perennial bunchgrass communities among grazing treatments over time with comparable increases in perennial bunchgrass abundance in the dormant season and grazing exclusion treatments.

Methods

Study Area

We implemented the study at the Northern Great Basin Experimental Range (NGBER; lat 43°29′N, long 119°43′W) 50–60 km west of Burns, Oregon. Study sites ranged in elevation from 1,300–1,500 m. Climate consisted of wet, cool winters followed by hot, dry summers with a long-term (1938–2019) average crop year (September-June) precipitation of 255 mm (NOAA station, Riley 10 WSW, OR US), typical of the northern Great Basin. Annual precipitation during the study was 120%, 80%, 126%, 92% and 62% of the long-term average for 2017, 2018, 2019, 2020 and 2021, respectively (Figure 1C). Study sites occurred in two ecological sites: R023XY220OR – CLAYEY 10-12 PZ and R023XY212OR – LOAMY 10-12 PZ (NRCS, 2023)). Soils consisted primarily of an Actem cobbly loam and a Raz-Bruce complex (LOAMY 10-12 PZ). All soils were well drained but underlain with a hardpan of welded tuff and basalt geology, that restricted root penetration around 30–50 cm in the Actem soils and 50–95 cm in the Raz-Brace. Dominant shrubs were Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis,* (Beetle and A. Young) S.L. Welsh) and green rabbitbrush (*Chrysothamnus viscidiflorus*, [Hook.] Nutt.) with low sagebrush (*Artemisia arbuscula* Nutt.) and gray rabbitbrush (*Ericameria nauseosa* [Pall. ex Pursh]) intermixed. Understory vegetation consisted of deep-rooted perennial bunchgrasses, including bluebunch wheatgrass (*Pseudoroegneria spicata,* [Pursh] A. Löve), Thurber's needlegrass (*Achnatherum thurberianum*, [Piper] Barkworth), bottlebrush squirreltail (*Elymus elymoides*, [Raf.] Swezey), Idaho fescue (*Festuca idahoensis*, Elmer), and prairie junegrass (*Koeleria macrantha*, (Ledeb.) J.A. Schultes). Bunchgrass species composition was similar among treatments within blocks. Plant communities exhibited minimal invasion by exotic annual grasses and were representative of the ARTRW8/PSSP6-FEID-ACTH7 and ARTRW8/PSSP6-ACTH7 plant associations (Bates and Davies, 2019). These sites had not burned in over 80 years, which is consistent with estimated fire return intervals of up to a century in Wyoming big sagebrush-dominated sites (Mensing et al., 2006).

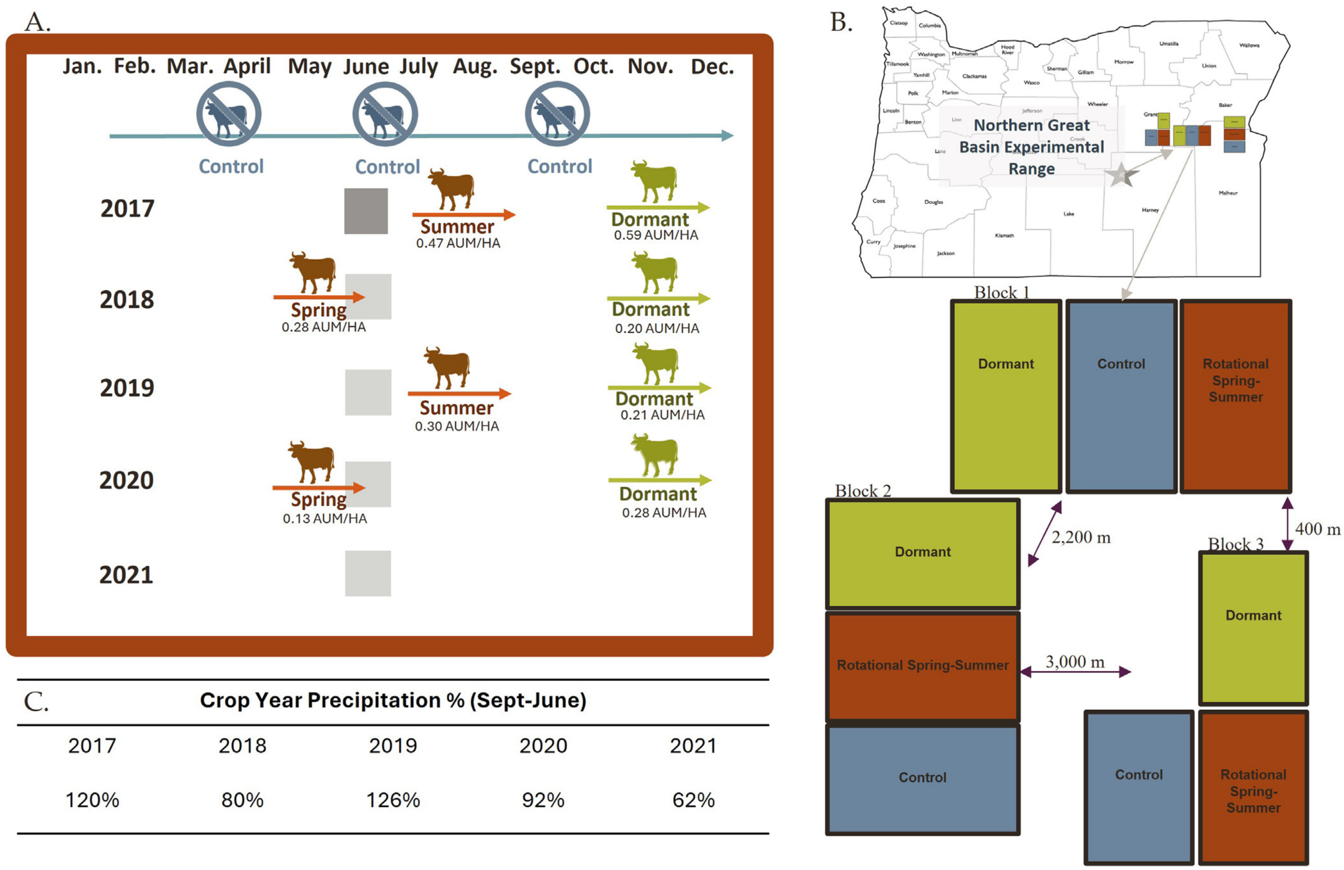

Figure 1. A, Timeline of grazing treatment application. Where grazing treatments are represented by cow icons and include dormant season (green), contemporary spring-summer graze (red orange) and non-grazed control (blue). Light grey boxes represent post-data collection and dark grey represents pre-treatment data collection. *2016 grazing prior to study establishment included one week of grazing during weaning in September in blocks one and two across all treatment sites and no grazing in block three. Animal Unit Months per Hectare are reported within the parentheses. Treatments were randomly assigned. Site size varied among, but not within, blocks (5.69–7.41 HA). B, Study site layout of randomized experimental block design, consisting of 3 blocks, each with one site of each treatment. Double sided arrows indicate the closest distance from fence to fence within blocks. C, Crop year (September–June) precipitation as a percentage of the long-term average. Study located at the Northern Great Basin Experimental Range (NGBER) in southeast Oregon, USA. Data presented only for 2017–2021 growing seasons.

Experimental Design and Grazing Treatment Application

We utilized a before-after-controlled-impact (BACI) randomized complete block design to compare vegetation dynamics between two grazing regimes (dormant, contemporary spring-summer) and grazing exclusion (control) across three blocks, from 2017–2021. Site size (5.69–7.41 HA) was similar among treatments within blocks (Figure 1B). The contemporary spring-summer grazing treatment (spring-summer rotational) included alternating between growing season grazing one year (around May) and deferment of grazing until after seed set of bunchgrasses the following year (around mid-July, year-dependent; Figure 1A). The dormant grazing treatment consisted of grazing during late fall (usually mid-October) when bunchgrasses were expected to be experiencing dormancy, but before snow prevented grazing (Figure 1A). The grazing exclusion treatment served as the control and did not experience grazing during the study time frame (Figure 1A).

Herbaceous forage production varied through time (year and season) and across space (blocks and sites). We varied stocking rates by herbaceous forage amount, as utilizing consistent stocking rates (Figure 1A) across sites and years would have resulted in variable grazing intensities due to differences in amounts of available forage. We quantified available forage by clipping herbaceous material in 15, 1-m^2 quadrats systematically placed throughout each site immediately prior to grazing to determine appropriate stocking rate to achieve moderate grazing utilization (Bates and Davies, 2014). A local Bureau of Land Management (BLM) resource management professional helped assess the post-treatment level of grazing utilization within a week of grazing occurring using BLM landscape appearance protocols (Coulloudon et al., 1999, Table S1). Stocking rate (animal unit months per hectare) varied by block and herbaceous standing crop, with 2017 having greater production and higher stocking rates (contemporary spring-summer: 0.42–0.58 AUM/HA, dormant: 0.37–0.75 AUM/HA) to reach moderate grazing compared to 2018 (contemporary spring-summer: 0.18–0.34, dormant: 0.14–0.23), 2019 (rotational: 0.19–0.30, dormant: 0.16–0.27) and 2020 (contemporary spring-summer: 0.10–0.16, dormant: 0.19–0.40; Figure 1A). These variable stocking rates resulted in average utilization of 48% (standard deviation = 9.3%).

Vegetation Sampling

We measured vegetation cover and density along twelve, 50-m transects evenly spaced throughout the study sites during June each year 2017–2021. Surveys were conducted throughout the month of June, annually. In 2017 vegetation surveys were conducted prior to grazing treatment application, which was applied mid/late July for the contemporary spring-summer treatment and late October for the dormant treatment (Figure 1A). Herbaceous canopy cover was measured using the line-point-intercept method (Herrick et al., 2009), where observers dropped a pin along transects at 1-m intervals and recorded every plant hit (species level for grasses, and functional group for forbs [non-native vs native, annual vs perennial]). All herbaceous material (current and prior years' growth) was included in cover estimates if still rooted (Herrick et al., 2009). Density of perennial herbaceous species was determined by counting all plants rooted within 0.25-m^2 quadrats placed at three-meter intervals for a total of 15 quadrats per transect. We used the line-intercept technique to quantify shrub canopy cover by species (Canfield, 1941), and we measured shrub density by counting all individuals rooted inside twelve, 2×50 m belt transects centered over each 50-m transect.

Analyses

We used a repeated measures ANOVA to analyze the influence of grazing treatment (fixed effect) on plant density (m^{-2}) and foliar cover (2018 – 2021) relative to the pre-treatment year (2017) by functional group (perennial forb, deep rooted perennial bunchgrass, shallow rooted perennial bunchgrass, sagebrush, rabbitbrush, non-native annual forb, native annual forb, and invasive annual grass [which was comprised of only cheatgrass]). Change relative to pretreatment year was calculated by subtracting pre-treatment values from post-treatment values (e.g., 2018 cover minus 2017 cover). Thus, a negative value represents a decline relative to the pre-treatment values, and a positive value indicates an increase. Within our repeated measures ANOVA model, we nested YEAR within BLOCK to account for annual variability, like precipitation, within each block. Precipitation variability and timing does directly influence annual forage production within the Northern Great Basin (Copeland et al., 2022; Bates et al., 2023, 2024). Tukey pair-wise comparisons of significant treatment effects were done post-hoc using the "emmeans" R package (Russell, 2018).

To test changes in bunchgrass community dynamics based on grazing treatment we ran a Non-Metric MultiDimensional Scaling analysis (NMDS) and Permutational Multivariate Analysis of Variance (PERMANOVA) in the "vegan" R package (Oksanen et al., 2024). We used bunchgrass species density data for each block and grazing treatment by year to see how each community changed over time. In setting up our analysis we used Bray-Curtis distance calculation for our dissimilarity index. All assumptions for NMDS were met and we proceeded with the PERMANOVA. We used the Bray-Curtis calculated perennial bunchgrass dissimilarity index as our response variable, with a three-way interaction model of grazing treatment X BLOCK X YEAR with BLOCK set to constrain permutations of grazing treatment and YEAR. Statistical significance for all models were set *a priori* with an $\alpha = 0.05$. All statistical analyses and data visualization were done in program R version 4.1.3 (R Core Team, 2022) with RStudio (RStudio Team, 2022).

Results

Cover

Treatment influenced change in cover relative to pre-treatment values of perennial bunchgrasses ($P < 0.01$), perennial forbs ($P = 0.04$), native annual forbs ($P < 0.01$), and sagebrush ($P = 0.03$; Figure 2). We did not detect a treatment effect for shallow-rooted perennial bunchgrass ($P = 0.21$), non-native annual forbs ($P = 0.24$), rabbitbrush ($P = 0.10$), or invasive annual grass ($P = 0.45$; Fig. 2). The contemporary spring-summer grazing treatment reduced perennial bunchgrass foliar cover relative to the control ($P < 0.01$) and dormant season grazing ($P < 0.01$; Fig. 2A). We did not detect a difference in perennial bunchgrass cover between control and dormant season grazing treatments ($P = 0.12$, Fig. 2A). Perennial bunchgrass cover on average decreased in contemporary spring-summer grazed sites by 4.32% (SE = 0.93) relative to pre-treatment levels but remained relatively consistent in control sites (mean 0.19%, SE = 0.88), and appeared to slightly decrease in dormant grazed sites by 1.22% (SE = 0.45%; Fig. 2A). Perennial forb cover trended downward in dormant season grazed sites, but the pair-wise comparisons were not significant (Fig. 2E). The non-native annual forb functional group was comprised primarily of the invasive desert alyssum (*Alyssum desertorum* Stapf var. *desertorum*), but also included other non-native, but non-invasive species. We did not distinguish between non-native and invasive species, and hereafter refer to this group as non-native annual forbs. Treatment did not affect non-native annual forb cover ($P = 0.21$, Fig. 2H). Native annual forb cover declined in all sites relative to pre-treatment values (including control) and was lower under dormant ($P < 0.01$) grazing and trended lower under contemporary spring-summer grazing ($P = 0.06$) relative to controls (Fig. 2F). Sites grazed during the dormant season experienced an average decrease of 1.57% (SE = 0.15%) and contemporary spring-summer grazed sites an average decrease of 1.72% (SE = 0.32) in native annual forb cover relative to pre-treatment values, while control sites decreased 0.70% (SE = 0.15; Fig. 2H). Sagebrush cover was lower in dormant grazed sites relative to controls and decreased 1.65% (SE = 0.61) relative to pre-treatment values (Fig. 2C).

Density

We did not detect an effect of treatment for any functional group except shallow rooted perennial bunchgrasses, which consisted solely of Sandberg bluegrass ($P < 0.01$, Figure 3). Sandberg bluegrass increased in dormant season grazed ($P = 0.01$) and trended upward in contemporary grazed ($P = 0.18$) treatments compared to the controls over time (Fig. 3B). There was no treatment effect detected for density of perennial bunchgrass ($P = 0.44$; Fig. 3A), sagebrush ($P = 0.55$; Fig. 3C), rabbitbrush ($P = 0.57$; Fig. 3D), or perennial forb ($P = 0.79$; Fig. 3E). We did not assess the effect of treatment on density of annuals.

Perennial Bunchgrass Community Change

PERMANOVA bunchgrass community analysis showed that bunchgrass communities differed by BLOCK ($P < 0.01$), YEAR ($P < 0.01$), grazing treatment ($P < 0.01$) and BLOCK by grazing treatment ($P < 0.01$). We did not detect change in grazing treatment and/or BLOCK through time (grazing treatment by BLOCK by YEAR). The bunchgrass community in BLOCK two was inherently different than the other two BLOCKS and remained distinct through the monitoring time frame (Supplemental Fig. 1). BLOCKS two and three had greater community overlap, which appears to have become more similar each year monitored (Supplemental Fig. 1).

Discussion

We found that contemporary spring-summer grazing and dormant season grazing had limited effects on the plant community composition. As hypothesized, contemporary spring-summer grazing induced a short-term decrease in perennial bunchgrass foliar cover, but not density (Figs. 2 and 3), consistent with other research (Davies et al., 2016b, 2021b; Thomas et al., 2022). We did observe differences in perennial bunchgrass communities between grazing treatments, BLOCKS, and among YEARs but these differences are likely due to the heterogeneity of each BLOCK (Supplemental Fig. 1). While dormant season grazing reduced native annual forb and sagebrush cover, we did not observe a decrease in perennial bunchgrass cover, or density, and we found no support that it altered the deep-rooted perennial bunchgrass community through time (Supplemental Fig. 1). However, these analyses did not include the shallow rooted perennial

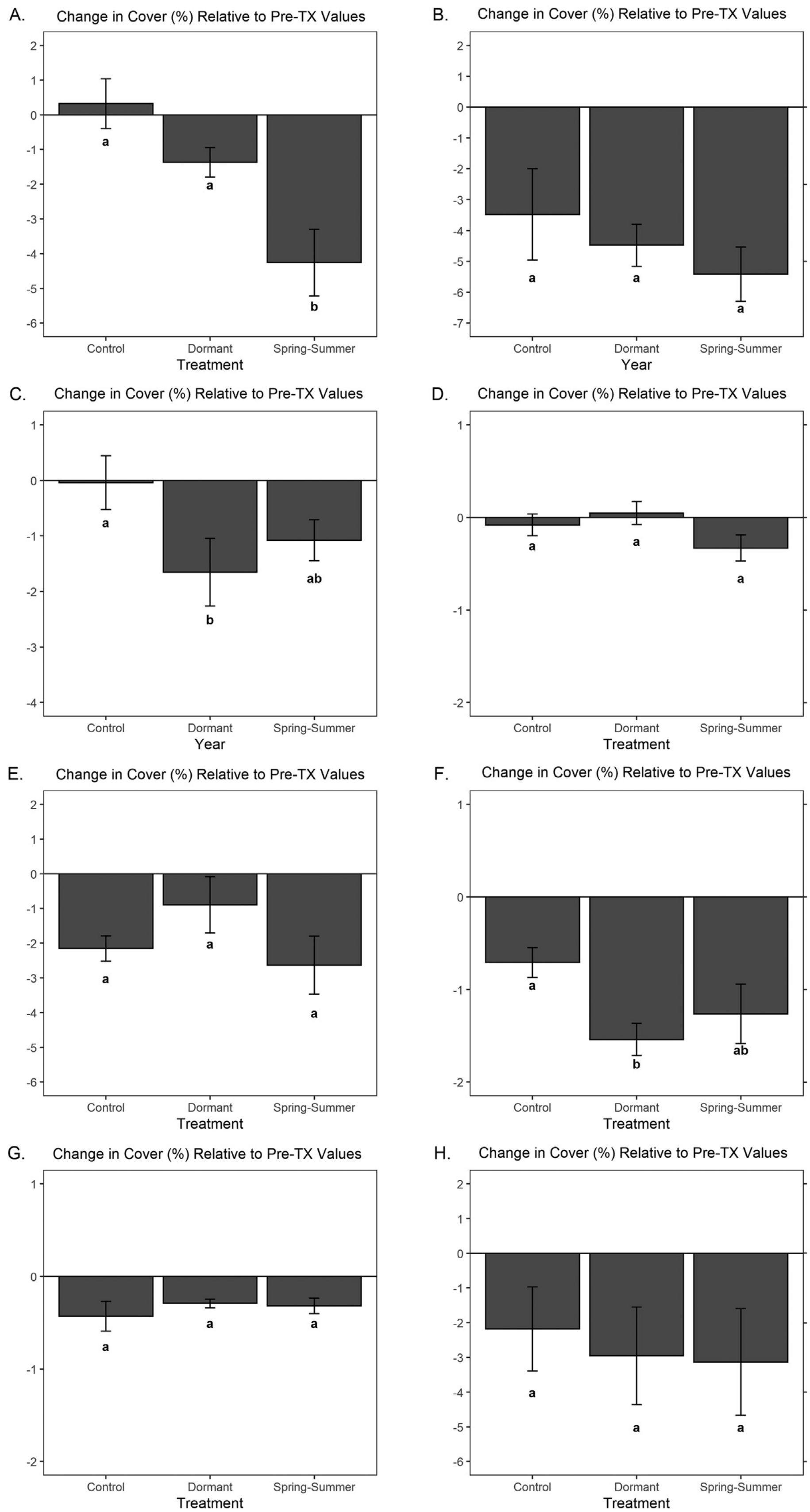

Figure 2. Post-treatment cover (mean ± standard error) by functional group (A, perennial bunchgrass, B, shallow rooted perennial bunchgrass, C, sagebrush, D, rabbitbrush, E, perennial forb, F, native annual forb, G, invasive annual grass and H, Non-native annual forb). Values represent relative change from pre-treatment (2017) values and error bars represent one standard error. Different letters indicate significant ($P < 0.05$) differences from mean separations.

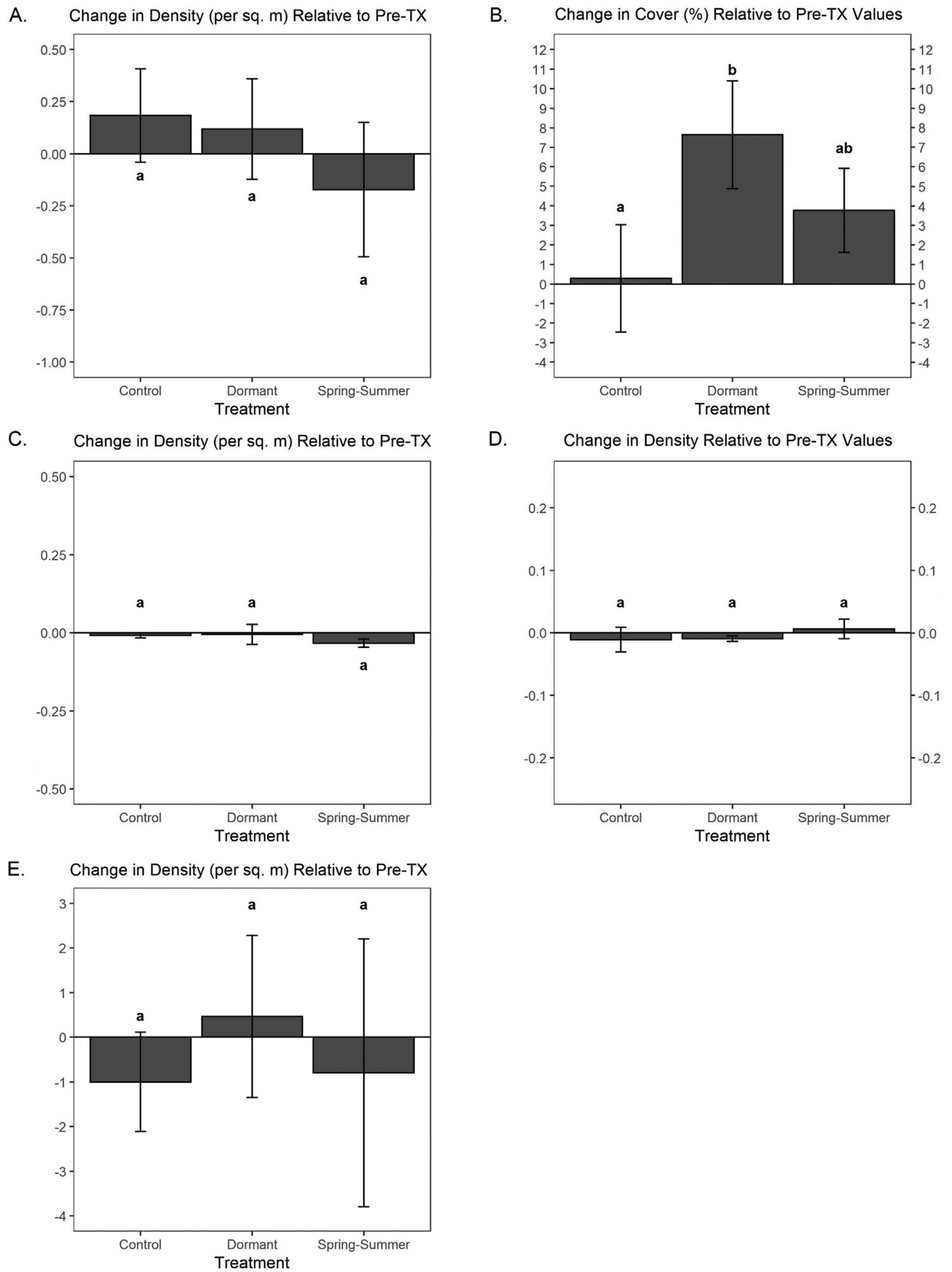

Figure 3. Post-treatment density (mean ± standard error) by functional group (A, perennial bunchgrass, B, shallow rooted perennial bunchgrass, C, sagebrush, D, rabbitbrush, and E, perennial forb). Values represent relative change from pre-treatment (2017) values and error bars represent one standard error. Different letters indicate significant ($P < 0.05$) differences from mean separations.

bunchgrass which increased under dormant season grazing relative to controls (Figure 3B). Our hypothesis that contemporary spring-summer grazing would not influence plant abundance, was mostly supported as grazing did not influence density of any functional groups (perennial bunchgrass cover, rabbitbrush cover, sagebrush cover, perennial forb cover) except shallow-rooted perennial bunchgrasses.

Livestock grazing can lead to plant community change in the sagebrush-ecosystem where unpalatable species increase in abundance relative to palatable species preferred by grazing animals

(Laycock, 1967; Adler et al., 2004). However, this has typically only been recorded under heavy, continuous grazing, and in contrast, only relatively weak impacts of moderate grazing have been recorded in Wyoming big sagebrush plant communities (Davies et al., 2009b; Condon et al., 2020; Copeland et al., 2021). We did not observe, nor expect to see drastic changes in functional group cover or density or plant community composition, and our results are unsurprising given the literature (Condon et al., 2020; Copeland et al., 2021). Dormant season grazing is increasingly being used to maintain healthy or improve marginal rangelands (Davies et al., 2014; Perryman et al., 2018), but there is a potential for warmer and wetter fall conditions to alter phenology of perennial bunchgrasses, changing the timing of dormancy and increasing the potential of defoliation occurring during periods of plant growth (i.e., fall green-up), which might reduce stored resources needed for the following spring (McShane and Sauer, 1985). We found few relationships between dormant season grazing and the bunchgrass plant community, supporting prior work suggesting that dormant season grazing does not harm bunchgrasses (Cook and Child, 1971; Davies et al., 2014, 2016b, 2022a). Dormant season grazing did not reduce densities of any functional group, but relative to controls, dormant grazed sites had a higher density of Sandberg bluegrass (Fig. 3B). This observed increase in Sandberg bluegrass density is consistent with other work examining grazing in healthy sagebrush ecosystems and could be due to lowered competition with grazed perennial bunchgrasses for light resources (Davies et al., 2022a; Thomas et al., 2022). However, these results are limited to the specific climate and condition of these study sites (intact sagebrush, low level of invasive annual grasses) and outcomes may differ in other locations.

Consistent with prior research, we observed lower total perennial bunchgrass cover (current and prior growth) in contemporary spring-summer grazed treatments relative to grazing exclusion, a pattern expected as grazing removed previous years' growth (Davies et al., 2016b, 2021b; Thomas et al., 2022). It is unlikely this decline is meaningful, as we did not observe changes in bunchgrass density or change in community composition through time. Although native annual forb cover declined in all sites during the study, we observed greater declines in the dormant grazed sites compared to the controls. The mechanism driving this reduction is unclear, as native annual forb cover was relatively low throughout all study blocks and comprised a miniscule portion of forage available to cattle. The small stature of many native annual forb species prevents easy consumption by cattle, suggesting this pattern may be driven more by seed bed characteristics, potentially influenced by cattle hoof action or litter reduction, as opposed to removal by grazing. Perennial forb cover declined relative to pretreatment levels across all treatments, with the lowest decline in dormant season grazing. While we found an overall effect of treatment on perennial forb cover, the pairwise comparisons were not significant.

One of the few effects we observed with dormant season grazing was a reduction in sagebrush cover. Cattle, unlike sheep, tend to avoid consuming sagebrush (Krysl et al., 1984), so the reduction we observed in sagebrush cover associated with dormant season grazing was likely a result of physical damage as animals traversed between plants. This is consistent with research that found cattle can alter the physical structure of sagebrush (Davies et al., 2018), but contrary to studies that found no effect of dormant season grazing on sagebrush cover (Davies et al., 2016b, 2022a). We did not detect changes in sagebrush cover in the contemporary spring-summer grazed sites, supporting other research finding of no long-term effect of spring-summer grazing on the shrubs (Davies et al., 2010). One potential explanation for why we detected an effect of dormant season grazing but not contemporary spring-summer grazing on sagebrush cover is that sagebrush during the dormant season is drier and often frozen, and thus more brittle and susceptible to mechanical damage during the fall and early winter compared to spring and summer. This effect may be limited to the specific climate and site conditions assessed in this study. Historically managers have sought to reduce sagebrush cover in order to increase herbaceous production either for cattle forage or more recently, to improve wildlife habitat in areas with overly dense sagebrush and a depleted understory (Davies et al., 2009a; Beck et al., 2012; Dahlgren et al., 2006, 2015). Mechanical treatments or the use of chemical applications have been the preferred method to reduce sagebrush, but recent work did not find that shrub reduction led to a positive response from sage-grouse, with the authors recommending against active shrub reduction (Smith et al., 2023). Dormant season grazing minimally reduced sagebrush cover in our study areas, and it may provide a less risky method for inducing small sagebrush reductions and is likely more compatible with management for sagebrush obligate wildlife (Schroeder et al., 2022).

Management Implications

Similar to other research, our results suggest that contemporary spring-summer grazing (West et al., 1984; Courtois et al., 2004; Davies et al., 2018; Copeland et al., 2021) and dormant season grazing (Davies et al., 2016b, 2021a) are compatible with maintaining desirable perennial bunchgrasses as a functional group. Based on our findings in an intact Wyoming sagebrush plant community, moderate dormant and contemporary spring-summer grazing will likely not result in increased invasive species or declines in Wyoming big sagebrush density, or in a short-term change in the perennial bunchgrass community. Dormant season grazing did result in small reductions in sagebrush cover, thus repeated dormant season grazing should be used with caution in areas where small declines in sagebrush cover are not acceptable, such as in areas of critical wildlife habitat with minimal shrub cover. However, research is needed to determine if dormant season grazing has effects on shrub cover when shrubs are less abundant, as cattle may more easily avoid contact with shrubs. Regardless, alternating dormant season grazing with rest or other seasons of use may help offset the loss of shrub cover, as growing season grazing has been shown to actually increase sagebrush seedling growth (Davies et al., 2020). Conversely, dormant season grazing could potentially be strategically used as an alternative to mechanical or herbicide treatments to reduce sagebrush cover in areas with higher than desirable shrub cover. Both moderate contemporary spring-summer and dormant season grazing are grazing management strategies that are consistent with maintaining the productivity and resiliency of healthy sagebrush rangeland in the remaining areas of core sagebrush rangelands in need of protection.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Vanessa M. Schroeder: Writing – original draft, Writing – review & editing, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Dustin D. Johnson:** Writing – review & editing, Supervision, Resources, Methodology, Funding acquisition, Conceptualization. **Kirk W. Davies:** Writing – review & editing, Methodology, Conceptualization. **Chad S. Boyd:** Writing – review & editing, Methodology, Conceptualization. **Rory C. O'Connor:** Writing – review & editing, Writing – original draft, Visualization, Formal analysis.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.rama.2024.07.006.

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