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Moderate Grazing During the Off-Season (Fall-Winter) Reduces Exotic Annual Grasses in Sagebrush-Bunchgrass Steppe☆

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ABSTRACT

Exotic annual grass invasion and dominance of sagebrush-bunchgrass steppe is a concern because it decreases biodiversity and promotes frequent wildfires. Management is needed to reduce exotic annual grasses to prevent sagebrush-bunchgrass communities from transitioning to annual grasslands. Grazing during the off season (fall-winter) has shown promise at reducing exotic annual grasses, but it has not been evaluated in plant communities dominated by sagebrush and native bunchgrasses. We compared moderate grazing during the off season with not grazing in five Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis* [Beetle & A. Young] S.L. Welsh)—bunchgrass communities in the northern Great Basin. Treatments were applied annually for 10 yr (2009–2010 through 2018–2019). Plant community characteristics were measured after treatments had been applied from 6 to 10 yr. Off-season grazing reduced exotic annual grass density and cover. After a decade, annual grass cover was twofold greater in ungrazed areas. Sandberg bluegrass (*Poa secunda* J. Presl) density increased with off-season grazing, but large bunchgrass density was similar between off-season grazed and ungrazed areas. Perennial and annual forb density and cover were similar between off-season grazed and ungrazed treatments. Biological soil crust cover was also similar between off-season grazed and ungrazed areas. The results of this study provide strong evidence that off-season grazing has application for managing exotic annual grasses in sagebrush-bunchgrass steppe. Considering the vast scope of the exotic annual grass problem, properly applied grazing may be the most cost-efficient tool to mediate the impacts of annual grass invasion.

Introduction

Invasion of sagebrush steppe communities by exotic annual grasses is a major threat to ecological sustainability and rural economies. Millions of hectares of sagebrush communities are now exotic annual grasslands, and the area dominated by annual grasses is increasing at a rate of almost 200 000 ha annually (Smith et al. 2022). Annual grass invasion exponentially decreases biodiversity (Davies 2011) and degrades habitat for sagebrush associated wildlife (Knick et al. 2003; Crawford et al. 2004). Exotic annual grasses are highly competitive, especially with bunchgrass seedlings (Nasri and Doescher 1995; Rafferty and Young 2002), and can deplete soil moisture and other resources, resulting in the exclusion of native plant species (Melgoza et al. 1990; Humphrey and Schupp 2004). Annual grass invasion is particularly devastating as it increases wildfire frequency (D'Antonio and Vitousek 1992; Balch et al. 2013). Annual grasses increase fine fuel amount and continuity and dry out earlier than native vegetation, thus elevating the probability of fire (Brooks et al. 2004; Davies and Nafus 2013). More frequent fire associated with annual grass invasion prevents reestablishment of fire intolerant native vegetation, resulting in annual grass monocultures and an exotic grass-fire cycle (D'Antonio and Vitousek 1992; Brooks et al. 2004; Eisworth et al. 2009). Most of these annual grasslands are permanent community transitions because efforts to restore them to native perennial dominance are expensive and generally futile (Davies et al. 2021a).

A different management approach is needed to address the exotic annual grass problem with management intervention occurring before annual grass dominance. Many sagebrush-bunchgrass communities already have a noticeable presence of exotic annual grasses. Management of these plant communities needs to focus

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on reducing the competitive advantage of exotic annual grasses over native perennial vegetation (Perryman et al. 2018). An understory dominated by perennial bunchgrasses is probably the single most important assurance against exotic annual grass dominance (Chambers et al. 2007; Davies 2008; Davies and Johnson 2017). Therefore, management approaches should strive to limit exotic annual grasses with neutral to positive effects on perennial bunchgrasses. Prior efforts have focused on limiting disturbances, most notably excluding or greatly reducing grazing, in these communities. However, this has largely been ineffective, unless grazing management was improper (e.g., heavy, repeated use during the growing season). Thus, land management needs an approach that recognizes the complexity of ecosystem problems such as exotic annual grasses.

Land management needs to apply actions that reduce exotic annual grass density and cover, but these management actions need to be feasible to apply across the vast rangelands already invaded. Preemergent herbicides have shown great promise at reducing annual grasses and not negatively impacting established perennial bunchgrasses (Kyser et al. 2007; Sheley et al. 2007; Davies and Sheley 2011). Application of preemergent herbicides is expensive and, therefore, not feasible to apply to the extensive areas in need of exotic annual grass management (Stohlgren and Schnase 2006). In contrast, strategic grazing may be feasibly applied to expansive landscapes. Grazing by cattle can be an efficient treatment to reduce fuels across vast rangelands (Davies et al. 2015), so grazing may be a practical treatment to manage exotic annual grasses.

However, there is disagreement over the ability of grazing to reduce exotic annual grasses without negatively impacting native perennial vegetation. Heavy, repeated grazing during the growing season has promoted exotic annual grasses by decreasing competition from native perennial bunchgrasses (Daubenmire 1970 Mack 1981; Knapp 1996). Subsequently, some have recommended reducing livestock grazing to decrease exotic annual grasses (e.g., Reisner et al. 2013; Williamson et al. 2020), while others have found that grazing can reduce annual grasses and promote native perennials (Davies et al. 2020; Porensky et al. 2021). Reductions in grazing have also been suggested to be a contributing factor to the recent expansion of exotic annual grasslands (Perryman et al. 2018). Some of these contrasting results are likely tied to differences in grazing management, and thus, specific, experimental applied grazing needs to be investigated.

Off-season (fall-winter) grazing is increasingly becoming a common grazing management alternative to growing season use in Wyoming big sagebrush communities, in part to reduce accumulations of fine fuels to decrease fire probability and also to decrease the cost associated with feeding hay. Moderate grazing in the off-season may decrease exotic annual grasses and favor native perennial vegetation but is an understudied grazing management strategy. Off-season grazing may decrease annual grasses by removing ground litter (usually annual grass litter). Litter is critical to annual grass success because it creates a favorable microenvironment for its emergence and growth (Evans and Young 1970; Facelli and Pickett 1991; Newingham et al. 2007; Wolkovich et al. 2009). Off-season grazing may also result in cattle selectively grazing exotic annual grasses because they can initiate growth earlier than native perennial grasses (Smith et al. 2012; Davies et al. 2021b). After a substantial postfire invasion of annual grasses, off-season grazing reduced annual grasses and increased Sandberg bluegrass (*Poa secunda* J. Presl), a native bunchgrass (Davies et al. 2021b). In a case study, off-season grazing reduced annual grasses and increased an introduced bunchgrass in an exotic annual grass–introduced bunchgrass community (Schmelzer et al. 2014). However, the effects of moderate grazing during the off season on unburned Wyoming big sagebrush communities with native bunchgrass-dominated understories are unknown.

The objective of this study was to investigate the effects of moderate grazing during the off-season on exotic annual grasses and native vegetation in Wyoming big sagebrush-bunchgrass communities that are moderately invaded by annual grasses. To accomplish this objective, we compared areas that for the past 6–10 yr were off-season grazed or not grazed. We hypothesized that 1) moderate grazing in the off-season would reduce exotic annual grass cover and density and, subsequently, 2) increase the density of native bunchgrasses compared with the ungrazed treatment. Native bunchgrass cover was not expected to be greater in grazed areas because off-season grazing would remove prior years' growth, which contributes substantially to bunchgrass cover.

Methods

Study area

This study was conducted in Wyoming sagebrush-bunchgrass steppe 65–70 km south and southeast of Burns, Oregon (43°04′N, 118°40′W). These sagebrush-bunchgrass communities have low resilience and resistance to annual grass invasion (Chambers et al. 2014a, 2014b). The understory in these communities was dominated by native perennial bunchgrasses, either Thurber's needlegrass (*Achnatherum thurberianum* [Piper] Barkworth) or bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] A. Löve). Other common bunchgrasses included Sandberg bluegrass and bottlebrush squirreltail (*Elymus elymoides* [Raf.] Swezey). Exotic annual grasses were observed across the study sites before study initiation. Average (1981–2010) annual precipitation across the study area was 280 mm (PRISM 2020). Precipitation patterns are representative of the northern Great Basin with most events occurring in the winter and spring, and summers are hot and dry. Study sites were generally flat, and elevation was approximately 1 450 m. Study sites were on Sandy Loam 10-12 PZ (R023XY213OR) and Droughty Loam 11-13 PZ (R023XY316OR) Ecological Sites. Historical fire occurrence for these steppe communities was infrequent with fire return intervals estimated to be 50–100+ yr (Wright and Bailey 1982; Mensing et al. 2006). We could find no evidence or record of recent (~ 50 yr) fire at the study sites.

Experimental design and measurements

We used a randomized complete block design with two treatments: grazed (moderate, off-season grazing) and ungrazed (not grazed since 2009). Treatments were applied to five blocks (sites) that varied in site and vegetation characteristics and randomly assigned to plots in each block. Vegetation characteristics were generally similar between treatments within blocks before treatment initiation (Davies et al. 2016a). The study was initiated in the fall of 2009 by building 60 × 100 m barbwire exclosures to exclude grazing from the ungrazed treatment. The grazed and ungrazed treatments were separated by a 20-m buffer. Grazing by cattle was applied as part of the normal management (initiated at the start of the study) of the pastures containing exclosures between November and early April each year. Pastures were ~800–1 000 ha and located adjacent to one another. Cattle consumed 40–60% of the available forage based on biomass determined by the method described in Anderson and Curreir (1973). Cattle were provided a protein supplement to ensure their nutritional needs were meet during the off-season. Sampling was not initiated until 2015 to allow vegetation time to respond to treatments. Treatments were applied annually for the duration of the study.

Vegetation characteristics were measured in mid to late June of each yr from 2015 through 2019. Four, parallel 45-m transects spaced at 5-m intervals were established in each treatment replicate to measure vegetation characteristics. Herbaceous vegetation

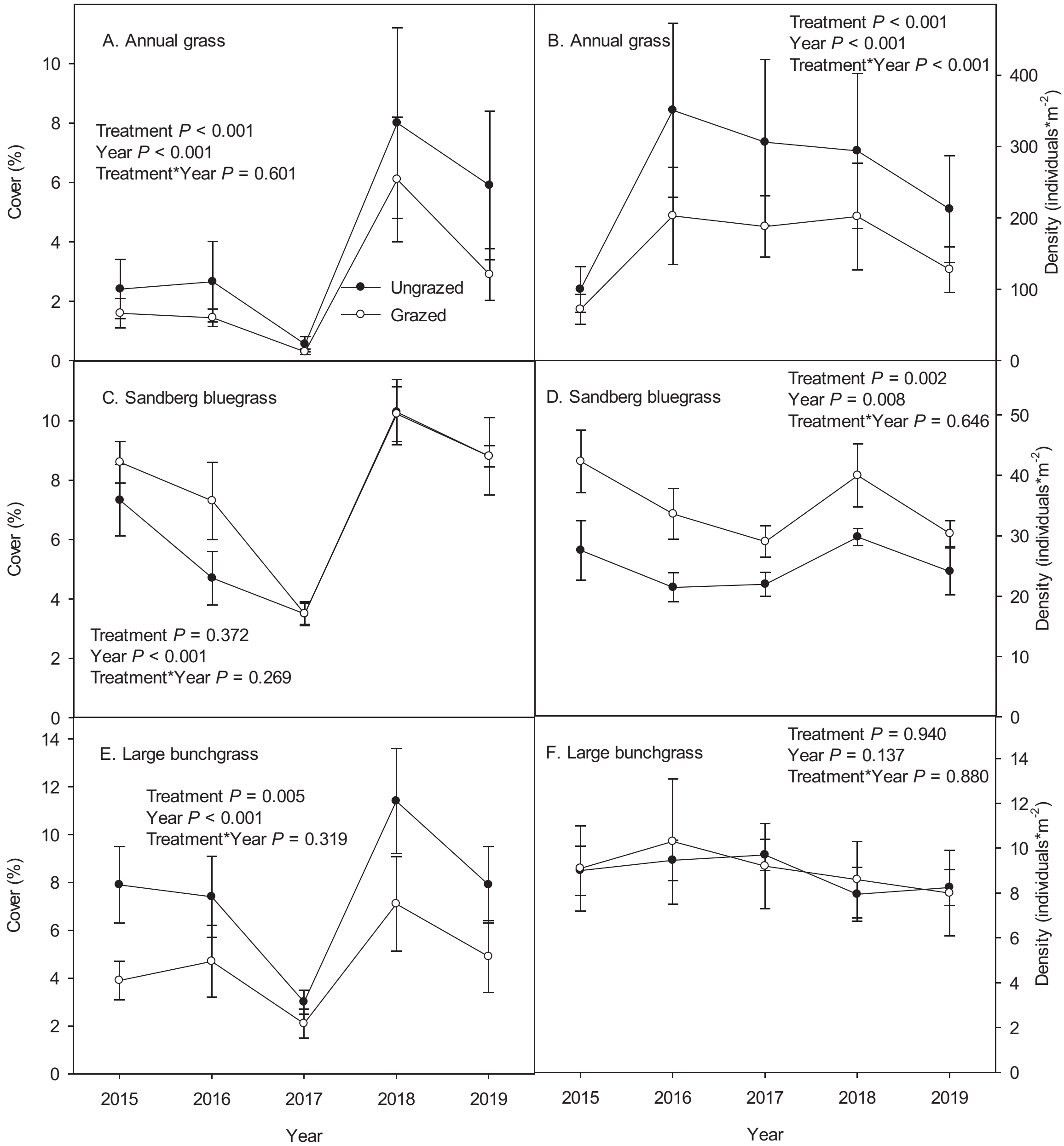

Figure 1. Exotic annual grass, Sandberg bluegrass, and large perennial bunchgrass cover and density (mean ± standard of error) in moderate off-season grazed (grazed) and ungrazed (ungrazed) treatments from 2015 to 2019.

cover was visually estimated by species in 0.2-m^2 quadrats located at 3-m intervals on each 45-m transect, starting at the 3-m mark and ending at the 45-m mark (15 quadrats•transect^{-1} and 60 quadrats•treatment replicate^{-1}). Bare ground, biological soil crust, and litter cover were also estimated in the 0.2-m^2 quadrats. Herbaceous vegetation density was measured by species by counting each plant rooted in the 0.2-m^2 quadrats. Sagebrush cover was measured using the line-intercept method along each 45-m transect. Sagebrush density was measured by placing a 2 × 45 m belt transect over each 45-m transect and counting all individuals rooted in it.

Statistical analyses

To compare treatments, we used a repeated-measures analysis of variance using the mixed model procedure (SAS v. 9.4, SAS Institute, Cary, NC). Block and block-by-treatment interactions were treated as random variables in analyses with year being the repeated variable. Treatment was treated as a fixed variable in analyses. The Akaike information criterion was used to select the appropriate covariance structure for analyses (Littell et al. 1996). Data that violated assumptions of analysis of variance were log-transformed. For analyses, herbaceous vegetation was separated into plant functional groups: exotic annual grasses, Sandberg bluegrass, large perennial bunchgrasses, perennial forbs, and annual forbs. The exotic annual grass group consisted primarily of cheatgrass (*Bromus tectorum* L.) with some medusahead (*Taeniatherum caput-medusae* [L.] Nevski). Sandberg bluegrass was analyzed independent of the other bunchgrasses because it generally develops phenologically earlier, is smaller in stature, and responds differently to grazing and fire (McLean and Tisdale 1972; Yensen et al. 1992; Davies et al. 2021b). The perennial bunchgrass and perennial forb groups were composed solely of native species. The annual forb group consisted of non-native and native species. All figures and text present nontransformed data. Means were reported with standard errors in the text and figures with statistical significance set at $P \leq 0.05$. Year-by-treatment interactions were included in all models, but only significant treatment-by-year interactions were reported in the text.

Results

Exotic annual grass cover was reduced with grazing and varied among years (Fig. 1A; $P < 0.001$ and < 0.001). At the final sampling, annual grass cover was twofold greater in the ungrazed compared with the grazed treatment. Density of exotic annual grasses was relatively similar the first sampling year but thereafter was substantially greater in ungrazed areas (Fig. 1B; $P < 0.001$). On average, annual grass density was 1.6-fold greater in ungrazed compared with grazed areas. Sandberg bluegrass cover was similar between treatments (Fig. 1C; $P = 0.372$) but varied among years ($P < 0.001$). Sandberg bluegrass density was greater in the grazed compared with the ungrazed treatment (Fig. 1D; $P = 0.002$) and varied among years ($P = 0.008$). Averaged across sample years, Sandberg bluegrass density was 1.4-fold greater in the grazed compared with the ungrazed treatment. Large perennial bunchgrass cover was reduced with grazing (Fig. 1E; $P = 0.005$) and varied among years ($P < 0.001$). In the final sampling year, perennial bunchgrass cover was 1.6-fold greater in the ungrazed compared with the grazed treatment. In contrast, large perennial bunchgrass density was similar between grazed and ungrazed areas (see Fig. 1F; $P = 0.943$). Large perennial bunchgrass density did not vary among years ($P = 0.137$). Perennial forb cover and density did not differ between grazed and ungrazed treatments (Fig. 2A and 2B; $P = 0.612$ and 0.993) but varied among years ($P < 0.001$). Annual forb cover and density were also similar between treatments (Fig. 2C and 2D; $P = 0.954$ and $= 0.79$) but varied among years ($P < 0.001$). Sagebrush cover did not differ between treatments (Fig. 2E; $P = 0.215$) but varied among years ($P = 0.046$). Sagebrush cover appeared to generally increase with time in both grazed and ungrazed areas. Sagebrush density was similar in the grazed and ungrazed treatment (Fig. 2F; $P = 0.785$) and did not vary among years ($P = 0.141$). Litter cover on the soil surface was similar between the grazed and ungrazed treatment (Fig. 3A; $P = 0.260$) but varied among years ($P < 0.001$). Bare ground was greater in the grazed compared with the ungrazed treatment (Fig. 3B; $P = 0.036$). At the conclusion of the study, bare ground was 1.3-fold greater in grazed compared with ungrazed areas. Bare ground varied among years ($P < 0.001$), but no clear pattern emerged. Biological soil crust cover did not differ between grazed (1.2% ± 0.2%) and ungrazed (1.5% ± 0.2%) areas ($P = 0.538$). Biological soil crust cover varied among years ($P < 0.001$), but no trend was apparent.

Discussion

Our hypotheses were largely supported by the response of Wyoming big sagebrush-bunchgrass communities to 6−10 yr of moderate grazing in the off-season compared with not being grazed. Off-season grazing reduced the density and cover of exotic annual grasses in Wyoming big sagebrush-bunchgrass communities in support of our first hypothesis. Partially supporting our second hypothesis that off-season grazing would increase native bunchgrass density, Sandberg bluegrass density was greater in grazed compared with ungrazed areas. However, large native bunchgrasses density was similar between grazed and ungrazed treatments. The response of annual grasses and Sandberg bluegrass aligned with our hypotheses, but the large bunchgrass response was not as expected.

Exotic annual grass cover and density were likely reduced with off-season grazing because cattle may selectively graze it during this time period and grazing may reduce safe sites for its emergence and growth. Annual grass may grow in the fall or late winter/early spring before native perennial grasses (Hironaka 1961; Harris 1977). This early growth of annual grasses may result in livestock selectively grazing it because other vegetation may be dormant or producing little accessible new growth (Smith et al. 2012; Davies et al. 2021b). Annual grass success is also expected to be less in grazed areas because grazing decreases safe sites for its emergence and growth by reducing herbaceous vegetation and litter cover (Davies et al. 2021b). In our current study, off-season grazing reduced large perennial bunchgrass cover, which may have contributed to the decline in annual grasses. Exotic annual grass success declined with reduced vegetation cover in a study in Colorado, likely because vegetation cover, similar to litter, creates a favorable microenvironment for the establishment of annual grass (Adair et al. 2008). Litter covering the soil surface improves annual grass emergence and growth because of its effects on microsites (Evans and Young 1970; Facelli and Pickett 1991; Newingham et al. 2007; Wolkovich et al. 2009) and nutrient cycling (Booth et al. 2003 Sperry et al. 2006). However, we did not find reduced litter cover with off-season grazing. Potentially, grazing reduced the litter biomass and thickness and, thus, negatively impacted annual grasses (Davies et al. 2021b). However, we did not investigate if litter biomass or thickness was influenced by off-season grazing. Bare ground was greater with off-season grazing, suggesting that favorable microsites for exotic annual grasses were reduced with this treatment, even without finding evidence that litter cover was reduced with grazing. Thus, we speculate that off-season grazing reduced annual grass density and cover through the physical effects of grazing it, as well as modifying the microenvironment for its emergence and growth.

The results from our current study provide additional evidence that off-season grazing may be a tool for reducing exotic annual grasses. Similar to our results, annual grass standing crop was reduced with fall grazing in an exotic annual grass−introduced bunchgrass community in Nevada (Schmelzer et al. 2014). Fall grazing in this community also reduced the annual grass seed bank (Schmelzer et al. 2014; Perryman et al. 2020). Off-season grazing also reduced exotic annual grass density and cover in sagebrush-bunchgrass steppe communities substantially invaded by annual grass after wildfire removed sagebrush (Davies et al. 2021b). Our study is the first to find that off-season grazing compared with not grazing can decrease exotic annual grass density and cover in sagebrush-bunchgrass−dominated plant communities. These results combined with prior studies (Schmelzer et al. 2014; Perryman et al. 2020; Davies et al. 2021b) suggest that off-season grazing can be used to reduce exotic annual grasses in plant communities with varying species and plant functional group composition.

The increased density of the native bunchgrass, Sandberg bluegrass, suggests that off-season grazing may be opening safe sites for native perennials by reducing exotic annual grasses. Similarly, Sandberg bluegrass increased with reductions in exotic annual grass with off-season (Davies et al. 2021b) and spring grazing (Davies et al. 2020) in recently burned sagebrush communities. Reductions in annual grasses likely favored Sandberg bluegrass because annual grasses are highly competitive and can exclude native vegetation (Melgoza et al. 1990; Nasri and Doescher 1995; Rafferty and Young 2002). Sandberg bluegrass may also be negatively impacted by shading from annual grasses because of its relatively short stature. Therefore, when grazing reduces exotic annual grasses, other vegetation may increase because of less competition and shading.

Large perennial bunchgrass density did not increase with reductions in annual grasses with off-season grazing. This outcome is similar to a prior study where off-season grazing applied after fire in an exotic annual grass−native bunchgrass community did

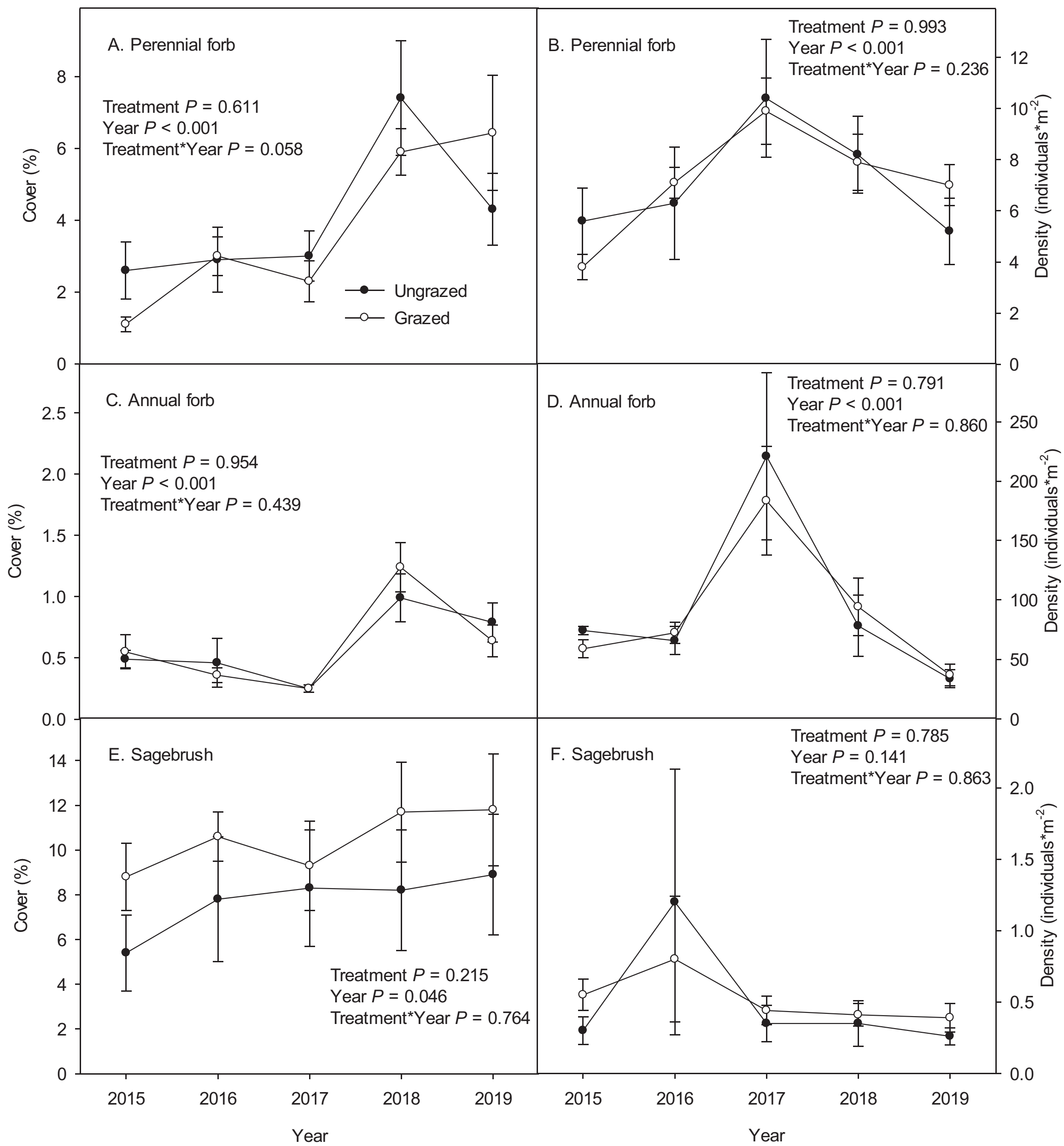

Figure 2. Annual forb, perennial forb, and Wyoming big sagebrush cover and density (mean ± standard of error) in moderate off-season grazed (grazed) and ungrazed (ungrazed) treatments from 2015 to 2019.

not increase large bunchgrass density (Davies et al. 2021b) but dissimilar to a study in Nevada where bunchgrass, largely composed of an introduced species, standing crop increased with fall grazing (Schmelzer et al. 2014). We did not measure large perennial bunchgrass standing crop in our current study but doubt it increased with grazing since large perennial bunchgrass cover was less in the grazed treatment. This was expected as grazing would reduce prior years' growth, a major contributor to both cover and standing crop of large perennial bunchgrasses (Davies et al. 2009, 2016b). There are a couple of possible reasons why large perennial bunchgrass density did not increase with the grazing-induced reduction in exotic annual grasses. First, recruitment of large native bunchgrasses is infrequent in arid and semiarid environments (Holmes and Rice 1996; James et al. 2009; Svejcar et al. 2017) and would need to be greater than mortality to see an increase in density. Second, the sagebrush steppe–bunchgrass communities included in this study may be near capacity for large perennial bunchgrass density. The off-season grazed and ungrazed treatments averaged 9.0 ± 0.87 and 8.9 ± 0.42 large perennial bunchgrasses•m^{-2}, respectively. The average density for large perennial bunchgrasses in intact Wyoming big sagebrush-bunchgrass steppe in this region is ~10 individuals•m^{-2} (Davies and Bates 2010; Bates and Davies 2019). Thus, large perennial bunchgrass density may not yet be affected by the limited exotic annual grass invasion in these communities. Regardless, off-season grazing for 6–10 yr did not increase large perennial bunchgrass density in sagebrush-bunchgrass communities with already high abundance of large bunchgrasses. Importantly, large bunchgrass density didn't decrease with grazing, suggesting that off-season grazing is compatible with bunchgrass conservation goals.

The differing response of Sandberg bluegrass and large bunchgrasses to off-season grazing is likely a product of their differences in stature and response to disturbances. Sandberg bluegrass may be especially sensitive to annual grass competition because it

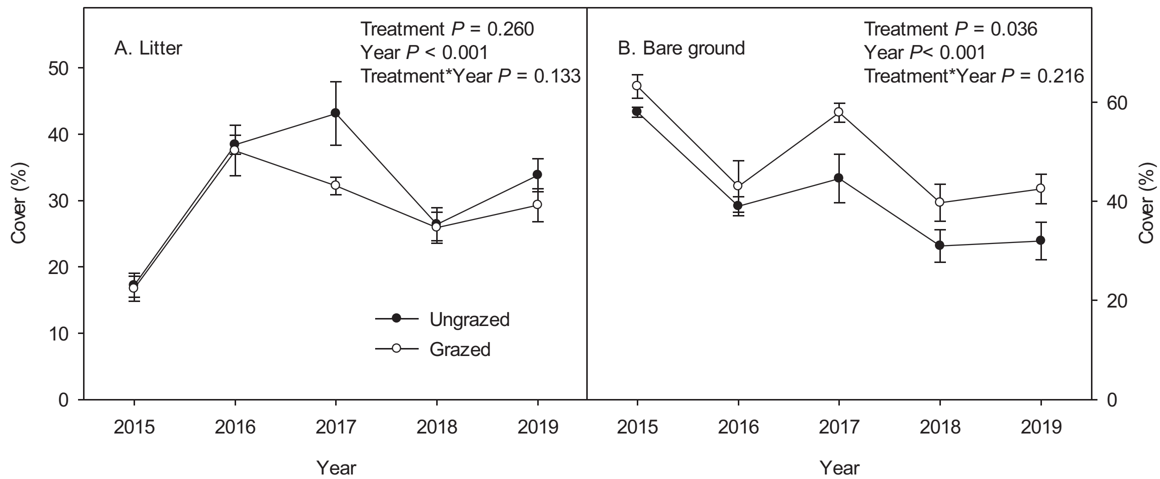

Figure 3. Litter and bare ground cover (mean ± standard of error) in moderate off-season grazed (grazed) and ungrazed (ungrazed) treatments from 2015 to 2019.

usually grows in the interspaces between large perennial bunchgrasses, the location where annual grasses proliferate during invasion (Reisner et al. 2013; Rayburn et al. 2014). In the current study, where annual grasses were not dominant and large bunchgrasses plentiful, reductions in annual grass abundance likely opened safe sites for Sandberg bluegrass, but not necessarily for large bunchgrasses. Sandberg bluegrass may also increase with grazing as it can be difficult for cattle to graze its short leaves (Davies et al. 2021b) and it is considered grazing tolerant because it will increase with heavy spring grazing when other native bunchgrasses decline (McLean and Tisdale 1972). Thus, the effects of off-season grazing likely differ by community characteristics, such as level of invasion, and possibly vary among species and plant functional groups.

Management Implications

Off-season grazing can be used to reduce exotic annual grass density and cover in Wyoming big sagebrush–bunchgrass communities without compromising the native bunchgrass component. This reduction in annual grasses can facilitate increases in Sandberg bluegrass density. However, off-season grazing does not appear to increase the density of other native bunchgrasses. This treatment may not benefit large bunchgrasses, or these communities may be at or near capacity for large bunchgrass abundance. Regardless, this study demonstrates that increases in the density of large bunchgrasses should not be expected with off-season grazing in Wyoming big sagebrush-bunchgrass communities with abundant large bunchgrasses. Prior research has shown that off-season grazing can be used to reduce exotic annual grasses in annual grass–native bunchgrass and annual grass–introduced bunchgrass communities (Schmelzer et al. 2014; Perryman et al. 2020; Davies et al. 2021b). The results of these prior studies and our current study suggest that off-season grazing by cattle may be a valuable tool for managing the expanding exotic annual grass problem. Further research evaluating the effects of off-season grazing is warranted. Investigating the effects of off-season grazing on restoration efforts may prove fruitful as success is frequently hindered by exotic annual grasses (Svejcar et al. 2017). Research into cattle performance, supplementation strategies, economics, and management contingencies for adverse weather are also needed to improve the application of off-season grazing. Finally, evaluations of the effects of off-season grazing on wildlife are also needed to ensure off-season grazing is applied in a manner that is compatible with species of conservation concern and to develop wildlife friendly management practices when and where they are needed.

Declaration of Competing Interest

We do not have any conflict of interest to declare.

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