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Fall-Winter Grazing After Fire in Annual Grass-Invaded Sagebrush Steppe Reduced Annuals and Increased a Native Bunchgrass[☆]

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ABSTRACT

Exotic annual grass invasion and dominance of rangelands is a concern across western North America and other semiarid and arid ecosystems around the world. Postfire invasion and dominance by exotic annual grasses in sagebrush communities is especially problematic as there are no cost-effective control strategies available for the vast acreages already invaded. However, fall-winter grazing by cattle has been suggested as a potential tool to decrease exotic annual grasses and encourage native perennial vegetation, but to date its efficacy has not been tested. We evaluated fall-winter grazing over 4 yr after wildfire in Wyoming big sagebrush (*Artemisia tridentata* Nutt. subsp. *wyomingensis* Beetle & Young) steppe invaded by exotic annual grasses. Fall-winter grazing reduced exotic annual grass and annual forb cover and density and increased the native perennial bunchgrass, Sandberg bluegrass (*Poa secunda* L.). Exotic annual grass cover and density were 1.5 × greater in ungrazed compared with fall-winter grazed areas after 4 yr. At this time, Sandberg bluegrass density and cover were 1.6 × and 2.3 × greater in fall-winter grazed compared with ungrazed areas. Large perennial bunchgrasses and perennial forbs did not increase with fall-winter grazing because either grazing did not facilitate their increase or they were slow to respond to decreases in exotic annuals. Fall-winter grazing likely decreased exotic annual grass by defoliating it during its early growth in the fall and late winter and by reducing ground cover that facilitates exotic annual grass emergence and growth. Fall-winter grazing clearly reduced exotic annual grasses, but its effects on native perennial vegetation were not conclusive. Careful application of fall-winter grazing appears to be a valuable tool for managing exotic annual grass cover and abundance, but longer-term research is necessary to determine if it can facilitate the return of native perennial dominance.

Introducton

Exotic annual grass invasion and dominance is a concern in arid and semiarid regions of the world (Purdie and Slatyer 1976; Mack 1981; Hobbs and Atkins 1988, 1990; Brooks et al. 2004; Milton 2004; Lui et al. 2006). Exotic annual grass invasion is a driver of plant community dynamics because of competition for resources and its alteration of fire regimes. Exotic annual grasses are highly competitive with native vegetation (Nasri and Doescher 1995; Rafferty and Young 2002). They often preempt resource use, resulting in the exclusion of native species (Melgoza et al. 1990). Increased fire frequency associated with exotic annual grass invasion further negatively impacts native perennial vegetation and leads to the development of an annual grass-fire cycle (Whisenant 1990; D'Antonio and Vitousek 1992; Brooks et al. 2004). Exotic annual grasses promote more frequent wildfire because they increase the amount (Stewart and Hull 1949; D'Antonio and Vitousek 1992; Knapp 1995), horizontal continuity, and ignitability of fine fuels (Brooks 2008; Davies and Nafus 2013).

Cheatgrass *(Bromus tectorum)* and medusahead (*Taeniatherum caput-medusae* [L.] Nevski) are problematic exotic annual grasses in the sagebrush steppe ecosystem of western North America, where they have invaded tens of millions of hectares (Pellant and Hall 1994; Bradley and Mustard 2005; Meinke et al. 2009). Increased fire frequency associated with these species has resulted in widespread loss of sagebrush-occupied rangeland (Stewart and Hull 1949; D'Antonio and Vitousek 1992; Davies et al. 2011;

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Balch et al. 2013). Exotic annual grass invasion and associated increased fire frequency is a major factor contributing to the decline of sagebrush-associated wildlife (Crawford et al. 2004; USFWS 2013). The exotic annual grass problem is so vast that, to date, there are no cost-efficient techniques to control the large acreages already invaded (Stohlgren and Schnase 2006).

Exotic annual grasses often increase after fire in sagebrush ecosystems (Steward and Hull 1949; Chambers et al. 2007; Davies et al. 2011). Fire kills sagebrush, a fire-intolerant shrub, and makes nutrients more available (Davies et al. 2007), which often favors exotic species that can take advantage of excess resources. Preventing all wildfire may seem like a management strategy to reduce the risk of further increase in exotic annual grasses but is generally unrealistic and most sagebrush communities will eventually burn. Furthermore, wildfires are a natural disturbance in sagebrush communities (Wright and Bailey 1982). Thus, we need to look for efficient methods to reduce exotic annual grasses after fire.

Fall-winter grazing has been suggested as a management tool to reduce exotic annual grasses and favor perennial vegetation in mixed annual-perennial rangelands (Schmelzer et al. 2014; Perryman et al. 2018). However, the effects of fall-winter grazing on exotic annual grasses and perennial vegetation have only been limitedly investigated and to date have not been evaluated shortly after fire. Livestock in the fall and winter may selectively graze exotic annual grasses because other vegetation may be dormant and therefore fall-winter grazing is speculated to reduce exotic annuals and favor native herbaceous vegetation (Smith et al. 2012). Fall-winter grazing also likely negatively impacts exotic annual grass and promote perennials by reducing exotic annual grass litter accumulations (Schmelzer et al. 2014; Perryman et al. 2020). Exotic annual grass abundance is greater when the ground is covered by plant litter because it improves the microenvironment for exotic annual grass seedling establishment and growth (Evans and Young 1970; Facelli and Pickett 1991; Newingham et al. 2007; Wolkovich et al. 2009). This same litter layer can act as a barrier to native perennial bunchgrass establishment (Evans and Young 1970). Herbaceous vegetation cover seems to convey a similar effect as litter on exotic annual grass emergence and growth (Adair et al. 2008). Therefore, it seems plausible that fall-winter grazing by livestock may reduce exotic annual grasses and encourage native vegetation. However, empirical studies evaluating the effects of fall-winter grazing on native vegetation are lacking in exotic annual grass–invaded rangelands.

Fall-winter grazing is expected to have minimal to no negative effects on most native perennial herbaceous plants (Davies et al. 2016) as they have limited growth or are dormant at this time, but it is unclear if fall-winter grazing of exotic annual grass–invaded rangelands translates into increases in native perennial vegetation. Fall-winter grazing may facilitate increases in native perennial vegetation by reducing competition from exotic annual grasses. In Nevada, fall grazing reduced exotic annual grass seed in the seedbank, but exotic annual grass seed still numbered in the 1 000s•m^{-2} (Perryman et al. 2020). Thus, exotic annual grasses may still be too abundant in some circumstances to allow native vegetation to increase. Even if exotic annual grasses are substantially decreased, other exotic species may increase (Schmelzer et al. 2014). Similarly, exotic annual forbs have been observed to increase in cheatgrass die-off areas (Nicholson 2014). Therefore, it is unknown if declines in exotic annual grasses induced by fall-winter grazing will result in increases in native perennial vegetation.

The purpose of this study was to determine if fall-winter grazing decreases exotic annual grasses and increases native perennial vegetation in postfire exotic annual grass–invaded rangeland. We evaluated fall-winter grazing effects on vegetation in seven Wyoming big sagebrush (*Artemisia tridentata* Nutt. subsp. *wyomingensis* Beetle & Young) steppe communities that had burned in the Buzzard Wildfire Complex in 2014. We hypothesized that fall-winter grazing would 1) decrease the abundance and cover of exotic annual grasses and 2) increase native perennial vegetation.

Methods

Study Area

The study was conducted in southeastern Oregon (Fig. 1). Seven study sites were located in the Buzzard Wildfire Complex 50–60 km southeast of Burns, Oregon. The Buzzard Wildfire Complex was started by multiple lightning ignitions on July 14, 2014 and burned 160 153 ha (395 747 ac). All study sites were Wyoming big sagebrush–bunchgrass communities before burning. Sagebrush was present at all study sites before burning. Common perennial bunchgrasses varied among sites and included Thurber's needlegrass (*Achnatherum thurberianum* [Piper] Barkworth); bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] A. Löve); prairie Junegrass (*Koeleria macrantha* [Ledeb.] J.A. Schultes); bottlebrush squirreltail (*Elymus elymoides* [Raf.] Swezey); and Sandberg bluegrass (*Poa secunda* J. Presl). Thurber's needlegrass or bluebunch wheatgrass was the dominant large perennial bunchgrass at study sites. Cheatgrass and medusahead were present in low abundance before fire, but cheatgrass and to a lesser extent medusahead increased substantially post fire. Elevation of study sites ranged from 1 290 m to 1 440 m above sea level. Slopes at study sites ranged from 0° to 14° and aspects were northwest, northeast, south, southeast, west, and east. Study sites were located on RO23XY212OR-Loamy 10-12 PZ, R023XY216OR-Clay Pan 12-16 PZ, RO23XY300OR-South Slope 10-12 PZ, and RO23XY308OR-North Slope 10-12 PZ Ecological Sites (NRCS 2020). Long-term (1981–2010) average annual precipitation was 283 mm (PRISM 2020). Crop year (October–September) precipitation in 2014–2015, 2015–2016, 2016–2017, 2017–2018, and 2018–2019 was 99%, 100%, 118%, 74%, and 130% of the long-term average, respectively (PRISM 2020). Wildlife were not excluded from study sites.

Experimental Design and Measurements

A randomized complete block design with study site ($n = 7$) being the blocking variable was used to investigate fall-winter grazing effects in exotic annual grass–invaded sagebrush rangelands. The seven study sites varied in soil characteristics, aspect, slope, elevation, and plant community composition. Study sites were separated by up to 16 km. At each study site two treatments, separated by a 10-m buffer, were applied post fire: 1) fall-winter grazed and 2) ungrazed. The fall-winter grazed treatment was applied with cattle between early November and late February (this was the only time grazing was applied) at the pasture level. Grazing was applied each year starting in the fall of 2015 (1 yr after the Buzzard Wildfire Complex). Grazing was managed by livestock producers as part of their operation; thus, cattle timing of use in each pasture varied among years. Similarly, the number of cattle varied among pastures and within pastures across years, but utilization of available forage was between 30% and 50%, which is considered moderate grazing. Cattle were provided protein supplements to ensure their nutritional needs were met. The ungrazed treatment was applied by constructing 30 × 30 m exclosures with cattle panels and steel t-posts.

Vegetation measurements were conducted in June 2016, 2017, 2018, and 2019. Vegetation cover and density were measured in 30, 0.2-m^{-2} quadrats placed at 3-m intervals along three 30-m transects spaced 5 m apart. Vegetation cover by species was measured to the nearest 1% in the 0.2-m^{-2} quadrats. Perennial vegetation cover estimates included prior years' growth if it was still

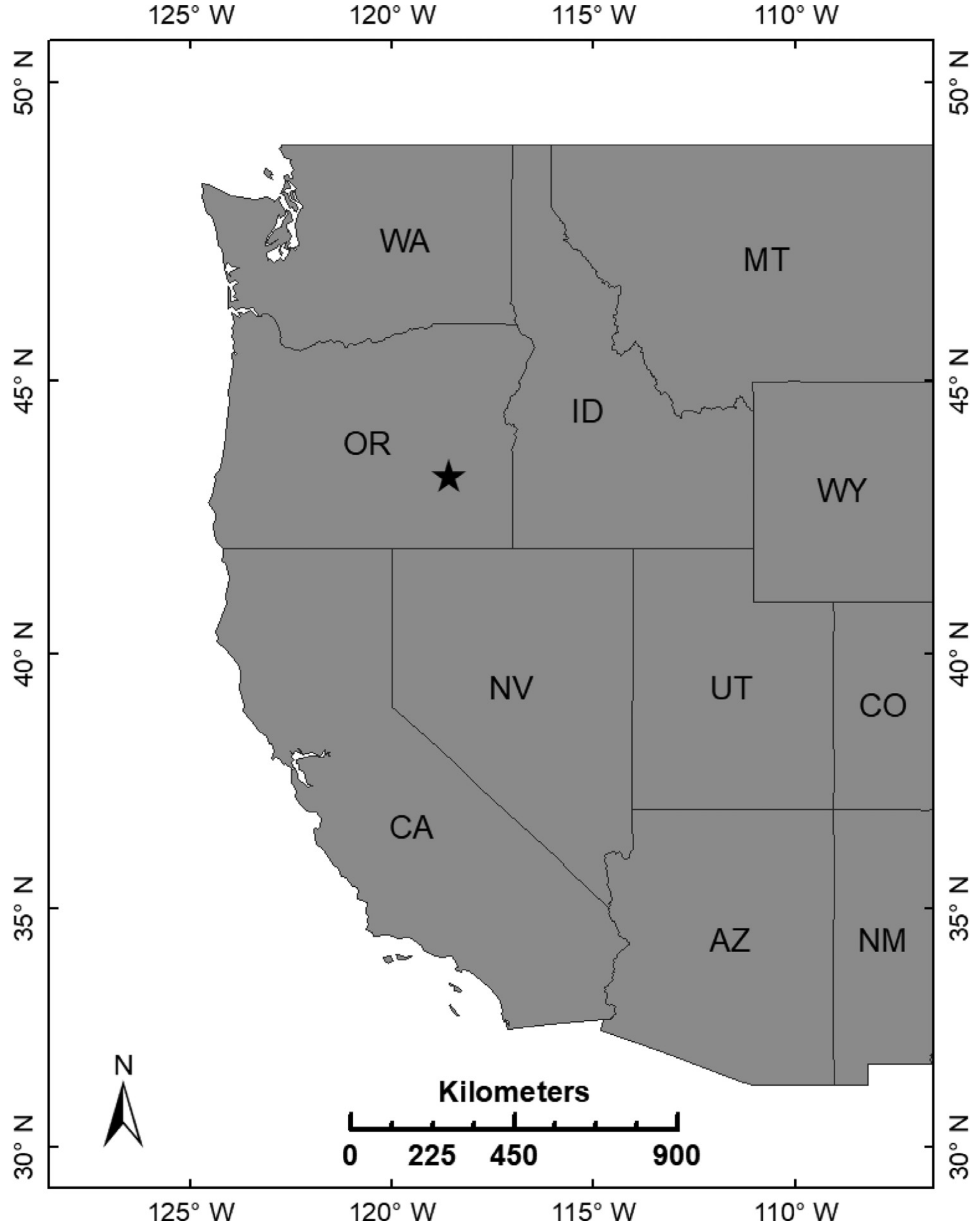

Fig. 1. Study location (marked by *star*) in the western United States.

erect. Annual vegetation cover estimates included only the current year's growth. Bare ground and litter (dead plant material on the soil surface) cover were also measured in the 0.2-m^{-2} quadrats. Perennial vegetation density by species was measured by counting all individuals rooted in the quadrats. Annual vegetation density by species was measured by counting all individuals in a 10% area of the quadrats. Shrub cover was measured using the line-intercept method on each 30-m transect. Shrub density was measured by counting all shrubs rooted in a 2 × 30 m belt-transect positioned over each 30-m transect.

Statistical Analyses

Repeated measures analysis of variance using a mixed model in SAS 9.4 (SAS Institute, Inc., Cary, NC) was used to evaluate the effects of fall-winter grazing. Treatment was considered a fixed variable, and year was the repeated variable. Block and block-by-treatment interactions were treated as random variables in the mixed models. Akaike's Information Criterion was used to select the appropriate covariance structure (Littell et al. 1996). Vegetation was separated into the following groups for analyses: Sandberg bluegrass, large perennial bunchgrasses, exotic annual grasses, perennial forbs, and annual forbs. Sandberg bluegrass was treated as a separate group from other native bunchgrasses because it is smaller in stature, phenologically develops earlier, and responds differently to disturbances and management (McLean and Tisdale 1972; Yensen et al. 1992). The exotic annual grass group was primarily composed of cheatgrass with some medusahead. The perennial forb group was solely composed of native species. The annual forb group largely consisted (> 90%) of exotic annual forbs. Shrub cover and density were not analyzed because shrubs were absent from many of the sites. Data that violated assumptions of analyses of variances were log or square root transformed. Original data were presented in the text and figures. Statistical significance was set at $P \leq 0.05$. Means were reported with standard errors in figures and text.

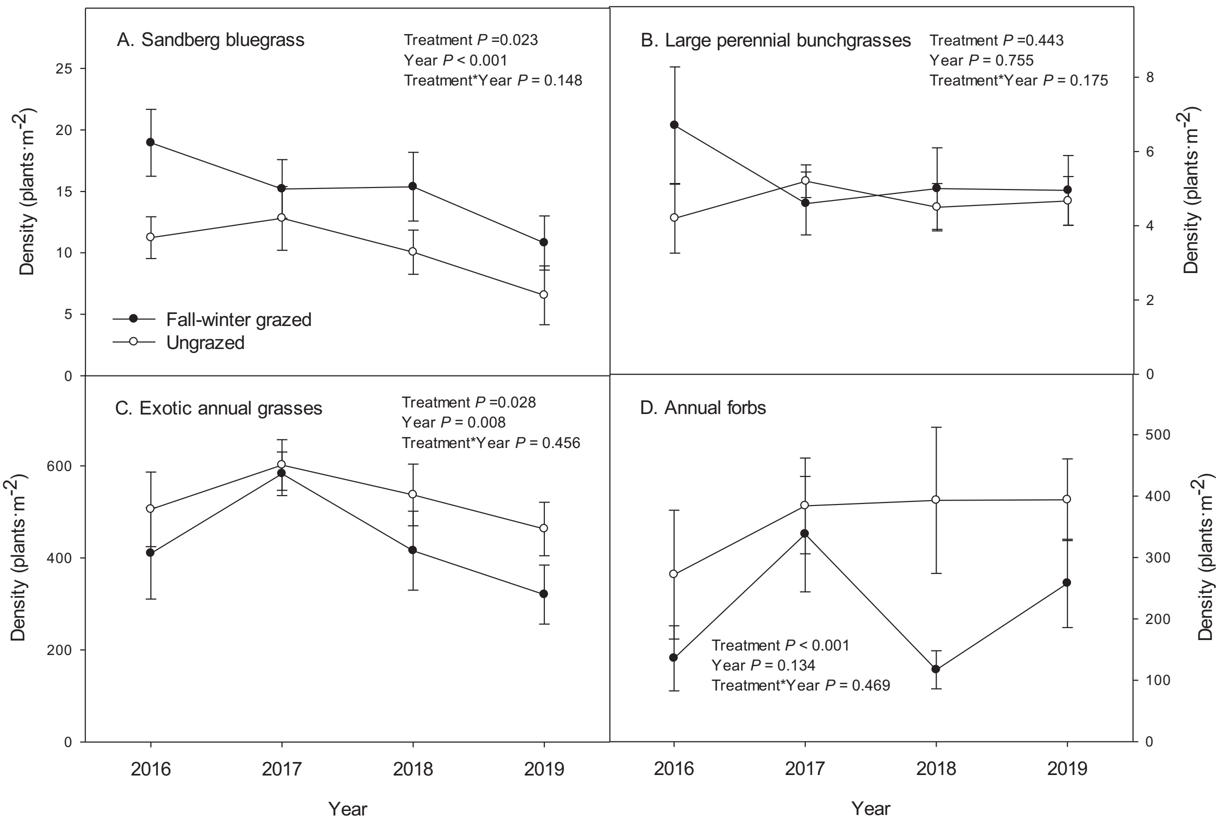

Fig. 2. Density (mean ± standard error) of plant groups in fall-winter grazed and ungrazed areas in exotic annual grass–invaded rangeland in southeast Oregon.

Results

Sandberg bluegrass density was greater in fall-winter grazed compared with ungrazed areas and varied among years (Fig. 2A; $P = 0.023$ and < 0.001, respectively). At the conclusion of the study (5 yr post fire), Sandberg bluegrass density was 1.6 × greater in grazed compared with ungrazed areas. Large perennial bunchgrass density was similar between grazed and ungrazed areas and among years (Fig. 2B; $P = 0.443$ and 0.744, respectively). Exotic annual grass density was less in postfire grazed compared with ungrazed areas and varied among years (Fig. 2C; $P = 0.028$ and 0.008, respectively). Exotic annual grass density was 1.5 × greater in ungrazed compared with grazed areas at the end of the study. Exotic annual grass density was generally greatest in 2017, the third growing season after fire. Perennial forb density did not differ between grazed (5.92 ± 1.3 individuals•m^{-2}) and ungrazed (5.60 ± 1.3 individuals•m^{-2}) areas or vary among years ($P = 0.581$ and 0.315, respectively). Density of annual forbs was 1.1–3.3 × greater in ungrazed compared with grazed areas (Fig. 2D; $P < 0.001$) but did not vary among years ($P = 0.134$).

Sandberg bluegrass cover showed a significant treatment-by-year interaction (Fig. 3A; $P = 0.008$). Initially, Sandberg bluegrass cover was greater in ungrazed areas but then became greater in grazed areas. At the end of the study, Sandberg bluegrass cover was 2.3 × greater in grazed compared with ungrazed areas. Large perennial bunchgrass cover differed between treatments and varied among years (Fig. 3B; $P = 0.034$ and 0.002, respectively). Large perennial bunchgrass cover was 1.3 × greater in the ungrazed compared with the grazed treatment at the conclusion of the study. Large perennial bunchgrass cover was generally greatest in the last 2 yr of the study. Exotic annual grass cover was less in the grazed compared with ungrazed areas and varied among years (Fig. 3C; $P = 0.013$ and < 0.001, respectively). In the final year of the study, exotic annual grass cover was 1.5 × greater in ungrazed compared with grazed areas. Exotic annual grass cover varied among years with it being lowest and highest in third (2017) and fourth (2018) yr post fire, respectively. Perennial forb cover did not differ between grazed (3.0% ± 0.56%) and ungrazed (3.2% ± 0.78%) areas ($P = 0.787$) or vary among years ($P = 0.073$). Annual forb cover was greater in ungrazed compared with grazed areas and varied among years (Fig. 3D; $P = 0.025$ and < 0.001, respectively). Annual forb cover was the least in 2017 and generally greatest in 2018 and 2019. Bare ground was influenced by the interaction between treatment and year (Fig. 3E; $P = 0.003$). Bare ground was generally greater in grazed compared with ungrazed areas except for the second yr post fire when it was greater in ungrazed areas. In the final yr of the study, bare ground was 2 × greater in grazed compared with ungrazed areas. Litter was influenced by the interaction between treatment and year (Fig. 3F; $P = 0.046$). Litter cover was generally similar between grazed and ungrazed areas the first 3 yr but was greater in ungrazed areas in the final yr of the study.

Discussion

Fall-winter grazing by cattle in exotic annual grass–invaded rangelands altered the plant community. Most notably, grazing decreased annual vegetation, primarily exotic species, and increased Sandberg bluegrass. In contrast, other native vegetation did not increase with fall-winter grazing. Fall-winter grazing provided some desired changes in exotic annual grass–invaded rangeland. However, it remains unknown if grazing-induced changes altered the plant community trajectory or if community composition will converge between grazed and ungrazed areas if fall-winter grazing ceases. In addition, the magnitude of fall-winter grazing effects

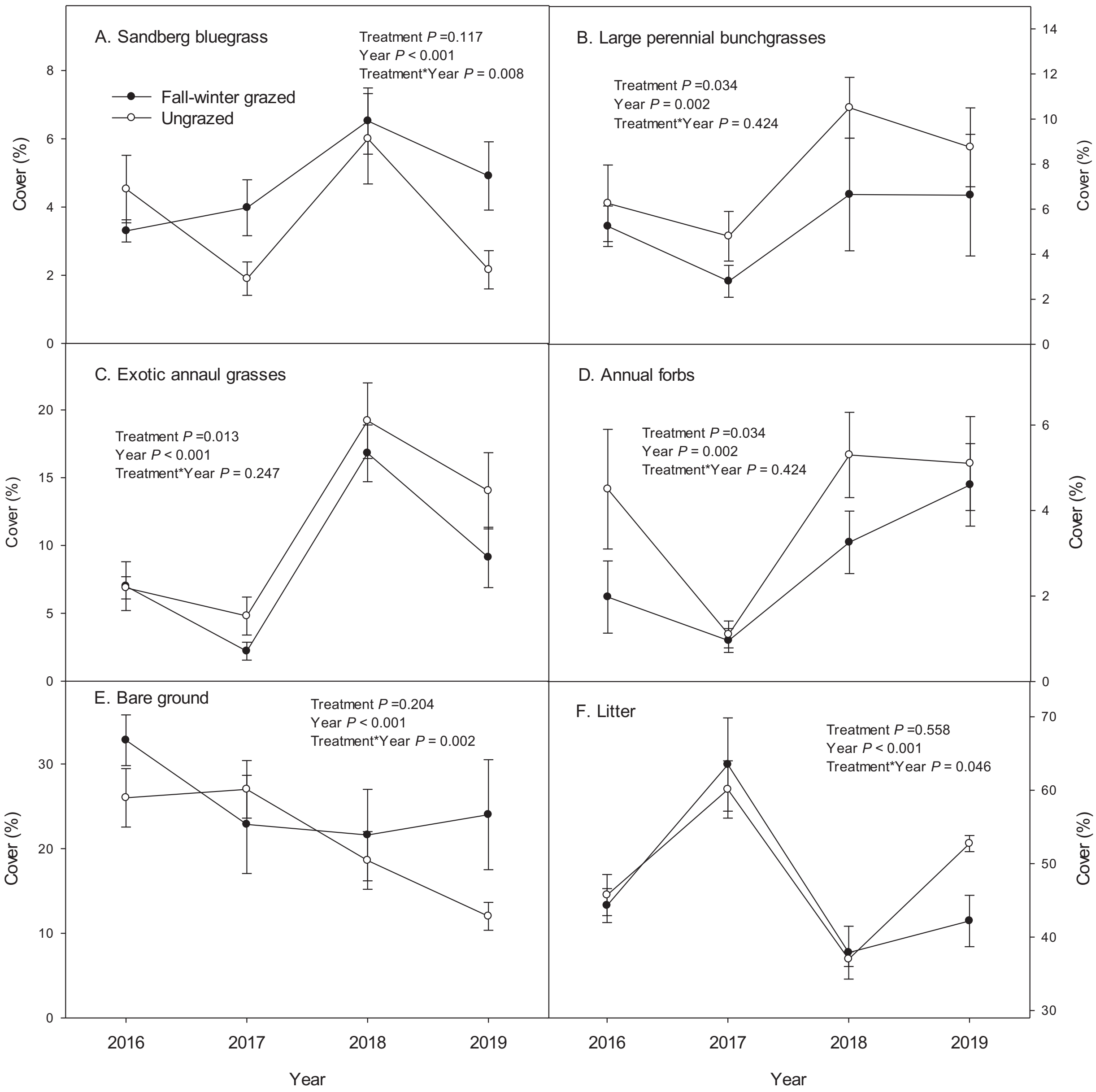

Fig. 3. Cover (mean ± standard error) of cover groups in fall-winter grazed and ungrazed areas in exotic annual grass–invaded rangeland in southeast Oregon.

may take longer to be realized because many native perennial species are slow growing and only successfully recruit new individuals sporadically.

Fall-winter grazing by cattle may have reduced exotic annual grass dominance through selective grazing. Exotic annual grasses may grow either in the fall or early in the growing season before native perennial grasses, resulting in a competitive advantage (Hironaka 1961; Harris 1977). However, early growth by exotic annual grasses may also allow grazing to be applied to target them, while limiting negative effects on native plants that may be dormant at this time. If exotic annual grasses are growing and native perennial grasses are dormant, cattle will select exotic annual grasses (Smith et al. 2012). In this study, we observed cattle focusing their grazing on exotic annual grass seedlings in the fall and winter when native bunchgrasses had limited green leaves. This may decrease the competitive advantage of exotic annual grasses. The loss of photosynthetic tissue places grazed plants at a competitive disadvantage with non-grazed plants (Caldwell et al. 1987; Briske and Richards 1995; Wan et al. 2015). Exotic annual grasses, however, are grazing tolerant and rapidly regrow lost photosynthetic material (Klemmedson and Smith 1964; Pyke 1987). The spring cohort of exotic annual grasses (Mack and Pyke 1983) may largely avoid defoliation in fall-winter grazed areas. Thus, fall-winter grazing may reduce exotic annual grass dominance but is unlikely to eliminate them from the community.

Fall-winter grazing was also expected to decrease safe sites for exotic annual grass seedlings by reducing vegetation cover and litter. In a study in Colorado, cheatgrass success was decreased with reduced vegetation cover, likely because vegetation cover improved the seedling establishment environment for exotic annual grasses (Adair et al. 2008). Thus, reduced cover of exotic annuals and large perennial bunchgrasses with grazing in our study may have contributed to decreased exotic annual grasses. Exotic annual grasses also establish better with a litter layer covering the soil surface 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). In contrast, native vegetation establishment in this ecosystem can be hindered by exotic annual grass litter (Evans and Young 1970). Reduced litter with grazing was not evident in our study until the final year. However, we measured litter as ground cover, which may not fully determine fall-winter grazing effects on it. Measuring litter as cover may not capture changes in litter thickness and biomass, which could be important factors influencing the microenvironment for exotic annual grass establishment. Litter thickness may have been reduced, but litter may still cover the same amount of the soil surface. More bare ground in fall-winter grazed areas suggests that reduced litter, at least in the final year of the study, and vegetation cover likely contributed to exotic annual grass declines.

Fall-winter grazing also reduced annual forb cover and density, which consisted primarily of non-native species. Dissimilar to our results, annual forb cover and density were greater in fall grazed compared with ungrazed areas in Nevada (Schmelzer et al. 2014). Likely, the composition of annual forbs differed significantly between Schmelzer et al. (2014) and our current study. In addition, annual forb abundance and cover were much greater in our study than Schmelzer et al. (2014). Annual forbs at our study sites may have been favored by the microenvironment created by exotic annual grass cover and subsequently were reduced when fall-winter grazing reduced annual grasses. Increases in Sandberg bluegrass with fall-winter grazing may have also reduced resources available to annual forbs, and early growing annual forbs may have been grazed. Likely, it was a combination of all or several of the aforementioned factors influenced by fall-winter grazing that reduced annual forb cover and density.

Sandberg bluegrass increased with fall-winter grazing, likely because decreases in exotic annual grasses favored it through reduced competition and shading. By the end of the study, Sandberg bluegrass cover was more than 2 × greater in fall-winter grazed areas compared with ungrazed areas. Reductions in annual grasses may create opportunities for other vegetation to increase, because exotic annual grasses are highly competitive with native vegetation (Melgoza et al. 1990; Nasri and Doescher 1995; Rafferty and Young 2002). Spring grazing of cheatgrass for several consecutive years also resulted in increases in Sandberg bluegrass (Davies et al. 2020). Sandberg bluegrass was likely susceptible to shading by exotic annual grasses and their litter layer because of its short stature. Even though Sandberg bluegrass starts growth earlier than other native bunchgrasses and may be growing when fall-winter grazing is applied, cattle grazing is unlikely to negatively impact it. Sandberg bluegrass is considered grazing tolerant because it can increase with heavy spring grazing when other bunchgrasses decrease (McLean and Tisdale 1972). Sandberg bluegrass is a short-stature bunchgrass; thus, it is difficult for cattle to graze its leaves. Fall-winter grazing also did not reduce Sandberg bluegrass cover because it almost exclusively consists of current year’s growth, whereas cover of other bunchgrasses often consists of current and prior years’ growth.

In contrast to Sandberg bluegrass, we did not find any evidence that large perennial bunchgrasses were positively influenced by fall-winter season grazing. This is dissimilar to a study in Nevada where fall grazing of exotic annual grass–invaded rangeland substantially increased the perennial bunchgrass standing crop (Schmelzer et al. 2014). We did not measure standing crop, but since fall-winter grazing reduced large bunchgrass cover in our study, we expect that its standing crop would not have increased. An introduced perennial bunchgrass, crested wheatgrass (*Agropyron cristatum* Nutt.), was the largest contributor to the bunchgrass standing crop production in the Nevada study (Schmelzer et al. 2014), but in our study area, the large bunchgrass group was composed of native species. Crested wheatgrass is well known to respond more rapidly and be more competitive than native bunchgrasses (Gunnell et al. 2010; Davies and Johnson 2017). Fall defoliation of crested wheatgrass can reduce exotic annual grass density, likely through stimulated growth of crested wheatgrass the following spring (Sheley et al. 2008). In the Nevada study, grazing pressure was also greater than applied in our study, which might have decreased exotic annual grasses more and thereby result in increases in crested wheatgrass. Large native bunchgrasses are also slow growing in arid and semiarid ecosystems (Holmes and Rice 1996; James et al. 2009), and thus additional time may be required to detect a response to fall-winter grazing. Large perennial bunchgrass cover was less in grazed areas, but this was expected since grazing would reduce prior years’ growth, a major contributor to large perennial bunchgrass cover. Though our study suggests that 4 yr of fall-winter grazing did not negatively impact large perennial bunchgrasses, our study detected no positive influence on large native bunchgrasses. Long-term evaluation of the application of fall-winter grazing in these communities is needed to better understand its effects on large native bunchgrasses.

Our study suggests that fall-winter grazing by cattle can be a tool for reducing exotic annual grass dominance and, possibly, encourage native perennials. However, fall-winter grazing effects on native perennial vegetation were inconclusive. Without substantial increases in large perennial bunchgrasses, it is hard to determine if this treatment has fundamentally altered long-term plant community dynamics. Thus, the question remains if fall-winter grazing can be a treatment to change the trajectory of the community from exotic annual grass–dominated to more perennial-dominated or if it needs to be constantly applied to maintain pressure on exotic annuals to allow increased expression of perennial vegetation. Refinement and long-term evaluation of fall-winter grazing is needed to increase its potential to be an effective tool for managing exotic annual grass invasion in rangeland communities. It may also be valuable to determine if fall-winter grazing can be integrated with other management actions to promote further increases in perennial vegetation.

Management Implications

Fall-winter grazing can reduce exotic annual grass cover and density, leading to increases in the native perennial grass, Sandberg bluegrass. Grazing-induced declines in exotic annual grasses may also decrease the risk of frequent wildfires fueled by abundant annual grass biomass. Preventing frequent wildfires is critical as native vegetation is generally intolerant of this accelerated fire occurrence. Abundance of large perennial bunchgrasses, the dominant herbaceous functional group in intact Wyoming big sagebrush–bunchgrass communities (Davies et al. 2006), did not increase with fall-winter grazing. Whether this treatment does not benefit large perennial bunchgrasses or they are slow to respond remains unanswered. Fall-winter grazing also reduced annual forbs, primarily exotic species, further suggesting that this type of grazing can be an effective tool to, at a minimum, reduce the dominance of exotic annuals in these systems. In the current study, grazing was applied after the first growing season post fire because of a substantial increase in exotic annual grasses. However, we caution against applying grazing this soon after wildfire in seeded areas because seedlings may not have enough root mass to prevent them from being pulled from the ground when grazed. Refinement and long-term evaluations of fall-winter grazing are clearly merited, and though refinement is still necessary, this should not preclude moderate levels of fall-winter grazing from being implemented to manage exotic annual grass–invaded areas now.

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.

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