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Effects of a decade of grazing exclusion on three Wyoming big sagebrush community types[☆],[☆☆]

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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. 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, richness, dissimilarity) were measured in 2020 and 2021 in five grazed and grazing excluded areas within each community type. 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. 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. 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.

1. 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

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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 subsequent loss of diversity and spread of exotic annual grasses like cheatgrass (*Bromus tectorum* L.) and medusahead (*Taeniatherum caput-medusae* (L.) Nevski) that characterize one-fifth (>77,000 km^2) of rangelands in the Great Basin (Mack, 1981; Young and Allen, 1997; Chambers et al., 2007; Smith et al., 2022). In addition, the effect of historic overgrazing and dominance of exotic annual grasses on sagebrush steppe have contributed to the identification of more than 350 sagebrush-associated plants and animals as species of conservation concern (Suring et al., 2005; Wisdom et al., 2005). However, contemporary grazing practices are vastly different from historic grazing practices (Borman, 2005; Davies and Boyd, 2020). The recovery of historically overgrazed rangelands and the transition from historic to contemporary grazing practices began with the Taylor Grazing Act and the formation of land management agencies that monitored and managed grazing on public lands (Yorks et al., 1992; Dittel et al., 2018). 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). This community type has been expanding its range across the Great Basin at an annual rate of > 3700 km^2 over the last decade (2011–2020) and is predicted to expand into higher elevation sites based on climate trends (Chambers et al., 2007; Johnson et al., 2019; Smith et al., 2022). 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.

2. Methods

2.1. 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 Press). 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 2020–21, respectively (PRISM, 2022). The elevation range across the study sites was 1027–1478-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.

2.2. 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 0.20–0.38 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-m^2) 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 × 50-m belt transects along each of the four 50-m transects at each site. Plant species richness, dissimilarity (Jaccard) indices, and diversity (Shannon diversity index) were calculated from species density measurements (Krebs, 1998). Exotic plants were included in estimates of diversity.

2.3. 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, species diversity, and species richness) 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.

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 $P \leq 0.05$. We also used an Analysis of Similarity (ANOSIM) to test for dissimilarity in plant community composition between treatments, community types, and years in R (package "vegan", R Studio v. 4.1.2, RStudio Team, 2022). Statistical significance was set at $P \leq 0.05$. Jaccard Distance was used to measure dissimilarity between treatments, community types, and years.

3. Results

3.1. Herbaceous plants: cover, density, diversity

Perennial grass density was not influenced by grazing exclusion (Fig. 1A, Table S1; $P = 0.138$) or year ($P = 0.150$), but was greatest

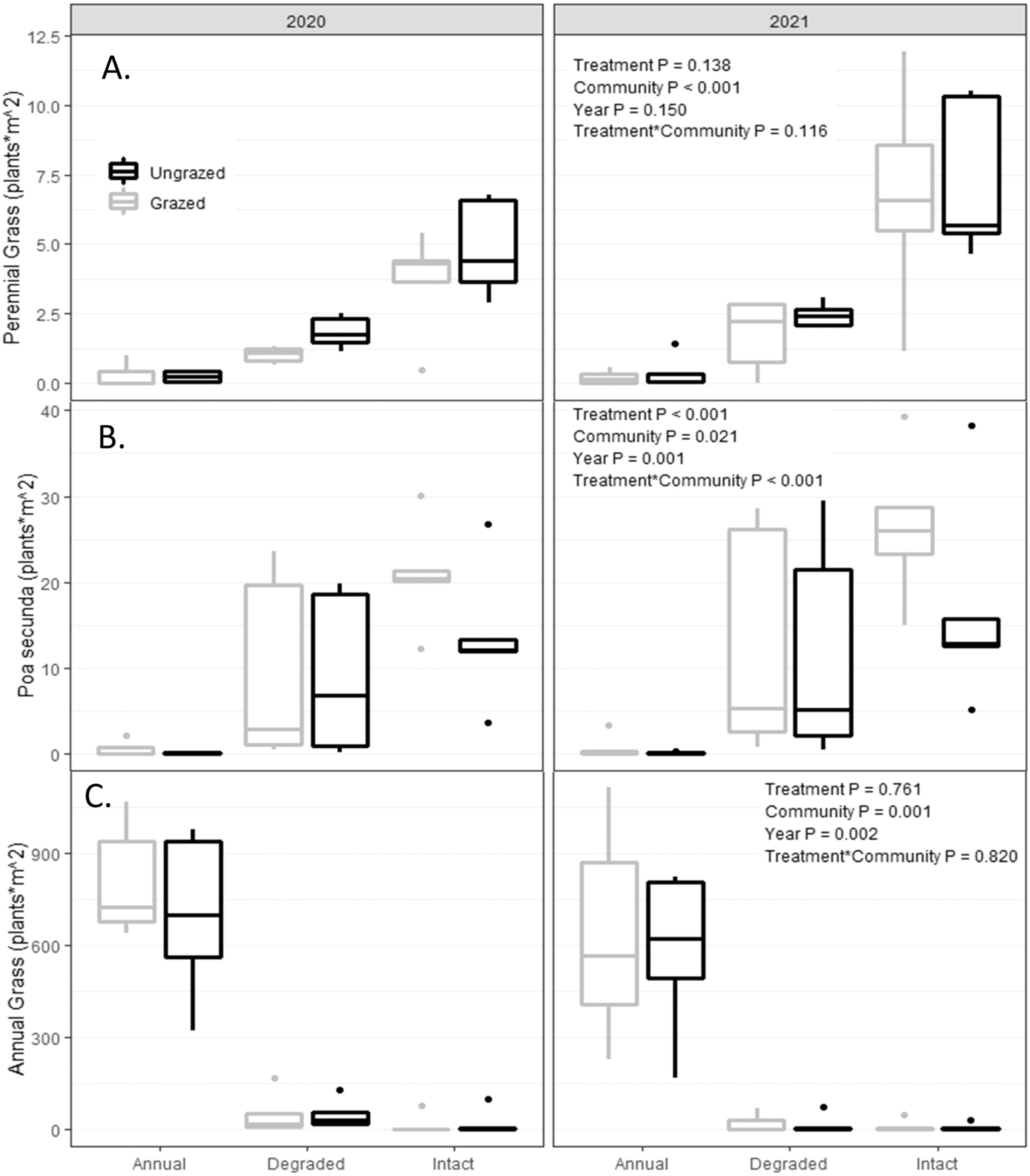

Fig. 1. Perennial grass density, Poa secunda density, and annual grass density in the annual grass, degraded, and intact community types in 2020 and 2021. The 25th and 75th percentiles are represented by upper and lower ends of the box. The line inside the box represents the median. The whisker ends represent the highest and lowest values within 1.5 * the interquartile range and the outliers are represented by the dots plotted past the whiskers.

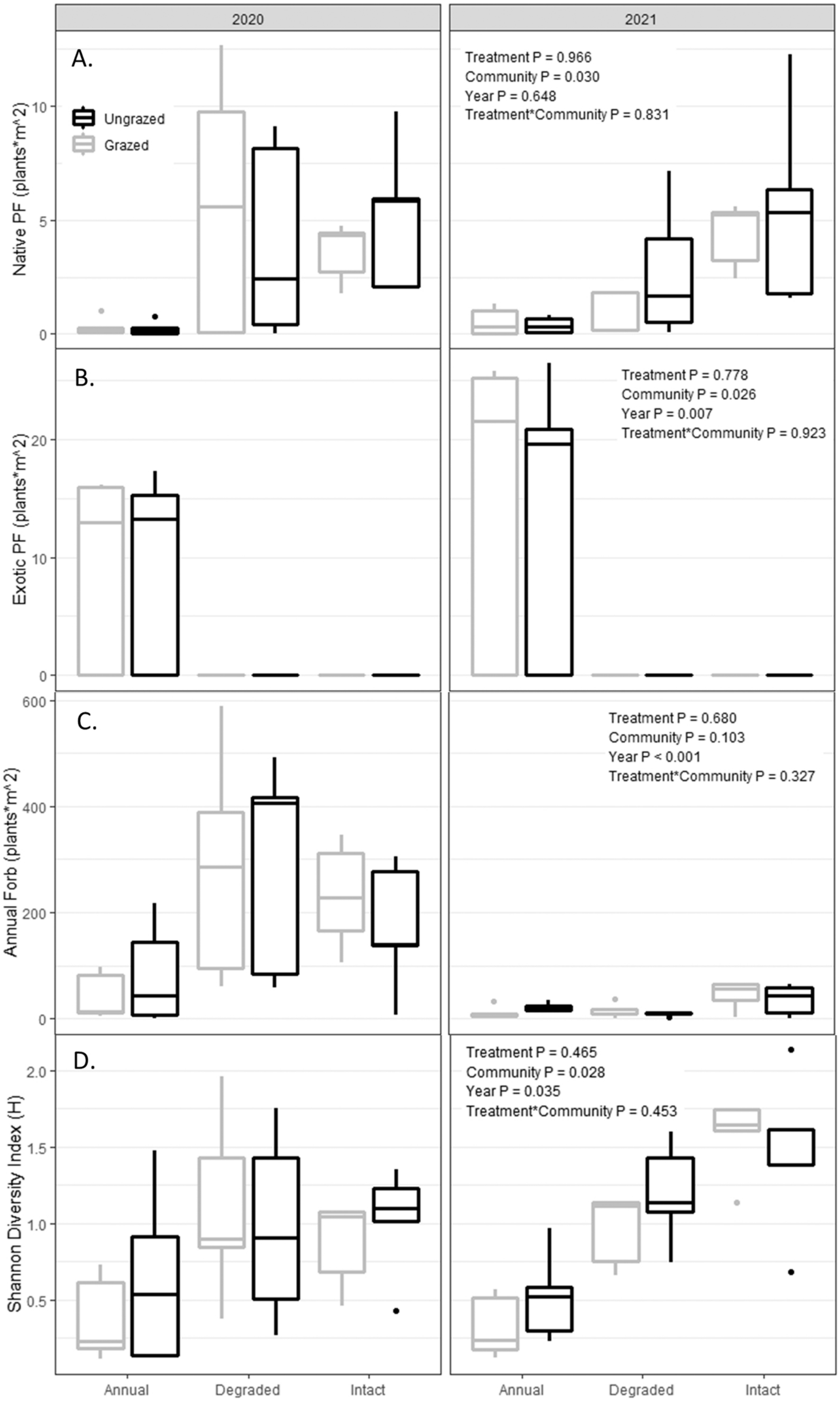

Fig. 2. Native perennial forb (PF) density, exotic perennial forb (PF) density, annual forb density and Shannon diversity index in the annual grass, degraded, and intact community types in 2020 and 2021. The 25th and 75th percentiles are represented by upper and lower ends of the box. The line inside 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.

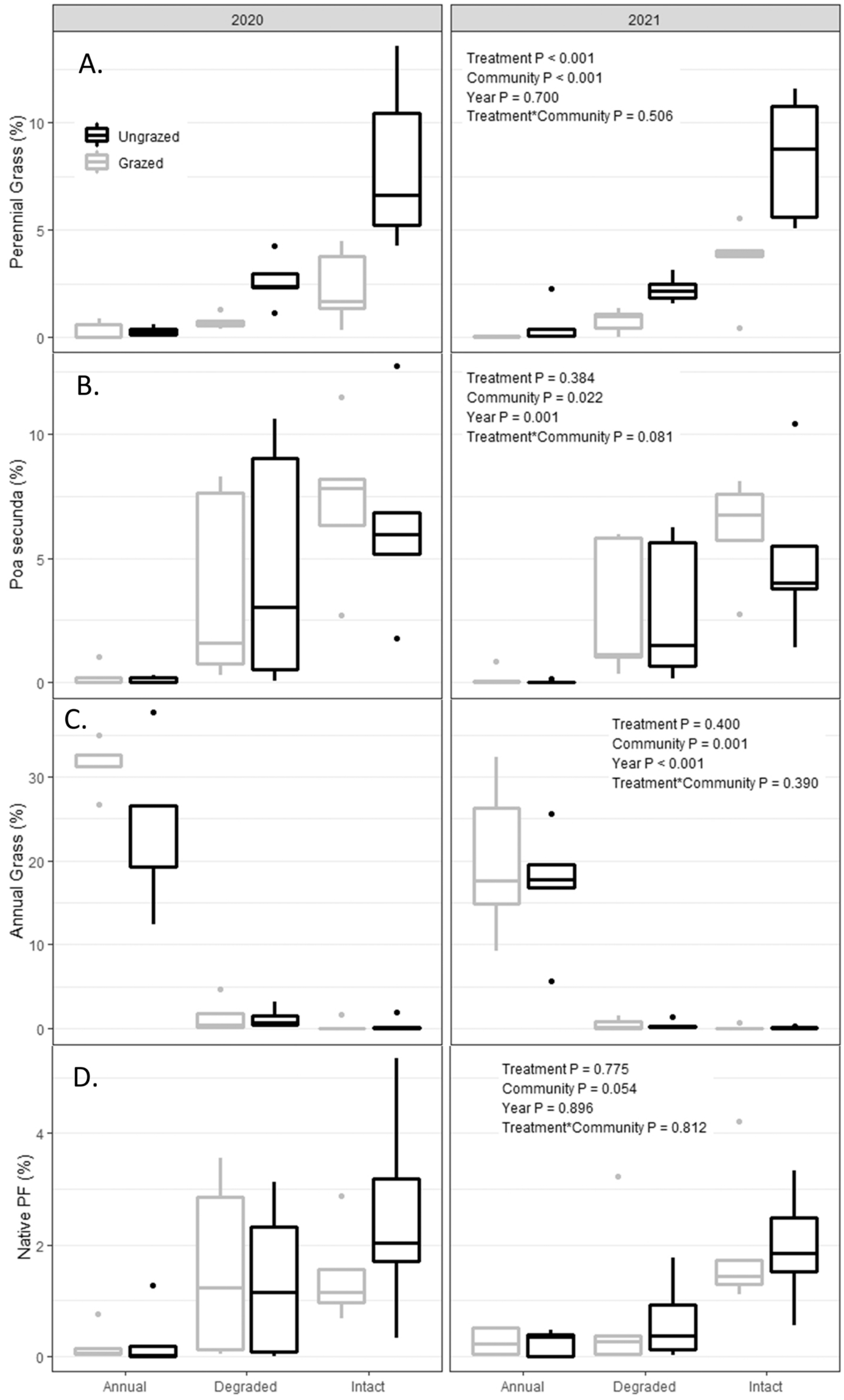

Fig. 3. Perennial grass cover, Poa secunda cover, annual grass cover, and native perennial forb (PF) cover in the annual grass, degraded, and intact community types in 2020 and 2021. The 25th and 75th percentiles are represented by upper and lower ends of the box. The line inside the box represents the 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.

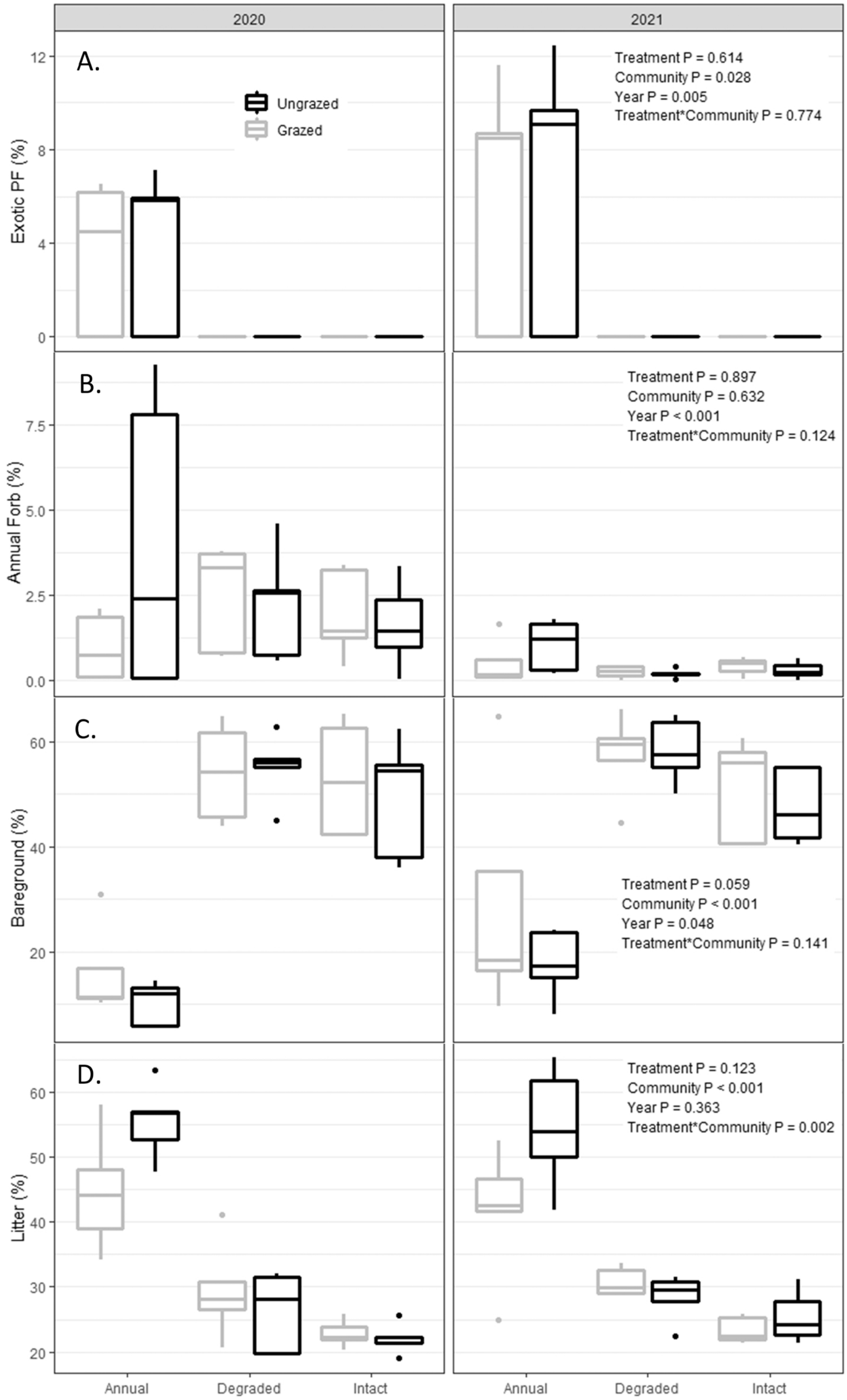

Fig. 4. Exotic perennial forb (PF) cover, annual forb cover, bare ground cover, and litter cover in the annual grass, degraded, and intact community types in 2020 and 2021. The 25th and 75th percentiles are represented by upper and lower ends of the box. The line inside the box represents the median. 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.

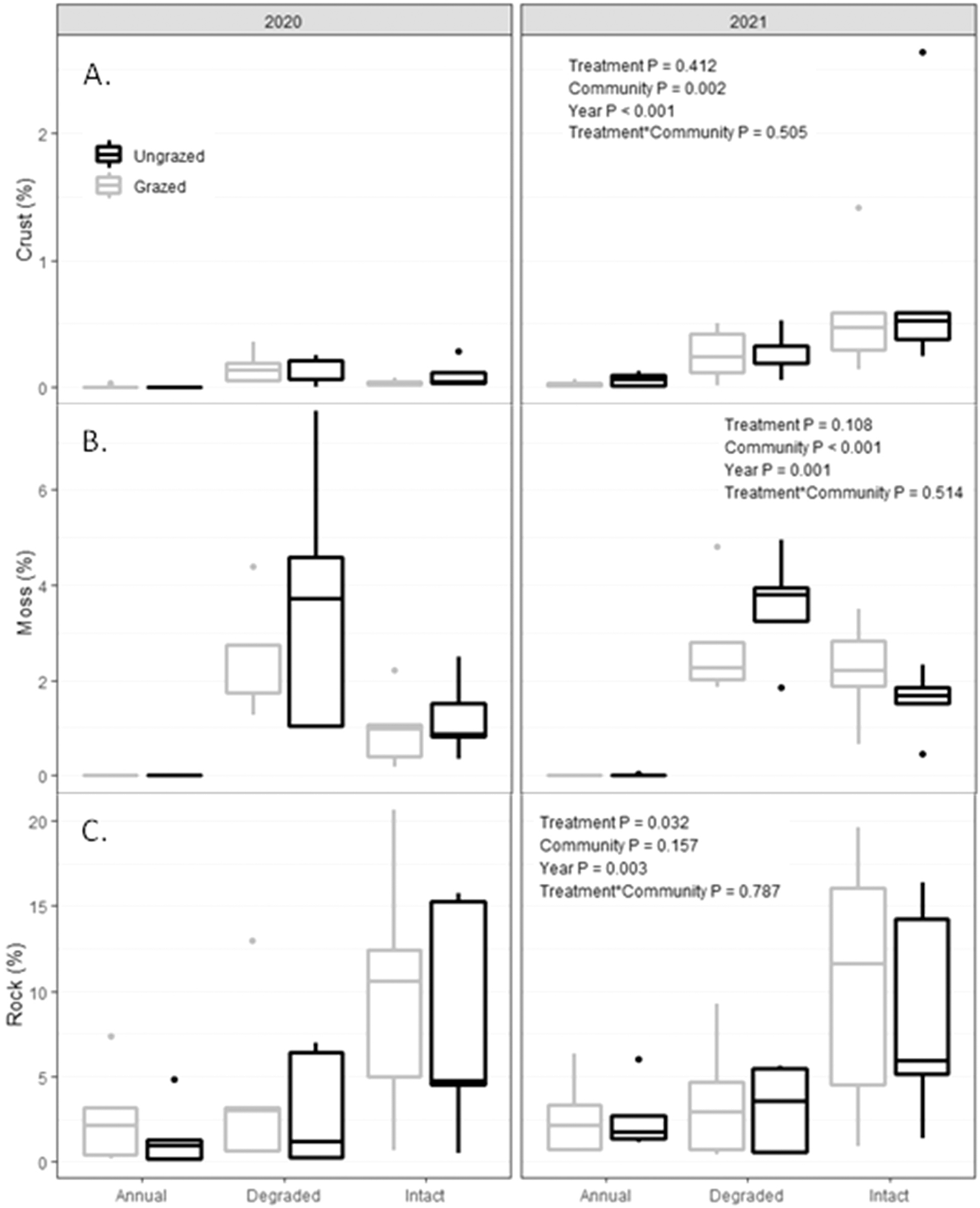

Fig. 5. Crust cover, moss cover, and rock cover in the annual grass, degraded, and intact community types in 2020 and 2021. The 25th and 75th percentiles are represented by upper and lower ends of the box. The line inside the box represents the median. The whisker ends represent the highest and lowest values within 1.5 * the interquartile range and the outliers are represented by the dots plotted past the whiskers.

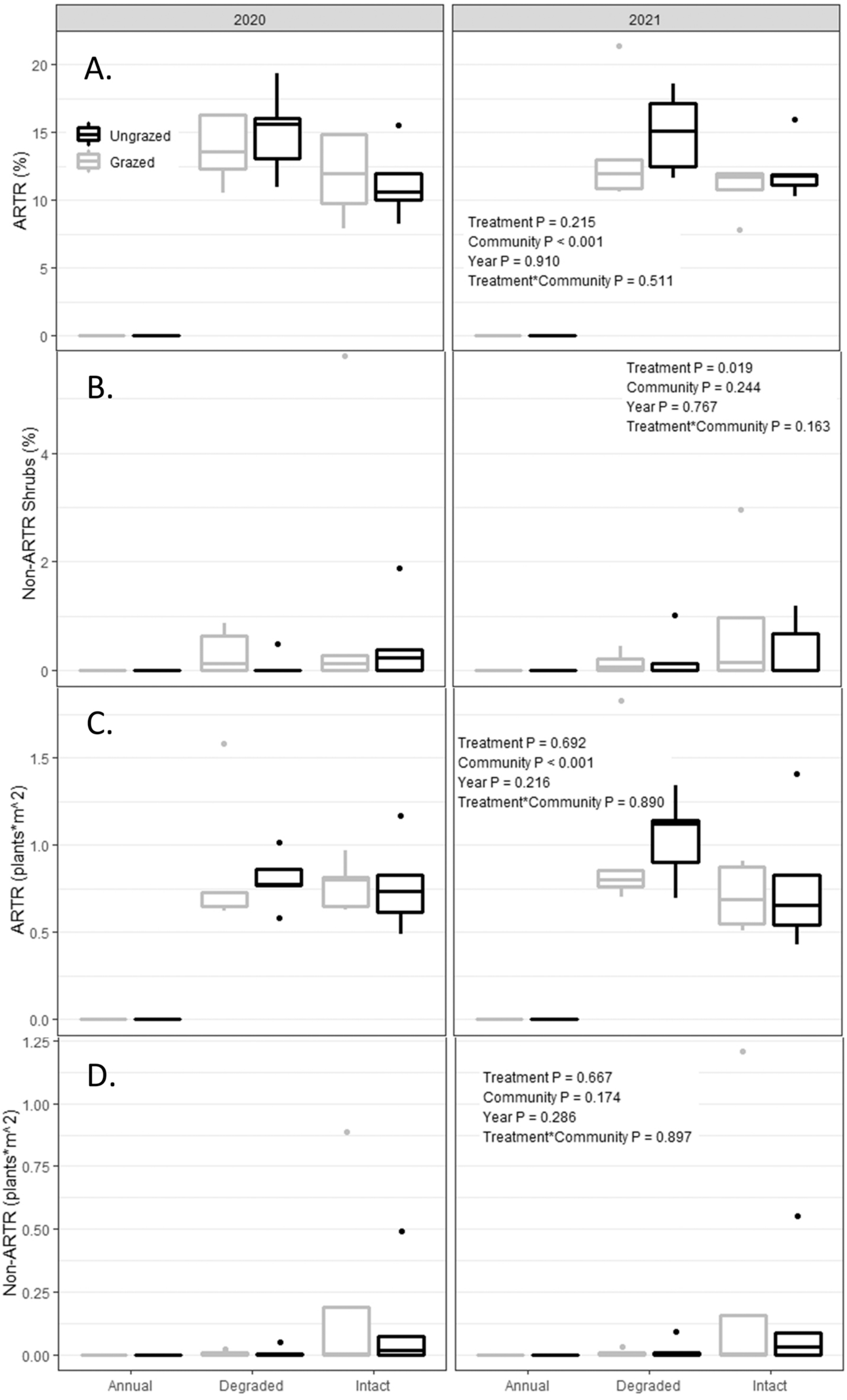

Fig. 6. Sagebrush (ARTR) cover and density (A, C), other shrubs (non-ARTR) cover and density (B, D) in the annual grass, degraded, and intact community types in 2020 and 2021. The 25th and 75th percentiles are represented by upper and lower ends of the box. The line inside each box represents the median. 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.

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 (Figs. 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 and species richness were not influenced by grazing exclusion (Fig. 2D & Table S1; $P = 0.465$ and 0.950), but differed among community types ($P = 0.028$ and 0.005) and between years ($P = 0.035$ and 0.013). Dissimilarity in plant community composition was not influenced by grazing exclusion (Table S3; $P = 0.958$), but was detected among community types ($P < 0.001$) and between years ($P = 0.006$). Dissimilarity in plant community composition between grazed and grazing excluded areas was 11.8% (Table S3). Among community types, dissimilarity in annual sites compared to degraded and intact sites was 36.5% and 42.3%, respectively, and degraded sites were 26.8% dissimilar compared to intact sites (Table S3). Between years, dissimilarity was 50% (Table S3).

Perennial grass cover increased with grazing exclusion (Fig. 3A, Table S2; $P < 0.001$) 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 (90% CI: 0.25–42.70, 2.24–4.87, and 1.91–4.43), respectively. *Poa secunda* and annual grass cover were not affected by grazing exclusion (Fig. 3B-C; $P = 0.384$ and 0.400), but differed between.

years ($P = 0.001$ and < 0.001), and among community types ($P = 0.022$ and 0.001). Native perennial, exotic perennial, and annual forb cover was not influenced by grazing exclusion (Figs. 3D, 4A, and 4B; $P = 0.775$, 0.614, and 0.897) and had varying responses to year and community type (Table S2). 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 ($P < 0.001$).

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 ($P = 0.157$).

3.2. *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 ($P = 0.286$).

4. 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., 2016b, 2016c), 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., 2016b,2016c, 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.

5. 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.

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.

Data Availability

Data will be made available on request.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gecco.2022.e02338.

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