Received: 5 April 2023 | Revised: 12 June 2023 | Accepted: 30 June 2023

DOI: 10.1002/ecs2.4671

ECOSPHERE
AN ESA OPEN ACCESS JOURNAL

ARTICLE

Agroecosystems

Grazing intensity effects on herbaceous community composition in burned sagebrush steppe

Jonathan D. Bates | **Kirk W. Davies**

United States Department of Agriculture, Agricultural Research Service, Eastern Oregon Agricultural Research Center, Burns, Oregon, USA

Correspondence
Jonathan D. Bates
Email: jon.bates@usda.gov

Funding information
USDA Agricultural Research Service; Oregon State University; Eastern Oregon Agricultural Research Center

Handling Editor: Justin duToit

Abstract

There is limited knowledge of grazing impacts on longer term plant community dynamics following fire in sagebrush steppe. This study evaluated vegetation response to different intensities of deferred rotation cattle grazing over 16 years (2007–2022) on burned Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis* (Beetle & Young) Welsh) steppe in eastern Oregon. Treatments were applied in a randomized complete block, which included no grazing on burned (nonuse, $n = 5$) and unburned (control, $n = 5$) steppe; and cattle grazing at low (low, $n = 4$), moderate (moderate, $n = 4$), and high (high, $n = 4$) intensities on burned steppe. Vegetation dynamics were evaluated by repeated measures analysis of canopy cover and density of shrub and herbaceous species and functional groups. Herbaceous functional groups were an early-season bunchgrass (one species, Sandberg bluegrass [*Poa secunda* J. Presl]), tall perennial bunchgrasses, perennial forbs, annual grass (one species, cheatgrass [*Bromus tectorum* L.]), and annual forbs. Tall perennial bunchgrass, Sandberg bluegrass, and perennial forb cover and density did not differ among the treatments but did decrease over time in all treatments. The cover of several tall bunchgrass species was generally less in the high treatment, mainly, Idaho fescue (*Festuca idahoensis* Elmer) and Thurber's needlegrass (*Achnatherum thurberianum* (Piper) Barkworth). The cover of cheatgrass and annual forbs varied among years but was greater in the burned-grazed and nonuse treatments than in the control. Native plant cover in the burned treatments (grazed and nonuse) represented 77%–85% of total herbaceous cover versus the control where native plants comprised 91% of the total. Annual weather variability appears to account for most of the compositional dynamics measured in the various grazed and ungrazed treatments.

KEYWORDS
cheatgrass, deferred rotation, grazing utilization, Great Basin, prescribed fire, stocking rate, Wyoming big sagebrush

This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.
Published 2023. This article is a U.S. Government work and is in the public domain in the USA. *Ecosphere* published by Wiley Periodicals LLC on behalf of The Ecological Society of America.

INTRODUCTION

Plant community composition is regulated by a number of interacting abiotic and biotic factors. In the big sagebrush (*Artemisia tridentata*) steppe of the Great Basin, USA, the main drivers of compositional changes are fire, annual and multiyear weather patterns, invasive species, and grazing (Anderson & Inouye, 2001; Dalgleish et al., 2010; Mack & Thompson, 1982; Pilliod et al., 2017; West & Yorks, 2002). In addition, long-term climate change since the glacial period has caused major landscape shifts in plant communities as well as northward migration of species (Mehringer & Wigand, 1990; Thompson, 1990). Prior to the Euro-American settlement of the region, plant community composition was mainly influenced by fire, weather patterns, and grazing by native herbivores (Griffin, 2002; Janis et al., 2000; Mensing, 2001; Minckley et al., 2007). Following the settlement of the region, which began in the mid-1800s, the introduction of domestic livestock and exotic annual grasses altered significant portions of the Great Basin, causing widespread rangeland degradation, which contributed to large areas being converted to dominance by annual grasses (Daubenmire, 1970; Dyksterhuis, 1958; Griffiths, 1902; Knapp, 1996; Sampson, 1919; Young, 2000). Annual grass, mainly cheatgrass (*Bromus tectorum* L.), has altered fire regimes in many areas by creating more continuous fuels and causing fires to begin earlier in the summer than the historic fire regime, to the detriment of native plant communities (Brooks et al., 2004; Pilliod et al., 2017; Reisner et al., 2013; Rowland & Wisdom, 2005). However, since the mid-1900s, many degraded sagebrush steppe rangelands have recovered because of reduced grazing pressure and adoption of grazing schemes appropriate for the sagebrush steppe, often involving various systems comprised of deferred and rest rotation (Copeland et al., 2021; Courtois et al., 2004; Davies et al., 2018; Sampson, 1951a, 1951b; Sneva et al., 1984; West & Yorks, 2002; Young, 2000).

The sagebrush steppe has recently undergone more frequent and larger fires than experienced historically, occurring in both intact native and invasive annual grass-dominated systems (Keane et al., 2008; Pilliod et al., 2017; Smith et al., 2022). For many years, rest has been recommended following fire on burned rangelands. On federally managed rangelands, a minimum of 2 years of rest is often required (Bureau of Land Management, 2007; USDA Forest Service, 2006). This can adversely affect livestock producer's dependence on federal lands for grazing their stock. Consequently, in the past two decades, several research efforts have focused on postfire grazing in sagebrush steppe. By and large, vegetation recovery following fire was not affected when compared with ungrazed controls under light to moderate intensity/utilization in Wyoming (*A. tridentata* spp. *wyomingensis* [Rydb.] Beetle) and mountain big sagebrush (*A. tridentata* spp. *vaseyana* [Rydb.] Beetle) communities (Bates et al., 2009; Bates & Davies, 2014; Bruce et al., 2007; Clark et al., 2016, 2018; Roselle et al., 2010; West & Yorks, 2002). Similar results are reported from the northern mixed prairie, central Great Plains, and forested rangelands (Augustine et al., 2010; Fuhlendorf & Engle, 2004; Kerns et al., 2011; Russell et al., 2013; Vermeire et al., 2014, 2018; Williams, Vermeire, et al., 2022). Perennial bunchgrass cover and yield were reduced after five years of high stocking/utilization, although herbaceous composition was largely unaffected after fire in Wyoming big sagebrush steppe (Bates & Davies, 2014).

Postfire grazing studies in sagebrush steppe have mostly evaluated short-term plant community response. In a 20-year study, West and Yorks (2002) recorded no major differences in vegetation composition following fire between grazed and ungrazed sagebrush steppe. Unfortunately, they were unable to provide a record of stocking rates, utilization, or intensity, making it difficult to critically evaluate and compare grazing impacts. The lack of detailed long-term grazing studies applying various stocking rates is potentially problematic as short-term research may not provide the time span necessary for detecting compositional changes. Population dynamics of sagebrush steppe species are highly influenced by annual climatic variation. Grazing pressure has the potential to disrupt important life cycle stages such as seed production of perennial bunchgrasses (Bates et al., 2009). Because perennial bunchgrasses, on average, turn over their population every 10 years (Lauenroth & Adler, 2008; Svejcar et al., 2014; West et al., 1979), grazing studies probably require at least a decade of observation to ascertain compositional changes in sagebrush steppe.

In this study, we evaluated different grazing intensities (light, moderate, high) by cattle and the impacts on plant community composition 20 years after fire. In two earlier studies on the same site, we concluded that: (1) light to moderate grazing 1–3 years after prescribed fire did not hamper recovery of the herbaceous plant community (Bates et al., 2009); and (2) as described previously, vegetation cover, density, and yield did not differ among low and moderate grazing use and nonuse areas; however, high grazing use resulted in lower cover and yield of perennial bunchgrasses (Bates & Davies, 2014). Our hypotheses were that: (1) herbaceous cover and density on light and moderate grazing intensities would not differ from ungrazed burned areas and (2) high grazing intensity would limit or reduce native herbaceous cover and density and increase non-native annual species. In addition, a recent work has shown that grazing of herbaceous vegetation enhances sagebrush recovery as sagebrush cover was twofold greater in grazed than in

non-grazed areas (Davies et al., 2020). Thus, we hypothesized that sagebrush recovery would be greater in grazed treatments, particularly at high grazing intensity, than in the ungrazed burned treatment.

METHODS

Study area

The study was located at the Northern Great Basin Experimental Range (lat 43°29′ N, long 119°43′ W), 56 km west of Burns, Oregon, USA. Elevation at the site is 1400 m and the slope is less than 2%. The study site was a complex of two ecological sites: Sandy Loam (10–12 PZ) and Droughty Loam (11–13 PZ) (NRCS, 2010). Soils are Durixerolls with loamy-sand textures and are well drained with a duripan at depths between 40 and 60 cm (Lentz & Simonson, 1986). Crop year (September–August) precipitation has averaged 280 mm in the past 30 years (1992–2022), although the past 16 years (2007–2022) of crop year precipitation averaged 255 mm annually. Precipitation distribution during the study was 21% in the fall, 33% in the winter, 33% in the spring, and 13% in the summer. Ten of the 16 years were below average in crop year precipitation (<90%), of which 5 years were considered to be in drought (<75% of average; Figure 1).

Wyoming big sagebrush was the dominant shrub, with canopy cover averaging 11.7 ± 0.6% prior to burning (2002) and 1.0 ± 0.2% five years (2006) postfire in burned treatments (Bates et al., 2009). The understory was co-dominated by three tall perennial bunchgrasses: Idaho fescue (*Festuca idahoensis* Elmer), Thurber's needlegrass (*Achnatherum thurberianum* (Piper) Barkworth), and bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) Á. Löve). Prairie Junegrass (*Koeleria macrantha* (Ledeb.) J.A. Schultes), needle-and-thread (*Hesperostipa comata* (Trin. & Rupr.) Barkworth), bottlebrush squirreltail (*Elymus elymoides* (Raf.) Swezey), and Sandberg bluegrass (*Poa secunda* J. Presl) were subordinate bunchgrasses.

Prescribed burning, using a gel-fuel terra torch (Firecon, Ontario, OR, USA), was carried out in late September and early October 2002, as described in Bates et al. (2009). Except for associated burned and unburned control plots, other burned plots were grazed by cattle at light to moderate utilization (25%–50%) between 2003 and 2005, to evaluate the effects of timing of grazing on vegetation recovery following fire (Bates et al., 2009). The recovery of herbaceous cover, density, and production did not differ among burned-grazed treatments and burned controls, indicating that light to moderate grazing intensity did not hinder herbaceous plant recovery (Bates et al., 2009). Prior to the implementation of the present study in 2007, the burned plots (previously grazed and nonuse) did not differ from each other in (1) cover and density of herbaceous and shrub species and (2) herbaceous standing crop and yield. The burned plots (grazed and nonuse) were greater in herbaceous cover, standing crop, and production, and had lower

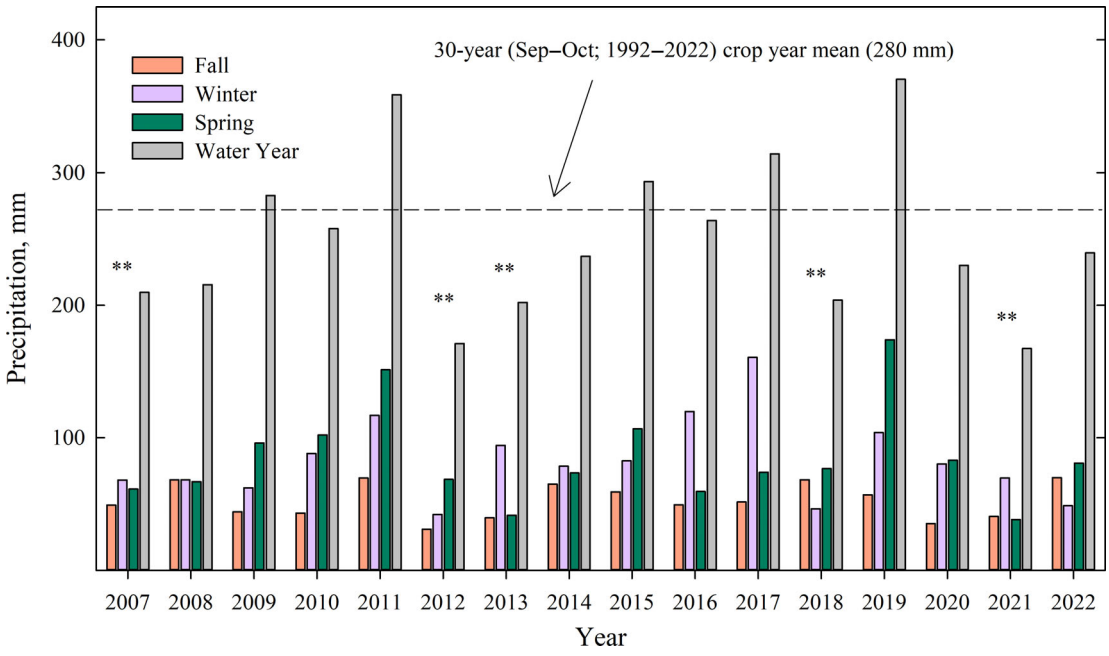


FIGURE 1 Fall (Sep–Nov), winter (Dec–Feb), spring (Mar–May), and crop year (Sep 1–Aug 31) precipitation from 2007 to 2022 at the Northern Great Basin Experimental Range, Oregon, USA. Drought years (<75% of crop year mean) are indicated by two asterisks.

shrub cover than unburned controls. All grazed plots in the 2003–2005 cycle had been rested in 2006 and through the active growing season (April–July) prior to summer dormancy in 2007.

Experimental design

The effects of grazing intensity on postfire vegetation dynamics and recovery were evaluated over 16 years (2007–2022). Twenty-two 2.1-ha plots, first established in 2001 (Bates et al., 2009), were randomly assigned different treatments in a randomized complete block design: Treatments included no grazing on burned (nonuse, $n = 5$) and unburned (control, $n = 5$) sagebrush steppe; and cattle grazing at low (low, $n = 4$), moderate (moderate, $n = 4$), and high (high, $n = 4$) intensities on burned sagebrush steppe:

1. Light intensity: 15%–30% utilization equivalent to a stocking rate of 0.051 ± 0.002 ha AUM^{-1} (0.125 ± 0.008 acre AUM^{-1}; AUM, animal unit equivalent) depending on the year and available forage (Table 1).
2. Moderate intensity: 40%–55% utilization equivalent to a stocking rate of $0.096 + 0.006$ ha AUM^{-1} (0.238 ± 0.015 acre AUM^{-1}).
3. High intensity: 60%–75% utilization equivalent to a stocking rate of $0.158 + 0.081$ ha AUM^{-1} (0.390 ± 0.020 acre AUM^{-1}).

All treatments were grazed by deferred rotation interspersed with rest years for vegetation measurements (Table 1). The deferred rotation we developed used the criteria suggested by Guinn (1994) for grazing of native, cool season bunchgrasses. This rotation generally consisted of grazing during the active growing season (mid-May–early June) once every three years followed by two years of grazing during summer dormancy (July–September). Grazing rotation is recommended for sagebrush steppe (Anderson, 1967; Burkhardt & Sanders, 2012; Guinn, 1994), as consecutive years of grazing or defoliation in the spring (late April–early June) reduce bunchgrass cover and forage yield (Ganskopp, 1988; Hyder & Sawyer, 1951).

During spring grazing periods (May–mid-June), when plants were growing, we used height–mass tables to assist in estimating utilization in the treatments (Eastern Oregon Agricultural Research Center, file data; Heady, 1949; Lommasson & Jensen, 1943) as well as visual methods described in Anderson and Currier (1973). This procedure was done because clipping for utilization in the spring often results in underestimating utilization because plants are continuing to grow (Bates et al., 2009; Burkhardt & Sanders, 2012). Utilization in July, August, and September, after herbaceous plants have stopped growing, was estimated as in the spring and infrequently, for calibration purposes, by clipping standing crop prior to cattle turnout and after cattle removal.

Vegetation measurements and analysis

Vegetation sampling took place in mid-June 2007, 2012, and 2022. Six permanent 50-m transects, marked by re-bar stakes, were randomly positioned within plots in 2001 (Bates et al., 2009). Herbaceous canopy cover, bare ground/rock, biological crust (moss and lichen), and litter and herbaceous perennial densities were visually estimated inside 40 × 50-cm frames (0.2 m^2) at 3-m intervals on each transect line. Herbaceous species richness was estimated by recording species presence for a 10-min period per plot. Shrub canopy cover was measured by line intercept (Canfield, 1941) and shrub density by belt transect along each 50-m transect. Belt transects were 2 m wide (1 m on each side of the transect line).

Repeated measures using the PROC MIXED procedure (SAS 9.4) for a randomized complete block design was used to test year, treatment, and year-by-treatment effects on herbaceous functional groups and species (canopy cover, perennial density, richness) and shrubs (cover and density). Plant functional groups were early-season bunchgrasses, tall perennial bunchgrasses, perennial forbs, cheatgrass, and annual forbs (Table 1). Early-season bunchgrasses were represented by one species, Sandberg bluegrass (*P. secunda* J. Presl). Sandberg bluegrass was collected separately from tall perennial bunchgrasses because it initiates growth and matures earlier in the spring (Passey et al., 1982; USDA Forest Service, 1937). An auto-regressive order one covariance structure was used because it provided the best fit for analysis (Littell et al., 1996). Mean separation involved the comparison of least squares using the LSMEANS statement. Statistical significance of all tests was $p < 0.05$.

RESULTS

Shrubs

The cover of Wyoming big sagebrush was 6.6 times greater in the control ($9.9 \pm 0.9\%$) than in the burned nonuse and three grazed treatments ($p < 0.001$). Collectively, sagebrush cover increased since 2007 ($p = 0.013$) in the burn treatments, and by 2021, it averaged $1.5 \pm 0.2\%$. Sagebrush density remained unchanged in all treatments since 2007 ($p = 0.583$), and density was greater ($p = 0.001$) in the

TABLE 1 Grazing season, periods, stock type, tall perennial bunchgrass phenology, and stocking rate, 2007–2022, Northern Great Basin Experimental Range, Riley, Oregon, USA.

Year	Grazing season, periods, and stock type	Tall perennial bunchgrass phenology	Stocking rate equivalent[a] (ha AUM^{-1})
2007	Early August: grazed 6–14 days; 4–6 dry cows/plot	Post seed shatter and summer dormancy	Light, 0.07–0.10; moderate, 0.16–0.18; high, 0.22–0.27
2008	Early May; grazed 3, 4–6, and 8–10 days for light, moderate, and high treatments, respectively; 3–5 cow–calf pairs per plot	Vegetative to early boot	Light, 0.04–0.050; moderate, 0.08–0.09; high, 0.13–0.18
2009	Mid-August; grazed 7–14 days; 3–5 dry cows/plot	Post seed shatter and summer dormancy	Light, 0.06–0.08; moderate, 0.10–0.12; high, 0.16–0.19
2010	Mid- to late June; grazed 4–12 days; 3–5 cow–calf pairs/plot	Flowering and soft dough stages	Light, 0.03–0.05; moderate, 0.06–0.11; high, 0.14–0.19
2011	Late July; grazed 5, 6–9, and 10–14 days for light, moderate, and high treatments, respectively; 3–5 dry cows/plot	Seed dispersal and summer dormancy	Light, 0.03–0.05; moderate, 0.06–0.12; high, 0.11–0.19
2012	Complete rest, no grazing		
2013	Early July; grazed 3, 8, and 14 days for light, moderate, and high treatments, respectively; 4 replacement heifers/plot	Hard dough and seed dispersal stages	Light, 0.05; moderate, 0.08; high, 0.12
2014	Mid-May; grazed 3, 6, and 10 days for light, moderate, and high treatments, respectively; 4–6 cow–calf pairs/plot	Vegetative to early boot	Light, 0.03; moderate, 0.08–0.09; high, 0.16
2015	Late June; grazed 3, 5, and 8 days for light, moderate, high treatments, respectively; 3–5 cow–calf pairs/plot	Hard dough to seed dispersal stages	Light, 0.03–0.04; moderate, 0.05–0.08; high, 0.11–0.13
2016	Late August; grazed 5, 8, and 13 days for light, moderate, and high treatments, respectively; 4–6 replacement heifers	Post seed shatter and summer dormancy	Light, 0.04–0.06; moderate, 0.07–0.11; high, 0.11–0.17
2017	Early June; grazed 5–14 days; 3–5 dry cows	Late flowering to seed ripening (soft dough) stages	Light, 0.04–0.06; moderate, 0.06–0.11; high, 0.12–0.160
2018	Early September; grazed 4–12 days; 3–5 cow–calf pairs/plot	Post seed shatter and summer dormancy	Light, 0.05–0.06; moderate, 0.09–0.13; high, 0.16–0.19
2019	Mid-August, grazed 4–5, 5–8, and 11–13 days for light, moderate, and high treatments, respectively; 4–6 replacement heifers/plot	Post seed shatter and summer dormancy	Light, 0.03–0.05; moderate, 0.08–0.13; high, 0.15–0.21
2020	Mid-May; grazed 3, 7, and 11 days for light, moderate, and high treatments, respectively; 4–6 cow–calf pairs/plot	Vegetative to early boot	Light, 0.04–0.06; moderate, 0.08–0.10; high, 0.11–0.16
2021	Mid-July, grazed 3, 5–6, and 8–10 days for light, moderate, and high treatments, respectively; 4–6 dry cows/plot	Post seed shatter and summer dormancy	Light, 0.04–0.05; moderate, 0.08–0.10; high, 0.12–0.18
2022	Complete rest, no grazing		

[a]To convert hectares to acres, multiply the stocking rate by 2.47105.

control (0.33 ± 0.02 plants m^{-2}) than in the burned treatments (0.04 ± 0.004 plants m^{-2}). Yellow rabbitbrush (*Chrysothamnus viscidiflorus* [Hook.] Nutt.) cover was 2- to 2.8-fold greater in burned treatments than in the control treatment ($p = 0.004$). Since 2007, rabbitbrush cover declined in all treatments by 50%–65% ($p < 0.001$). Rabbitbrush density has not changed and has remained 2.2- to 2.6-fold greater in the burned treatments (0.29–0.37 plants m^{-2}) compared with the control treatment ($p < 0.001$; 0.12 + 0.01 plants m^{-2}).

Tall perennial bunchgrass

Tall perennial bunchgrass canopy cover was not different among treatments ($p = 0.116$; Figure 2A) and decreased over time in all treatments between 2007 and 2022 (Figure 2A, $p < 0.001$). Tall bunchgrass cover averaged 14.6 ± 0.6%, 10.6 ± 0.6%, and 8.4 ± 0.5% in 2007, 2012, and 2022, respectively. There were several treatment differences among specific bunchgrass. Species that decreased were Idaho fescue ($p < 0.001$), Junegrass ($p < 0.001$), squirreltail ($p < 0.001$), and Thurber's needlegrass ($p < 0.001$). Much of the decrease in tall bunchgrass cover was because of a decline in Idaho fescue cover (34%–80%) between 2007 and 2022. The largest decline was in the high treatment, and consequently, Idaho fescue cover (1.2 ± 0.1%) was significantly less (1.4- to 2.8-fold) than in the other treatments and in the control in 2012 and 2022 ($p = 0.015$). Thurber's needlegrass cover in the high treatment (1.2 ± 0.1%) was significantly less (1.2- to 1.4-fold) than the light, nonuse, and control treatments in 2012 and 2022 ($p = 0.025$).

The density of tall bunchgrasses declined between 2012 and 2022 (Figure 2B, $p = 0.002$). Tall bunchgrass density averaged 9.0 ± 0.3 plants m^{-2}, 9.3 ± 0.3 plants m^{-2}, and 7.5 ± 0.3 plants m^{-2} in 2007, 2012, and 2022, respectively. Tall perennial bunchgrasses species that decreased across years were Idaho fescue ($p = 0.001$), Junegrass ($p = 0.001$), squirreltail ($p = 0.018$), and Thurber's needlegrass ($p = 0.005$). The density of tall bunchgrasses did not differ among treatments ($p = 0.940$), nor were there any treatment differences for specific bunchgrass species.

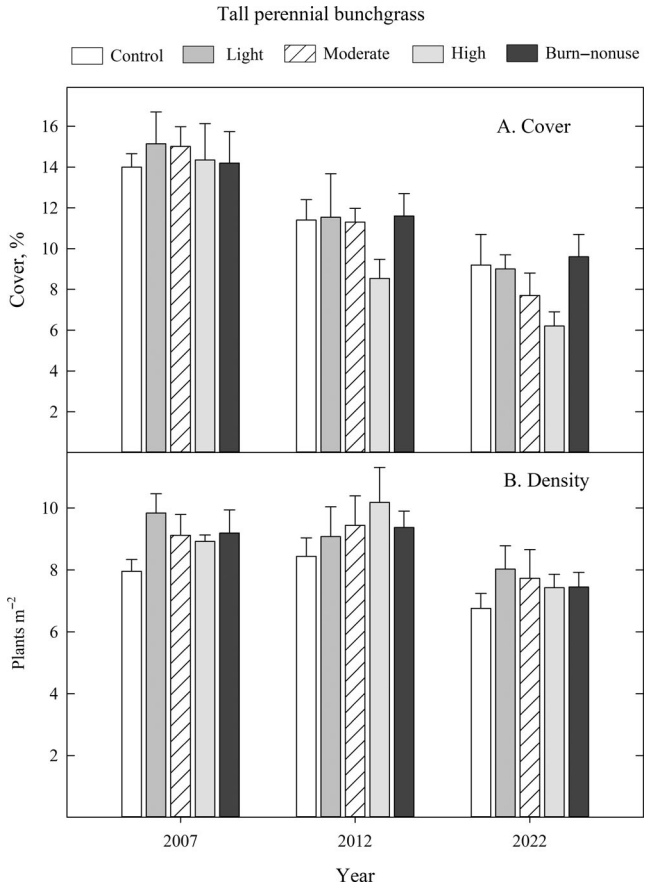


FIGURE 2 Tall perennial bunchgrass (A) canopy cover values and (B) density; Wyoming big sagebrush steppe, Northern Great Basin Experimental Range, Oregon, June 2007, 2012, and 2022. Bars represent means and 1 SE. Different lowercase letters indicate significant differences among the treatments within a year.

Sandberg bluegrass

Sandberg bluegrass canopy cover was not different among the treatments (Figure 3A, $p = 0.202$) and declined over time (Figure 3A, $p < 0.001$). In 2022, cover was about half (control, light, moderate, high) to one third (burn non-use) of 2007 values. The density of Sandberg bluegrass varied widely in all treatments (Figure 3B, $p < 0.001$), with higher values in 2012 than in 2007 and 2022.

Perennial forbs

There were no differences among the treatments for total perennial forb cover ($p = 0.051$) or density ($p = 0.122$). The canopy cover of perennial forbs across all treatments was 58%–73% lower in 2012 and 2022 than in 2007 (Figure 4A, $p < 0.001$). Perennial forb densities were 40%–50% lower in 2022 than in 2007 (Figure 4B, $p < 0.001$). The decline in forb cover and density during the time period was defined by three species: sicklepod milk-vetch (*Astragalus curvicarpus* [Sheld Macbr.]; [cover, $p < 0.001$; density, $p = 0.006$]), taper-tip hawksbeard (*Crepis acuminata* Nutt.; [cover, $p < 0.001$; density, $p = 0.001$]), and long-leaf phlox (*Phlox longifolia* Nutt.; [cover, $p < 0.001$; density, $p < 0.001$]).

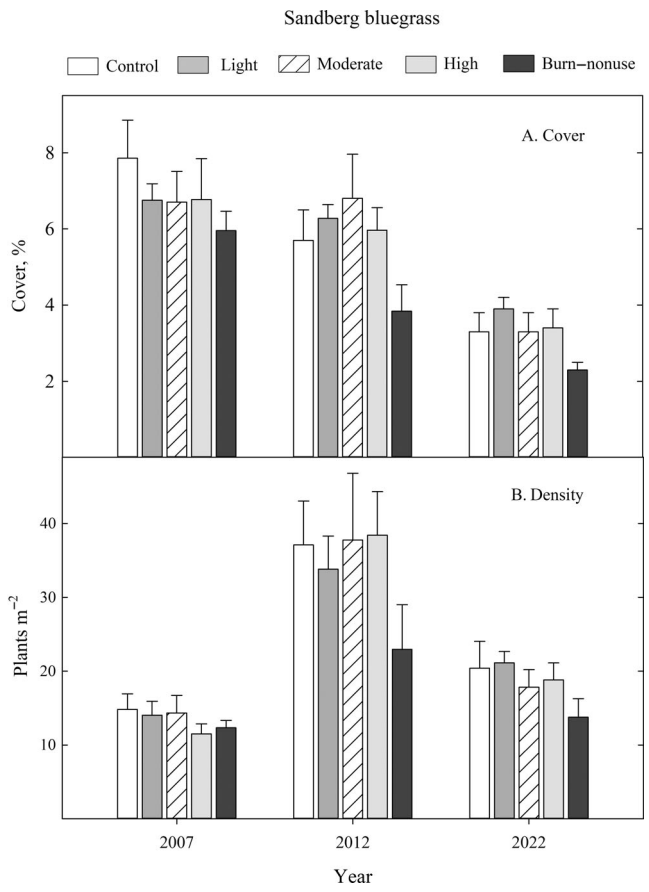


FIGURE 3 Sandberg bluegrass forb (A) canopy cover values and (B) density; Wyoming big sagebrush steppe, Northern Great Basin Experimental Range, Oregon, June 2007, 2012, and 2022. Bars represent means and 1 SE. Different lowercase letters indicate significant differences among the treatments within a year.

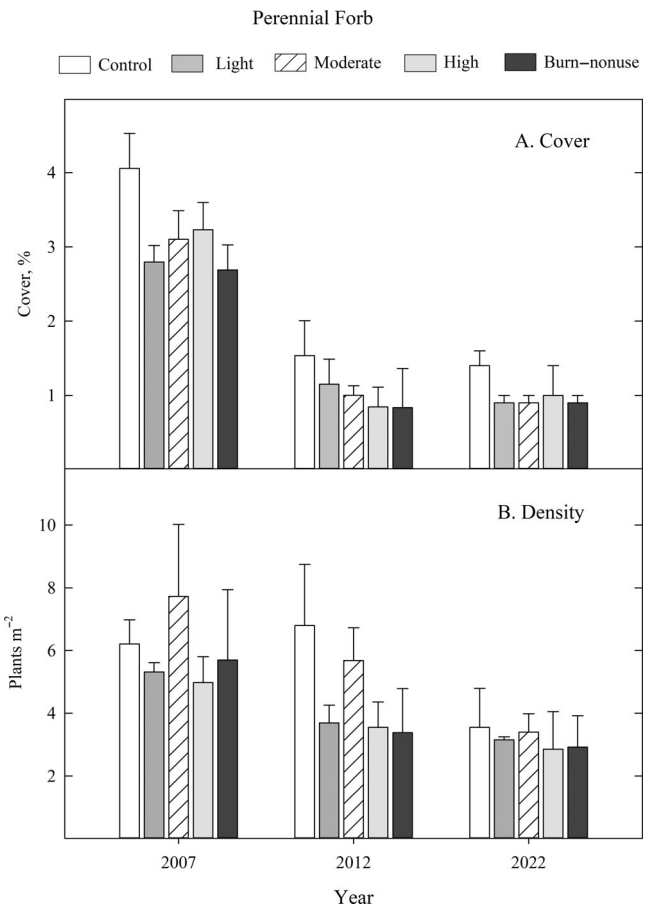


FIGURE 4 Perennial forb (A) canopy cover values and (B) density; Wyoming big sagebrush steppe, Northern Great Basin Experimental Range, Oregon, June 2007, 2012, and 2022. Bars represent means and 1 SE. Different lowercase letters indicate significant differences among the treatments within a year.

There were individual species differences among the treatments. Taper-tip hawksbeard was 2- to 3-fold greater in cover ($p = 0.002$; 0.28 + 0.05%) and 2- to 20-fold greater in density ($p = 0.016$; 0.44 + 0.11 plants m^{-2}), respectively, in the control than in other treatments in 2012 and 2022. Sicklepod milk-vetch density was twofold to ninefold greater ($p = 0.026$) in light, moderate, and high treatments (0.7–1.0 plants m^{-2}) than the nonuse and control (0.1–0.3 plants m^{-2}) in 2012 and 2022.

Cheatgrass and annual forbs

A year-by-treatment interaction indicated the cheatgrass cover was greater in the burned treatments (grazed and nonuse) than in the control treatments in 2022 ($p = 0.039$; Figure 5A). Cheatgrass cover in the control treatment ranged from nil to less than 0.2%, and in the burned (nonuse and grazed) treatments from nil to about 3%.

Annual forb canopy cover varied by year ($p < 0.001$), with cover greater in 2007 and 2022 than in 2012 (Figure 5B). The nonuse and grazing treatments all had higher cover overall than the control treatment ($p = 0.018$). The treatment differences were a result of greater cover of non-native pale alyssum (*Alyssum alyssoides* (L.) L.) in the nonuse and grazing treatments ($p < 0.018$). Pale alyssum comprised over 90% of annual forb cover. Native annual forb cover was only affected by year, including blue-eyed Mary (*Collinsia parviflora* Lindl., $p < 0.001$), tansy mustard (*Descurainia richardsonii* (Sweet) Schulz, $p = 0.002$), and Microsteris (*Microsteris gracilis* Hook., $p < 0.001$).

Other cover and species richness

Total herbaceous canopy cover did not differ among treatments ($p = 0.176$) and decreased across years (2007–2022) in all the treatments and the control

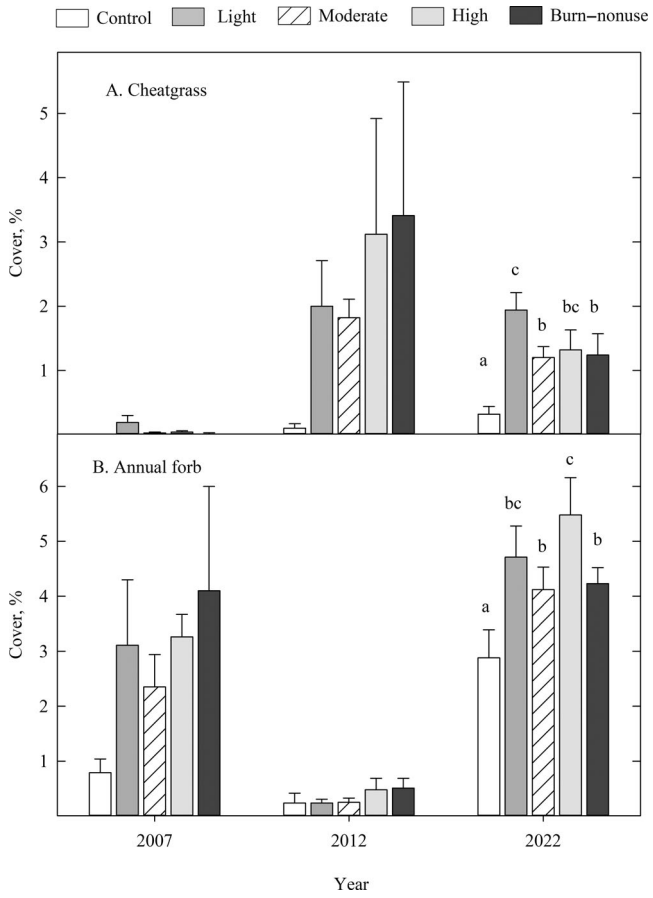


FIGURE 5 Canopy cover values for (A) cheatgrass and (B) annual forbs; Wyoming big sagebrush steppe, Northern Great Basin Experimental Range, Oregon, June 2007, 2012, and 2022. Bars represent means and 1 SE. Different lowercase letters indicate significant differences among the treatments within a year.

(Figure 6A; $p < 0.001$). Bare ground fluctuated across years ($p < 0.001$) and was slightly greater in the moderate and high treatments ($p = 0.008$; Figure 6B). Litter cover varied across years ($p < 0.001$) and by treatment ($p = 0.041$; Figure 6C). Overall litter cover was lowest in the moderate and high grazing treatments. Moss cover varied by year ($p = 0.026$) and treatment ($p < 0.001$; Figure 6D). Lichen cover varied by year ($p = 0.002$) and treatment ($p = 0.001$; Figure 6E). Both moss and lichen cover increased between 2007 and 2022 and, in all years, were greater in the control than in the nonuse and grazing treatments.

There was no difference in herbaceous species richness among the treatments ($p = 0.913$) or across years ($p = 0.724$). Herbaceous richness averaged 7.8 ± 0.7, 12.6 ± 0.3, 3.6 ± 1.1, and 2.7 ± 0.4 species for perennial grasses, perennial forbs, native annual forbs, and non-native annuals, respectively. Native species comprised 90% of the species recorded.

DISCUSSION

The deferred rotation grazing treatments (light, moderate, and high) implemented over a 15-year period had little to no impact on herbaceous cover, density, and richness in a Wyoming big sagebrush steppe community. Minor compositional changes among grazed and ungrazed treatments mirrored each other over time, indicating that interannual weather has a stronger impact than deferred rotation grazing (regardless of grazing intensity) on herbaceous dynamics in this system. Other compositional differences were a product of the lingering effects of the prescribed burn treatment implemented in 2002, which also suggests that fire had a greater long-term impact on composition than the grazing treatments.

Grazing impacts

We hypothesized that grazing at a high intensity (e.g., stocking rate) would reduce native herbaceous cover and density and increase non-native annual species. However, at the functional group level, there were no differences in cover, density, and composition across the grazing gradients and nonuse treatments. The lower cover of Idaho fescue and Thurber's needlegrass in the high treatment remained consistent, with measurements made in the early phase of this study (Bates & Davies, 2014). Others have reported that grazing of bunchgrass species within and across seasons of use can reduce their cover and production (France et al., 2008; Ganskopp, 1988; Jordan et al., 2022; Rickard et al., 1975; West & Yorks, 2002). However, because bunchgrass density was not affected, these species would likely recuperate their cover with grazing rest or by reducing stocking.

While there are examples that livestock grazing can alter herbaceous species composition or induce species replacement in grasslands (Adler et al., 2001; Anderson & Briske, 1995; Hutchings & Stewart, 1953; Knapp, 1996; Pickford, 1932), the accumulated evidence from the sagebrush steppe indicates that the system is resilient to grazing under current grazing practices that have been increasingly implemented since the mid-1900s. Similar to our results, Jordan et al. (2022) measured no difference in herbaceous species richness and composition across levels of grazing intensity at 17 big sagebrush steppe sites in Wyoming. Other studies in sagebrush steppe have measured little to no effect of light and moderate grazing compared with grazing exclusion on community structure and species composition (Copeland et al., 2021; Courtois et al., 2004; Davies et al., 2018; Holechek et al., 2006; Holechek & Stephenson, 1983; Veblen et al., 2015).

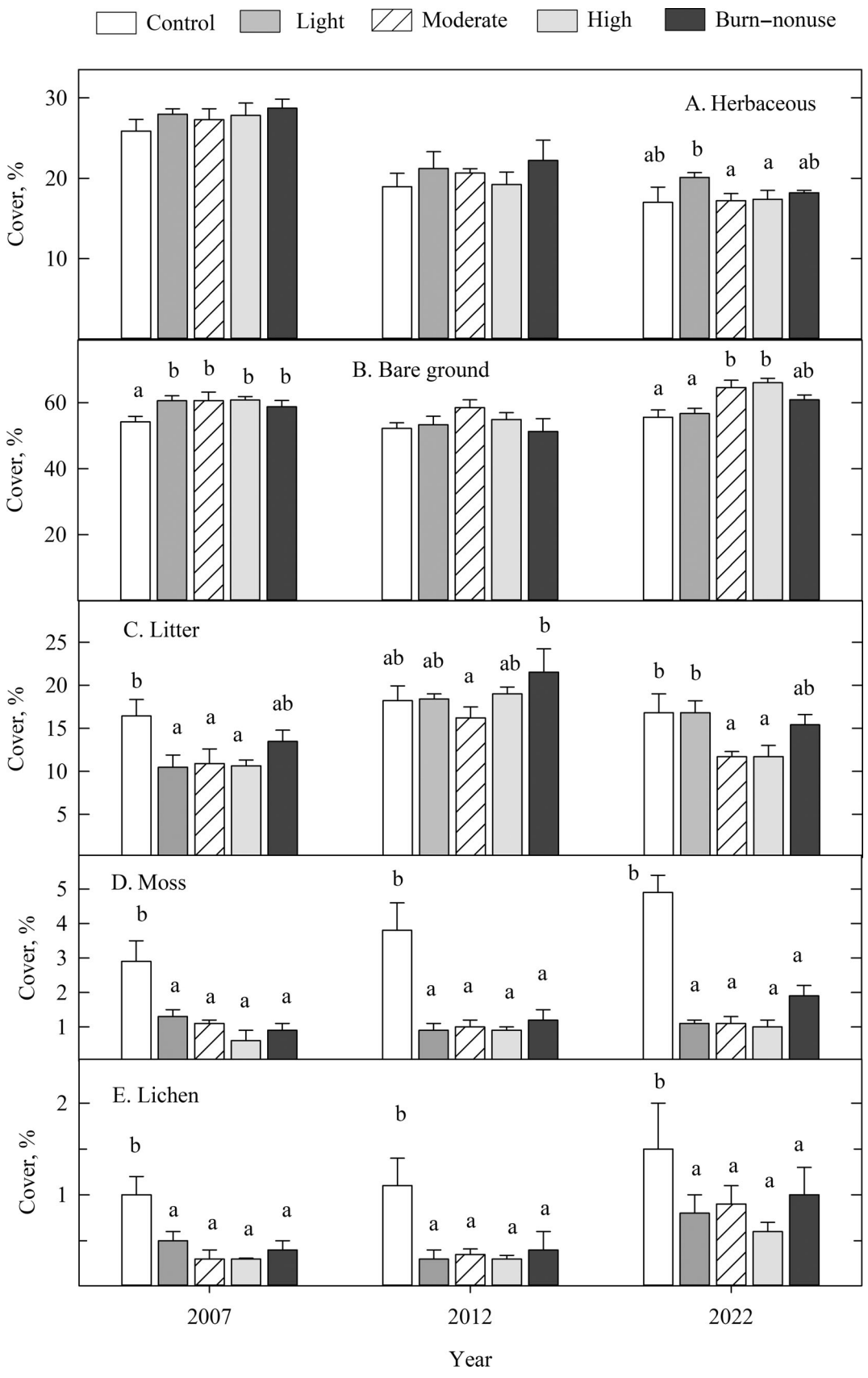


FIGURE 6 Canopy cover values for (A) total herbaceous, (B) bare ground, (C) litter, (D) moss, and (E) lichen; Wyoming big sagebrush steppe, Northern Great Basin Experimental Range, Oregon, June 2007, 2012, and 2022. Bars represent means and 1 SE. Different lowercase letters indicate significant differences among the treatments within a year.

Compositional changes

The declines in cover and density of perennial grass and forb species and the decrease in yellow rabbitbrush cover were the significant compositional changes spanning the 16-year study period.

The overall decrease in perennial grass and forb densities clearly indicates that the establishment of new individuals has diminished in the intervening years. The likely explanation for these changes is the current mega-drought affecting much of the Western United States that began in 2000 (Williams, Cook, & Smerdon, 2022). Since 2007, crop year precipitation at our study site has been, on average, 25 mm lower annually than the 30-year average (1992–2022). Drought is linked to significant mortality of perennial grasses and reducing recruitment of new plants (Hacker et al., 2006; Hodgkinson & Miller, 2005; O'Connor, 1994). Robins et al. (2013) determined that perennial grass establishment and persistence are difficult in areas averaging less than 310 mm of annual precipitation. Precipitation at our study site has averaged 255 mm annually since 2007. Thus, it is likely that this dry period has been a major cause for the measured decrease in perennial grass and forb cover and density and yellow rabbitbrush cover.

The presence of cheatgrass and pale alyssum, both exotic annuals, may also be interfering with the establishment of perennial grasses and forbs, especially in the grazed and ungrazed burn sites. The proportion of exotic annuals to total herbaceous cover increased from 10%–15% in 2012 to 25%–35% in 2022. Cheatgrass is highly competitive with perennial grass seedlings (Harris, 1967; Humphrey & Schupp, 2004), and this suppressive effect may be enhanced under drier soil conditions, especially when available soil nitrogen (N) levels are elevated (Larson et al., 2018). Available soil N was higher at this site during the first two years after fire (Davies et al., 2007). Information on the competitive abilities of pale alyssum is lacking, though another invasive annual alyssum (e.g., desert alyssum, *Alyssum desertorum* Stapf.) is mildly competitive with native annual forbs (Meyer-Morey, 2021).

Fire impacts

Persistent impacts of the fire treatment among the burn treatments (all grazed treatments and nonuse) and the control treatment included lower sagebrush cover and density, greater yellow rabbitbrush and herbaceous annual cover, and lower moss and lichen cover in the burn treatments.

After 20 years, sagebrush cover has remained low in the burn treatments. Sagebrush cover in the burn treatments (nonuse and all grazing treatments) was 10% of the control and contrary to expectations, sagebrush recovery was not enhanced in the grazing treatments. The slow postfire recovery of Wyoming big sagebrush is not unusual, and our results are similar to those of other studies. The cover of Wyoming big sagebrush was only 10% and 16% of that measured in associated unburned controls 14 and 18 years, respectively, after fire (Beck et al., 2009; Lesica et al., 2007; Wambolt & Payne, 1986). Recovery may have been hindered by the drier conditions that have persisted over the past 15 years. After fire, recovery of big sagebrush species is entirely dependent on establishment from seed (Tisdale & Hironaka, 1981). In most years, seed production in Wyoming big sagebrush communities is lacking because of low annual precipitation (Bates et al., 2005) and seedling recruitment is reliant on years with higher precipitation and snow cover (Cawker, 1980; Maier et al., 2001). There were only 3 years when winter precipitation was greater than average, which may, in part, explain the limited amount of sagebrush recruitment. Because sagebrush seed only persists in the soil seed bank for 1–4 years (Booth, 2002; Hassan & West, 1986; Young & Evans, 1975), establishment of new plants is problematic without favorable environmental conditions (Chambers, 2000). In addition, site occupancy by herbaceous plants also limits the establishment of sagebrush seedlings (Davies et al., 2017). In our study, the herbaceous community had recovered in the third year after fire. It was estimated that sagebrush recovery on our study site requires a minimum of 115 years (Bates et al., 2020).

Greater cover of yellow rabbitbrush cover in the burn treatments than in the control was expected, and until sagebrush recovers, yellow rabbitbrush will continue to provide the main overstory cover. Rabbitbrush species resprout easily and produce high amounts of seed, both factors that facilitate a rapid increase in cover and density following fire (Blaisdell, 1953; Tisdale & Hironaka, 1981).

Exotic annual forbs and cheatgrass cover were greater in the burn treatments than in the control treatment. Exotic annual increases after fire in Wyoming big sagebrush steppe is a common event and can persist for more than a decade even when native herbaceous composition remains largely intact (Ellsworth et al., 2016; Swanson et al., 2018; West & Yorks, 2002). The degree of postfire exotic annual composition is defined by the resilience of the native herbaceous plant community (Chambers et al., 2007, 2014). In only a few examples have native understories dominated postfire, with little exotic annual presence, in Wyoming big sagebrush communities (Bates et al., 2011; Swanson et al., 2018). In our study, the persistence of annuals and their increasing contribution to total herbaceous cover, we think, was largely the result of

the declines in herbaceous perennial cover and density as a result of drier conditions over the past 15 years. These results further reinforce observations that the presence of sagebrush in combination with intact native understories provides the most effective impediment to the expansion of invasive annuals (Chambers et al., 2014; Copeland et al., 2021; Davies et al., 2018).

Lichen and moss cover slowly recovered in the burn treatments but remained less than the control, and grazing had no effect on the recovery of moss and lichen. On other big sagebrush studies, lichens and mosses have not recovered 8–16 years after fire (Condon & Pyke, 2018; Hilty et al., 2004; Root et al., 2017; Warren et al., 2015). Moss cover has been the slowest to increase in the burn treatment and may require concurrent recovery of the sagebrush canopy. *Tortula ruralis* (Hedw.) G. Gaertn., B. Mey. & Scherb. (star moss) often comprises the bulk of biological crust in many sagebrush communities and primarily grows beneath sagebrush canopies (Bates et al., 2011).

IMPLICATIONS

This study demonstrated that properly applied deferred rotation grazing has limited long-term impact on herbaceous species composition of previously burned sagebrush steppe plant communities. We found that herbaceous recovery and composition, 20 years after fire, were largely unaffected by light, moderate, and high grazing intensities and utilization using a deferred rotation grazing scheme. Herbaceous composition was affected because of: (1) the impacts of long-term drought and (2) the persistent impacts of fire. Drier-than-normal weather in the past 16 years caused decreases in herbaceous perennial cover and density, resulting in exotic annuals contributing a greater proportion to overall herbaceous cover. Burned plots, whether grazed or not, had lower sagebrush cover, and greater rabbit brush and exotic annual cover than the control, indicating that fire has a greater effect on sagebrush steppe plant composition than deferred rotation grazing.

ACKNOWLEDGMENTS

We recognize many summer range technicians, 73 and counting, who assisted in the field and laboratory during the study. The research was supported by the USDA Agricultural Research Service (ARS), Oregon State University, and Eastern Oregon Agricultural Research Center. The Eastern Oregon Agricultural Research Center is jointly funded by the USDA-ARS and Oregon State Agricultural Experiment Station. Mention of a proprietary product does not constitute a guarantee or warranty of the product by USDA, Oregon State University, or the authors and does not imply approval to the exclusion of other products. USDA-ARS and Oregon State University are equal-opportunity providers and employers.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data (Bates, 2023) are available from Dryad: https://doi.org/10.5061/dryad.t1g1jwt7m.

REFERENCES

Adler, P., D. Raff, and W. Lauenroth. 2001. "The Effect of Grazing on the Spatial Heterogeneity of Vegetation." *Oecologia* 128: 465–479.

Anderson, E. W. 1967. "Rotation of Deferred Grazing." *Journal of Range Management* 20: 5–7.

Anderson, E. W., and W. F. Currier. 1973. "Evaluating Zones of Utilization." *Journal of Range Management* 26: 87–91.

Anderson, J. E., and R. S. Inouye. 2001. "Landscape-Scale Changes in Plant Species Abundance and Biodiversity of a Sagebrush Steppe over 45 Years." *Ecological Monographs* 71: 531–556.

Anderson, V. J., and D. D. Briske. 1995. "Herbivore-Induced Species Replacement in Grasslands: Is It Driven by Herbivory Tolerance or Avoidance?" *Ecological Applications* 5: 1014–24.

Augustine, D. J., J. D. Derner, and D. G. Milchunas. 2010. "Prescribed Fire, Grazing, and Herbaceous Plant Production in Shortgrass Steppe." *Rangeland Ecology & Management* 63: 317–323.

Bates, J. 2023. "Grazing Intensity Effects on Herbaceous Community Composition in Burned Sagebrush-Steppe." Dataset. Dryad. https://doi.org/10.5061/dryad.t1g1jwt7m.

Bates, J., T. Svejcar, R. Miller, and R. Angell. 2005. "The Effects of Precipitation Timing on Sagebrush Steppe Vegetation." *Journal of Aridland Environments* 64: 670–697.

Bates, J. D., and K. W. Davies. 2014. "Cattle Grazing and Vegetation Succession in Burned Sagebrush Steppe." *Rangeland Ecology & Management* 67: 412–422.

Bates, J. D., K. W. Davies, and C. S. Boyd. 2020. "Longer-Term Post-Fire Plant Succession on Wyoming Big Sagebrush Steppe." *International Journal of Wildland Fire* 29: 229–239.

Bates, J. D., E. C. Rhodes, and K. W. Davies. 2011. "Impacts of Fire on Sage-Grouse Habitat and Diet Resources." In *Proceedings of 16th Wildland Shrub Symposium, Logan, Utah, May 20-24 2010, Natural Resources and Environmental Issues*, Vol. 17, edited by T. Monaco, Article 15. 17 pp. Logan, UT: Natural Resource Library. http://digitalcommons.usu.edu/nrei/vol17/iss1/15.

Bates, J. D., E. C. Rhodes, K. W. Davies, and R. N. Sharp. 2009. "Post-Fire Succession in Big Sagebrush Steppe with Livestock Grazing." *Range Ecology and Management* 61: 98–110.

Beck, J. L., J. W. Connelly, and K. P. Reese. 2009. "Recovery of Greater Sage Grouse Habitat Features in Wyoming Big Sagebrush Flowing Prescribed Fire." *Restoration Ecology* 17: 393–403.

Blaisdell, J. P. 1953. *Ecological Effects of Planned Burning of Sagebrush-Grass Range on the Upper Snake River Plains*. Technical Bulletin 1075. Washington, DC: United States Department of Agriculture. 39 pp.

Booth, D. T. 2002. "Seed Longevity and Seeding Strategies Affect Sagebrush Revegetation." *Journal of Range Management* 55: 188–193.

Brooks, M. L., C. M. D'Antonio, D. M. Richardson, J. B. Grace, J. E. Keeley, J. M. DiTomaso, R. J. Hobbs, M. Pellant, and D. Pyke. 2004. "Effects of Invasive Alien Plants on Fire Regimes." *Bioscience* 54: 677–688.

Bruce, L. B., B. Perryman, K. Conley, and K. McAdoo. 2007. "Case Study: Grazing Management on Seeded and Unseeded Post Fire Public Rangelands." *The Professional Animal Scientist* 23: 285–290.

Bureau of Land Management. 2007. *H-1742-1 Burned Area Emergency Stabilization and Rehabilitation Handbook*. Washington, DC: Department of Interior.

Burkhardt, J. W., and K. Sanders. 2012. "Management of Growing-Season Grazing in the Sagebrush Steppe: A Science Review of Management Tools Appropriate for Managing Early-Growing-Season Grazing." *Rangelands* 34: 30–35.

Canfield, R. H. 1941. "Application of the Line Interception Methods in Sampling Range Vegetation." *Journal of Forestry* 39: 388–394.

Cawker, K. B. 1980. "Evidence of Climatic Control from Population Age Structure of *Artemisia tridentata* (Nutt.) in Southern British Columbia." *Journal of Biogeography* 7: 237–248.

Chambers, J. C. 2000. "Seed Movements and Seedlings Fates in Disturbed Sagebrush Steppe Ecosystems: Implications for Restoration." *Ecological Applications* 10: 1400–1413.

Chambers, J. C., B. A. Bradley, C. S. Brown, C. D'Antonio, M. J. Germino, J. B. Grace, S. P. Hardegree, R. F. Miller, and D. A. Pyke. 2014. "Resilience to Stress and Disturbance, and Resistance to *Bromus tectorum* L. Invasion in Cold Desert Shrublands of Western North America." *Ecosystems* 17: 360–375.

Chambers, J. C., B. A. Roundy, R. R. Blank, S. E. Meyer, and A. Whittaker. 2007. "What Makes Great Basin Sagebrush Ecosystems Invasible by *Bromus tectorum*?" *Ecological Monographs* 77: 117–145.

Clark, P. E., C. Jason Williams, P. R. Kormos, and F. B. Pierson. 2018. "Post-Fire Grazing Management Effects on Mesic Sagebrush-Steppe Vegetation: Mid-Summer Grazing." *Journal of Arid Environments* 151: 104–112.

Clark, P. E., C. J. Williams, F. B. Pierson, and S. P. Hardegree. 2016. "Post-Fire Grazing Management Effects on Mesic Sagebrush-Steppe Vegetation: Spring Grazing." *Journal of Arid Environments* 132: 49–59.

Condon, L. A., and D. A. Pyke. 2018. "Resiliency of Biological Soil Crusts and Vascular Plants Varies among Morphogroups with Disturbance Intensity." *Plant and Soil* 433: 271–287.

Copeland, S. M., K. W. Davies, C. S. Boyd, and J. D. Bates. 2021. "Recovery of the Herbaceous Component of Sagebrush Steppe Unimpeded by 75 Years of Moderate Cattle Grazing." *Ecosphere* 12(3): e03445. https://doi.org/10.1002/ecs2.3445e.

Courtois, D. R., B. L. Perryman, and H. S. Hussein. 2004. "Vegetation Change after 65 Years of Grazing and Grazing Exclusion." *Journal of Range Management* 57: 574–582.

Dalgleish, H. J., D. N. Koons, and P. B. Adler. 2010. "Can Life-History Traits Predict the Response of Forb Populations to Changes in Climate Variability?" *Journal of Ecology* 98: 209–217.

Daubenmire, R. 1970. "Steppe Vegetation of Washington." Washington Agricultural Experiment Station Technical Bulletin 62. 131 pp.

Davies, K. W., J. D. Bates, and C. S. Boyd. 2020. "Response of Planted Sagebrush Seedlings to Cattle Grazing Applied to Decrease Fire Probability." *Rangeland Ecology & Management* 73(5): 629–635.

Davies, K. W., J. D. Bates, and A. Hulet. 2017. "Attempting to Restore Mountain Big Sagebrush (*Artemisia tridentata* spp. *vaseyana*) Four Years after Fire." *Restoration Ecology* 25: 717–722.

Davies, K. W., J. D. Bates, and R. F. Miller. 2007. "Short-Term Effects of Burning Wyoming Big Sagebrush Steppe in Southeast Oregon." *Rangeland Ecology & Management* 60: 515–522.

Davies, K. W., C. S. Boyd, and J. D. Bates. 2018. "Eighty Years of Grazing by Cattle Modifies Sagebrush and Bunchgrass Structure." *Rangeland Ecology & Management* 71: 275–280.

Dyksterhuis, E. J. 1958. "Ecological Principles in Range Evaluation." *Botanical Review* 24: 253–272.

Ellsworth, L. M., D. W. Wrobleski, J. B. Kauffman, and S. A. Reis. 2016. "Ecosystem Resilience Is Evident 17 Years after Fire in Wyoming Big Sagebrush Ecosystems." *Ecosphere* 7(12): e01618. https://doi.org/10.1002/ecs2.1618.

France, K. A., D. C. Ganskopp, and C. S. Boyd. 2008. "Interspace/Undercanopy Foraging Patterns of Beef Cattle in Sagebrush Habitats." *Rangeland Ecology & Management* 61: 389–393.

Fuhlendorf, S. D., and D. M. Engle. 2004. "Application of the Fire-Grazing Interaction to Restore a Shifting Mosaic on Tallgrass Prairie." *Journal of Applied Ecology* 41: 604–614.

Ganskopp, D. 1988. "Defoliation of Thurber Needlegrass: Herbage and Root Response." *Journal of Range Management* 41: 472–76.

Griffin, D. 2002. "Prehistoric Human Impacts on Fire Regimes and Vegetation in the Northern Intermountain West." In *Fire, Native Peoples, and the Natural Landscape*, edited by T. R. Vale, 77–100. Washington, DC: Island Press.

Griffiths, D. 1902. "Forage Conditions on the Northern Border of the Great Basin: Being a Report upon Investigations Made during July and August, 1901, in the Region between Winnemucca, Nevada, and Ontario, Oregon." Bulletin No. 15. Washington, DC: U.S. Department of Agriculture, Bureau of Plant Industry. https://www.biodiversitylibrary.org/bibliography/65066.

Guinn, K. 1994. "Grazing Management Guidelines." Spokane, WA: USDA-Soil Conservation Service, Technical Notes, Range 34. http://county.wsu.edu/kittitas/nrs/forestry/Documents/WA-RANGE-TN34.pdf.

Hacker, R. B., K. C. Hodgkinson, G. J. Melville, J. Bean, and S. P. Clipperton. 2006. "Death Model for Tussock Perennial Grasses: Thresholds for Grazing-Induced Mortality of Mulga Mitchel Grass (*Thyridolepis micthelliana*)." *The Rangeland Journal* 28: 105–114.

Harris, G. A. 1967. "Some Competitive Relationships between *Agropyron spicatum* and *Bromus tectorum*." *Ecological Monographs* 37: 89–111.

Hassan, M. A., and N. E. West. 1986. "Dynamics of Burned and Unburned Sagebrush and Unburned Semi-Deserts." *Ecology* 67: 269–272.

Heady, H. F. 1949. "Methods of Determining Utilization of Range Forage." *Journal of Range Management* 2: 53–63.

Hilty, J. H., D. J. Elderidge, R. Rosentreter, M. C. Wicklow-Howard, and M. Pellant. 2004. "Recovery of Biological Crusts Following Wildfire." *Journal of Range Management* 57: 89–96.

Hodgkinson, K. C., and W. J. Miller. 2005. "Death Model for Tussock Perennial Grasses; a Rainfall Threshold for Survival and Evidence for Landscape Control of Death in Drought." *The Rangeland Journal* 27: 105–115.

Holechek, J. L., T. T. Baker, J. C. Boren, and D. Galt. 2006. "Grazing Impacts on Rangeland Vegetation: What We Have Learned Livestock Grazing at Light-to-Moderate Intensities Can Have Positive Impacts on Rangeland Vegetation in Arid-to-Semiarid Areas." *Rangelands* 28: 7–13.

Holechek, J. L., and T. Stephenson. 1983. "Comparison of Big Sagebrush Vegetation in North Central New Mexico under Moderately Grazed and Grazing Excluded Condition." *Journal of Range Management* 36: 455–57.

Humphrey, L. E., and E. W. Schupp. 2004. "Competition as a Barrier to Establishment of a Native Perennial Grass (*Elymus elymoides*) in Alien Annual Grass (*Bromus tectorum*) Communities." *Journal of Arid Environments* 58: 405–422.

Hutchings, S. S., and G. Stewart. 1953. "Increasing Forage Yields and Sheep Production on Intermountain Winter Ranges." U.S. Department of Agriculture Circular No. 925. https://www.biodiversitylibrary.org/item/130764#page/2/mode/1up.

Hyder, D. N., and W. A. Sawyer. 1951. "Rotation-Deferred Grazing as Compared with Season-Long Grazing on Sagebrush Bunchgrass Ranges in Oregon." *Journal of Range Management* 4: 30–34.

Janis, C. M., J. Damuth, and J. M. Theodor. 2000. "Miocene Ungulates and Terrestrial Primary Productivity: Where Have All the Browsers Gone?" *Proceedings of the National Academy of Sciences of the United States of America* 97: 7899–7904.

Jordan, S. E., K. A. Palmquist, I. C. Burke, and W. K. Lauenroth. 2022. "Small Effects of Livestock Grazing Intensification on Diversity, Abundance, and Composition in a Dryland Plant Community." *Ecological Applications* 32(8): e2693. https://doi.org/10.1002/eap.2693.

Keane, R. E., J. K. Agee, P. Fulé, J. E. Keeley, C. Key, S. G. Kitchen, R. Miller, and L. A. Schulte. 2008. "Ecological Effects of Large Fires on US Landscapes: Benefit or Catastrophe?" *International Journal of Wildland Fire* 17: 696–712.

Kerns, B. K., M. Buonopane, W. G. Thies, and C. Niwa. 2011. "Reintroducing Fire into a Ponderosa Pine Forest with and without Cattle Grazing: Understory Vegetation Response." *Ecosphere* 2: 1–23.

Knapp, P. A. 1996. "Cheatgrass (*Bromus tectorum* L.) Dominance in the Great Basin Desert: History, Persistence, and Influences to Human Activities." *Global Environmental Change* 6: 37–52.

Larson, C. D., E. A. Lehnhoff, C. Noffsinger, and L. J. Rew. 2018. "Competition between Cheatgrass and Bluebunch Wheatgrass Is Altered by Temperature, Resource Availability, and Atmospheric CO_2 Concentration." *Oecologia* 186: 855–868.

Lauenroth, W. K., and P. B. Adler. 2008. "Demography of Perennial Grassland Plants: Survival, Life Expectancy and Life Span." *Journal of Ecology* 96: 1023–32.

Lentz, R. D., and G. H. Simonson. 1986. *A Detailed Soils Inventory and Associated Vegetation of Squaw Butte Range Experiment Station*. Oregon Agricultural Experiment Station Special Report 760. Corvallis, OR: Oregon State University.

Lesica, P., S. V. Cooper, and G. Kudray. 2007. "Recovery of Big Sagebrush Following Fire in Southwest Montana." *Rangeland Ecology & Management* 60: 261–69.

Littell, R. C., G. A. Milliken, W. W. Stroup, and R. D. Wolfinger. 1996. *SAS System for Mixed Models*. Cary, NC: SAS Institute Inc.

Lommasson, T., and C. Jensen. 1943. "Determining Utilization of Range Grasses from Height-Weight Tables." *Journal of Forestry* 41: 589–593.

Mack, R. N., and J. N. Thompson. 1982. "Evolution in Steppe with Few Large Hooved Animals." *American Naturalist* 119: 757–773.

Maier, A. M., B. L. Perryman, R. A. Olson, and A. L. Hild. 2001. "Climatic Influences on Recruitment of 3 Subspecies of *Artemisia tridentata*." *Journal of Range Management* 54: 699–703.

Mehringer, P. J., Jr., and P. E. Wigand. 1990. "Comparison of Late Holocene Environments from Woodrat Middens and Pollen." In *Packrat Middens: The Last 40,000 Years of Biotic Change*, edited by J. L. Betancourt, T. R. VanDevender, and P. S. Martin, 294–325. Tucson, AZ: University of Arizona Press.

Mensing, S. A. 2001. "Late-Glacial and Early Holocene Vegetation and Climate Change Near Owens Lake, Eastern California." *Quaternary Research* 55: 57–65.

Meyer-Morey, J. 2021. "Impacts of a Non-Native Forb, *Alyssum desertorum* Stapf., and Non-Target Effects of Indaziflam in the Sagebrush Steppe of Yellowstone National Park." MS thesis, Montana State University. 112 pp.

Minckley, T. A., C. Whitlock, and P. J. Bartlein. 2007. "Vegetation, Fire, and Climate History of the Northwestern Great Basin during the Last 14,000 Years." *Quaternary Science Reviews* 26: 2167–84.

Natural Resource Conservation Service (NRCS). 2010. *Ecological Site Description*. Washington, DC: United States Department of Agriculture. http://esis.sc.egov.usda.gov/Welcome/pgApprovedSelect.aspx?type=ESD.

O'Connor, T. G. 1994. "Compositional Response of African Savanna Grassland to Rainfall and Grazing." *Journal of Ecology* 31: 155–171.

Passey, H. B., V. K. Hugie, E. W. Williams, and D. E. Ball. 1982. *Relationships between Soil, Plant Community, and Climate on Rangelands of the Intermountain West*. Washington, DC: U.S. Department of Agriculture Soil Conservation Service. Technical Bulletin 1662. 52 pp.

Pickford, G. D. 1932. "The Influence of Continued Heavy Grazing and of Promiscuous Burning on Spring-Fall Ranges in Utah." *Ecology* 13: 159–171.

Pilliod, D. S., J. L. Welty, and R. S. Arkle. 2017. "Refining the Cheatgrass–Fire Cycle in the Great Basin: Precipitation Timing and Fine Fuel Composition Predict Wildfire Trends." *Ecology and Evolution* 7: 8126–51.

Reisner, M. D., J. B. Grace, D. A. Pyke, and P. A. Doescher. 2013. "Conditions Favoring *Bromuus tectorum* Dominance of Endangered Sagebrush Steppe Ecosystems." *Journal of Applied Ecology* 50: 1039–49.

Rickard, W. H., D. W. Uresk, and J. F. Cline. 1975. "Impact of Cattle Grazing on Three Perennial Grasses in South-Central Washington." *Journal of Range Management* 28: 108–112.

Robins, J. G., K. B. Jensen, T. A. Jones, B. L. Waldron, M. D. Peel, C. W. Rigby, K. P. Vogel, R. B. Mitchell, A. J. Palazzo, and T. J. Cary Robins. 2013. "Stand Establishment and Persistence of Perennial Cool-Season Grasses in the Intermountain West and the Central and Northern Great Plains." *Rangeland Ecology & Management* 66: 181–190.

Root, H. T., J. C. Brinda, and E. K. Dodson. 2017. "Recovery of Biological Soil Crust Richness and Cover 12–16 Years after Wildfires in Idaho, USA." *Biogeosciences* 14: 3957–69.

Roselle, L., S. S. Seefeldt, and K. Launchbaugh. 2010. "Delaying Sheep Grazing after Wildfire in Sagebrush Steppe May Not Affect Vegetation Recovery." *International Journal of Wildland Fire* 19: 115–122.

Rowland, M. M., and M. J. Wisdom. 2005. "The Great Basin at Risk." In *Habitat Threats in the Sagebrush Ecosystem*, edited by M. J. Wisdom, M. M. Rowland, and L. H. Suring, 83–93. Lawrence, KS: Alliance Communications Group.

Russell, M. L., L. T. Vermeire, N. A. Dufek, and D. J. Strong. 2013. "Fire, Defoliation, and Competing Species Alter *Aristida purpurea* Biomass, Tiller, and Axillary Bud Production." *Rangeland Ecology & Management* 66: 290–96.

Sampson, A. W. 1919. "Plant Succession in Relation to Range Management." United States Department of Agriculture, Bulletin No. 791. 76 pp. https://ucanr.edu/sites/UCCE_LR/files/180448.pdf.

Sampson, A. W. 1951a. "A Symposium on Rotation Grazing in North America." *Journal of Range Management* 4: 19–24.

Sampson, A. W. 1951b. *Range Management—Principles and Practices*. New York: John Wiley & Sons, Inc. 570 pp.

Smith, J. T., B. W. Allred, C. S. Boyd, K. W. Davies, M. O. Jones, A. R. Kleinhesselink, J. D. Maestas, and D. E. Naugle. 2022. "Where There's Smoke, There's Fuel: Dynamic Vegetation Data Improve Predictions of Wildfire Hazard in the Great Basin." *Rangeland Ecology & Management* 89: 20–32. https://doi.org/10.1016/j.rama.2022.07.005.

Sneva, F. A., L. R. Rittenhouse, P. T. Tueller, and P. Reece. 1984. "Changes in Protected and Grazed Sagebrush-Grass in Eastern Oregon, 1937 to 1974." Station Bulletin 663. Corvallis, OR: Oregon State Agricultural Experiment Station. 11 pp. http://oregonstate.edu/dept/EOARC/sites/default/files/publication/274.pdf.

Svejcar, T., J. James, S. Hardegree, and R. Sheley. 2014. "Incorporating Plant Mortality and Recruitment into Rangeland Management and Assessment." *Rangeland Ecology & Management* 67: 603–613.

Swanson, J. C., P. J. Murphy, S. R. Swanson, B. W. Schultz, and J. K. McAdoo. 2018. "Plant Community Factors Correlated with Wyoming Big Sagebrush Site Responses to Fire." *Rangeland Ecology & Management* 71: 67–76.

Thompson, R. S. 1990. "Late Quaternary Vegetation and Climate in the Great Basin." In *Packrat Middens: The Last 40,000 Years of Biotic Change*, edited by J. L. Betancourt, T. R. VanDevender, and P. S. Martin, 200–239. Tucson, AZ: University of Arizona Press.

Tisdale, E. W., and M. Hironaka. 1981. "The Sagebrush-Grass Region: A Review of the Ecological Literature." Bulletin No. 33. University of Idaho College of Forestry, Wildlife and Range Science. http://lib.uidaho.edu/digital/fwres/items/fwres169.html.

USDA Forest Service. 1937. *Range Plant Handbook*. Washington, DC: USDA Forest Service.

USDA Forest Service. 2006. "Interagency Burned Area Emergency Response Guidebook." Interpretation of Department of the Interior 620 DM 3 and USDA Forest Service Manual 2523. For the Emergency Stabilization of Federal and Tribal Trust Lands: 4.0. http://npshistory.com/publications/fire/interagency-baer-guidebook-2006.pdf.

Veblen, K. E., K. C. Nehring, C. M. Glone, and M. E. Ritchie. 2015. "Contrasting Effects of Different Mammalian Herbivores on Sagebrush Plant Communities." *PLoS One* 10(2): e0118016.

Vermeire, L. T., J. L. Crowder, and D. B. Wester. 2014. "Semiarid Rangeland Is Resilient to Summer Fire and Post-Fire Grazing Utilization." *Rangeland Ecology & Management* 67: 52–60.

Vermeire, L. T., D. J. Strong, and R. C. Waterman. 2018. "Grazing History Effects on Rangeland Biomass, Cover and Diversity Response to Fire and Grazing Utilization." *Rangeland Ecology & Management* 71: 770–75.

Wambolt, C. L., and G. F. Payne. 1986. "An 18-Year Comparison of Control Methods for Wyoming Big Sagebrush in Southwestern Montana." *Journal of Range Management* 39: 314–19.

Warren, S. D., L. L. S. Clair, J. R. Johansen, P. Kugrens, L. S. Baggett, and B. J. Bird. 2015. "Biological Soil Crust Response to Late Season Prescribed Fire in a Great Basin Juniper Woodland." *Rangeland Ecology & Management* 68: 241–47.

West, N. E., K. H. Rea, and R. O. Harniss. 1979. "Plant Demographics Studies in Sagebrush–Grass Communities of Southeastern Idaho." *Ecology* 60: 266–274.

West, N. E., and T. P. Yorks. 2002. "Vegetation Response Following Wildfire on Grazed and Ungrazed Sagebrush Semi-Desert." *Journal of Range Management* 55: 171–181.

Williams, A. P., B. I. Cook, and J. E. Smerdon. 2022. "Rapid Intensification of the Emerging Southwestern North American Megadrought in 2020-2021." *Nature Climate Change* 12: 232–34.

Williams, A. R., L. T. Vermeire, R. C. Waterman, and C. B. Marlow. 2022. "Grazing and Defoliation Timing Effects in Great Plains Ponderosa Pine Woodland Following a Large Summer Wildfire." *Forest Ecology and Management* 520: 120398.

Young, J. A. 2000. "Range Research in the Far Western United States: The First Generation." *Journal of Range Management* 53: 2–11.

Young, J. A., and R. A. Evans. 1975. "Germinability of Seed Reserves in a Big Sagebrush (*Artemesia tridentata*) Community." *Weed Science* 23: 358–364.

How to cite this article: Bates, Jonathan D., and Kirk W. Davies. 2023. "Grazing Intensity Effects on Herbaceous Community Composition in Burned Sagebrush Steppe." *Ecosphere* 14(10): e4671. https://doi.org/10.1002/ecs2.4671