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Abstract

There is limited information about the effects of cattle grazing to longer-term plant community composition and herbage production following fire in sagebrush steppe. This study evaluated vegetation response to cattle grazing over 7 yr (2007–2013) on burned Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis* [Beetle & Young] Welsh) steppe in eastern Oregon. Treatments, replicated four times and applied in a randomized complete block design, included no grazing on burned (nonuse) and unburned (control) sagebrush steppe; and cattle grazing at low (low), moderate (moderate), and high (high) stocking on burned sagebrush steppe. Vegetation dynamics were evaluated by quantifying herbaceous (canopy and basal cover, density, production, reproductive shoot weight) and shrub (canopy cover, density) response variables. Aside from basal cover, herbaceous canopy cover, production, and reproduction were not different among low, moderate, and nonuse treatments. Perennial bunchgrass basal cover was about 25% lower in the low and moderate treatments than the nonuse. Production, reproductive stem weight, and perennial grass basal cover were greater in the low, moderate, and nonuse treatments than the control. The high treatment had lower perennial bunchgrass cover (canopy and basal) and production than other grazed and nonuse treatments. Bunchgrass density remained unchanged in the high treatment, not differing from other treatments, and reproductive effort was comparable to the other treatments, indicating these areas are potentially recoverable by reducing stocking. Cover and production of *Bromus tectorum* L. (cheatgrass) did not differ among the grazed and nonuse treatments, though all were greater than the control. Cover and density of *A.t.* spp. *wyomingensis* did not differ among the burned grazed and nonuse treatments and were less than the control. We concluded that light to moderate stocking rates are compatible to sustainable grazing of burned sagebrush steppe rangelands.

Key Words: bunchgrass, fire, stocking rate, utilization, Wyoming big sagebrush

INTRODUCTION

Fire in rangeland systems has a long history of prescribed use from early hunter-gatherer societies to present day pastoralists and land managers (Pyne 1997). Prescribed reduces the abundance of shrubs and trees, enhancing biodiversity, and increasing yield and abundance of herbaceous species. Following fire, herbivory by ungulates can influence plant composition and succession (Harrison et al. 2003; Fuhlendorf and Engle 2004; Kerns et al. 2011). The interaction of fire and grazing often creates a mosaic of successional communities and increases spatial heterogeneity that supports a wider array of species across landscapes (Engle and Bidwell 2001; Fuhlendorf and Engle 2004; Collins and Smith 2006; Boakye et al. 2013). Despite these effects, herbaceous plant species in an array of rangelands, including semiarid grasslands (Guevara et al. 1999; Valone and Kelt 1999), tall and short grass prairie (Fuhlendorf and Engle 2004; Augustine et al. 2010; Russell et al. 2013), and big sagebrush (*Artemisia tridentata* Nutt.) steppe (West and Yorks 2002; Bruce et al. 2007; Bates et al. 2009; Roselle et al. 2010) are often resilient to postfire grazing. However, in the sagebrush steppe, resiliency of herbaceous species is likely to be dependent on timing, intensity, and duration of herbivory because several grazing (Pickford 1932; Drewa and Havstad 2001; Kerns et al. 2011; Reisner et al. 2013) and defoliation (Jirik and Bunting 1994; Bunting et al. 1998) studies indicate that herbaceous recovery may be set back or slowed by improper livestock use.

The sagebrush steppe is a major vegetation complex extending across 62 million ha in 11 states of the western United States and two provinces of southwestern Canada (Küchler 1970). Approximately 56% of the sagebrush steppe remains intact with the remaining 44% degraded or lost because of conifer encroachment, replacement by invasive annual grasses, and agricultural and urban development (West 1983; West and Young 2000; Rowland and Wisdom 2005; Schroeder et al. 2005). Unmanaged livestock grazing from the late 1800s through the mid-1900s is thought to have shifted a codominance of shrubs and herbaceous plant to dominance by shrubs, such as big sagebrush, and favored the expansion and understory dominance by exotic annual grasses, especially in the Wyoming big sagebrush (*A. t.* ssp. *wyomingensis* [Beetle & A. Young] S.L. Welsh) alliance (Dyksterhuis 1958; Daubenmire 1970; Mack 1981; Knapp 1996; Jones 2000). Dominance by annual grasses, particularly cheatgrass (*Bromus tectorum* L.), increases fire frequency, which prevents recovery of sagebrush and associated native species (Whisenant 1990; Brooks et al. 2004; Rowland and Wisdom 2005). Because cheatgrass is

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present even on largely intact undisturbed big sagebrush steppe (Davies et al. 2006; Davies and Bates 2010) appropriate grazing requires knowledgeable application on unburned and burned rangelands (Bruce et al. 2007; Burkhardt and Sanders 2012). Moderate grazing use often does not decrease abundance or productivity of native herbaceous plants on sagebrush steppe plant communities (Sneva et al. 1984; West et al. 1984; Courtois et al. 2004; Manier and Hobbs 2006) or inhibit their postfire recovery (Bruce et al. 2007; Bates et al. 2009; Roselle et al. 2010).

However, there is a lack of replicated grazing studies evaluating the effects of stocking rate on sagebrush steppe. In many studies, knowledge of the timing, intensity, and duration of grazing is lacking, making it difficult to critically evaluate and compare effects across studies. This is particularly of concern for making postfire grazing decisions where exotic annual grasses are present and may threaten sagebrush steppe recovery. Most postfire grazing studies have also measured short-term (< 5 yr) plant community response. This is problematic when evaluating rangelands where shrubs and trees are important ecosystem components and recovery of nonsprouting woody species may be a decadal process. In sagebrush steppe of the Intermountain region, recovery of nonsprouting big sagebrush varies by subspecies with estimated presettlement recovery periods of 15 yr to greater than 100 yr (Baker 2006; Miller and Heyerdahl 2008; Ziegenhagen and Miller 2009).

Determining the impacts of postfire grazing is important for developing approaches to successfully recover big sagebrush steppe plant communities. In an earlier study we evaluated herbaceous recovery of a Wyoming big sagebrush community as influenced by timing of grazing 1–3 yr after fire (Bates et al. 2009). This study concluded that light to moderate grazing following prescribed fire did not hamper recovery of the herbaceous plant community. In the present study, we evaluated different stocking levels (light, moderate, high) of cattle and the impacts to plant community dynamics on the same site 5–11 yr after the fire. Our hypotheses were 1) herbaceous cover, density, and production and shrub cover and density on light and moderate stocking rate treatments would not differ from ungrazed burned areas and 2) a high stocking rate treatment would limit or reduce native herbaceous cover and production, increase native and non-native annual species, and promote reestablishment of Wyoming big sagebrush and yellow rabbitbrush (*Chrysothamnus viscidiflorus* [Hook.] Nutt.).

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 1 400 m and the slope less than 2%. Wyoming big sagebrush was the dominant shrub with canopy cover averaging $11.7\% \pm 0.6\%$ prior to burning and $1.0\% \pm 0.2\%$ 5 yr (2007) postfire in burned treatments. Yellow rabbitbrush was a secondary shrub with cover averaging $3.3\% \pm 0.4\%$ prior to burning and $5.8\% \pm 0.9\%$ 5 yr (2007) after fire in burned areas. The

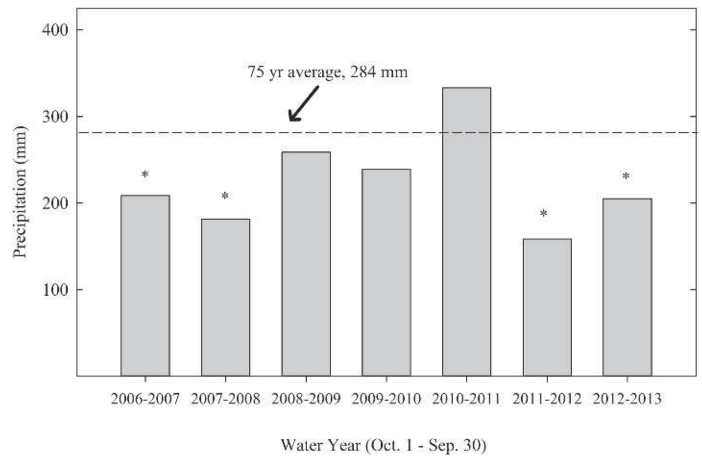

Figure 1. Water year (1 October–30 September) precipitation 2006–2013 at the Northern Great Basin Experimental Range (NGBER), Oregon, USA. Drought years are indicated by asterisks.

understory was codominated by the cool season 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), and bottlebrush squirreltail (*Elymus elymoides* [Raf.] Swezey) were subordinate bunchgrasses. Sandberg's bluegrass (*Poa secunda* J.Presl.) was the most common grass species but because of its small stature composed less than 15% of total standing crop (Bates et al. 2009). The composition of the plant communities and soil series fits two Ecological Site Descriptions: Sandy Loam (10-12PZ) and Droughty Loam (11-13PZ) (NRCS 2010). Soils are a complex of two series sharing several attributes; both are Durixerolls, surface texture is loamy sand, and both are well drained with a duripan at depths of 40–60 cm (Lentz and Simonson 1986). Crop year (October–September) precipitation has averaged 284 mm since the 1930s, and the majority falls between November and late May (Fig. 1). During the study period 6 yr of the 7 yr were below average in precipitation, of which 4 of the years were considered as drought ($< 75\%$ of average).

Prescribed burning, using a gel-fuel terra torch (Firecon, Ontario, OR, USA), was done in late September and early October 2002 and is 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). Recovery of herbaceous cover, density, and production did not differ among burned-grazed treatments and burned controls, indicating that light to moderate grazing did not retard herbaceous plant recovery (Bates et al. 2009). Prior to implementation of our new 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 shrub cover than unburned controls. All grazed plots in the 2003–2005 cycle had been rested in 2006 and through the active growing season in 2007 (April–July) prior to summer dormancy.

Experimental Design

The effects of cattle stocking rate on postfire vegetation dynamics and recovery were evaluated over 7 yr (2007–2013), spanning a period of 5 to 11 yr after fire. Four 12.6 ha blocks, first established in 2001 (Bates et al. 2009), consisted of five independent 2.1 ha plots, each of which was randomly assigned a different treatment:

A. Light Stocking (Light): 15–30% utilization equivalent to a stocking rate of 2.2 to 4.5 $ha \cdot AUM^{-1}$ (animal unit equivalent) depending on the year and available forage.
B. Moderate Stocking (Moderate): 30–50% utilization equivalent to a stocking rate of 1.3 to 2.2 $ha \cdot AUM^{-1}$.
C. High Stocking (High): 50–70% utilization equivalent to a stocking rate of 1.0 to 1.3 $ha \cdot AUM^{-1}$.
D. Sagebrush Control (Control): unburned and ungrazed sagebrush steppe.
E. Burn Nonuse (Nonuse): ungrazed, burned sagebrush steppe.

Each year stocking rate and grazing duration were based on available forage; indexed by clipping standing crop in 15 randomly located 1-m^2 frames prior to cattle turnout. Utilization was determined immediately after cattle exited, by harvesting standing crop in 15 randomly located 1-m^2 frames in each plot. During spring grazing periods, when plants were growing, we also used height–weight tables to assist in estimating utilization in the treatments (Lommasson and Jensen 1943; Heady 1949; Eastern Oregon Agricultural Research Center, file data). 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 and Sanders 2012). All treatments were grazed with the following rotation, animal class, and corresponding perennial bunchgrasses phenological stage:

2007: Early August, grazed 6–14 d by 4 to 6 dry cows per plot, and perennial bunchgrasses plants were dormant.
2008: Early May, grazed 3–10 d by 3 to 5 cow–calf pairs, and perennial bunchgrasses were in vegetative to early boot (prereproductive stem emergence).
2009: August, grazed 7–14 d by 3 to 5 dry cows, and perennial bunchgrasses were dormant.
2010: Mid- to late June, grazed 4–12 d by 3 to 5 cow–calf pairs, perennial bunchgrasses were flowering and in soft dough stages (early seed development).
2011: Late July, grazed 5–14 d by 3 to 5 dry cows, and perennial bunchgrasses were at seed dispersal and dormant stages.
2012: Rest and main response year to compare vegetation dynamics among the treatments.
2013: Early July 2013, grazed 4–14 d by 4 replacement heifers per plot, and perennial bunchgrasses were at hard dough (late seed development) to seed dispersal stages. Plots were grazed after gathering production data in June 2013.

The fewer number of days, as indicated above, would conform to light stocking and so on. Grazing rotation is used or recommended for sagebrush steppe (Burkhardt and Sanders 2012) because consecutive years of grazing or defoliation in the spring (late April–early June) reduces bunchgrass cover and forage yield (Hyder and Sawyer 1951; Ganskopp 1988). The rotation we developed used criteria suggested by Guinn (2009) for grazing of cool season bunchgrasses.

Vegetation Measurements

Herbaceous responses to treatments were evaluated by quantifying canopy cover, perennial grass basal cover, perennial density, standing crop, production, and reproductive stem weight. Sampling took place in mid-June pre- (2007) and post-grazing (2012 and 2013). Six permanent, 50-m transects marked by rebar stakes had been 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. Perennial herbaceous basal cover and shrub canopy cover were measured by line intercept (Canfield 1941) along each 50-m transect in 2007 and 2012. Shrub canopy gaps less than 15 cm were included in the shrub cover measurements (Boyd et al. 2007).

Standing crop biomass was determined for herbaceous lifeforms by clipping 15, 1-m^2 frames per treatment plot at peak production in early June 2007, 2012, and 2013. Lifeforms were *P. secunda*, perennial bunchgrasses (e.g., Idaho fescue, Thurber's needlegrass, and bluebunch wheatgrass), *B. tectorum*, perennial forbs, and annual forbs. Perennial bunchgrasses were clipped to 2-cm stubble height. *Poa secunda* and other functional groups were clipped to near ground level. Harvested herbage was dried at 48°C for 48 h prior to weighing. Production (current year's growth) was determined by separating current year's growth from standing crop for *P. secunda* and perennial bunchgrasses (Society for Range Management 1962). Ten 10–15 g subsamples of *P. secunda* and perennial bunchgrasses per treatment replication were separated into current year's growth and standing residual biomass (previous year's growth). The percentage of current year's growth was calculated by dividing current year's growth by standing crop. Standing crop values of *P. secunda* and perennial bunchgrasses were multiplied by the respective percentages of current year's growth to derive production. Perennial bunchgrass and *P. secunda* reproductive stalks were also separated from production to estimate reproductive biomass in 2012 and 2013. Standing crop of perennial forbs, annual forbs, and cheatgrass were equivalent to their current year's growth (production) and required no separations.

Statistical Analysis

Repeated measures using the PROC MIXED procedure (SAS Institute 2008) for a randomized complete block design was used to test year, treatment, and year by treatment effects. Response variables were standing crop, herbaceous production, canopy cover, reproductive stalk weight, basal cover, and density. An autoregressive order one covariance structure was used because it provided the best fit for analysis (Littell et al. 1996). Mean separation involved comparison of least squares using the LSMEANS statement. The model included block (4

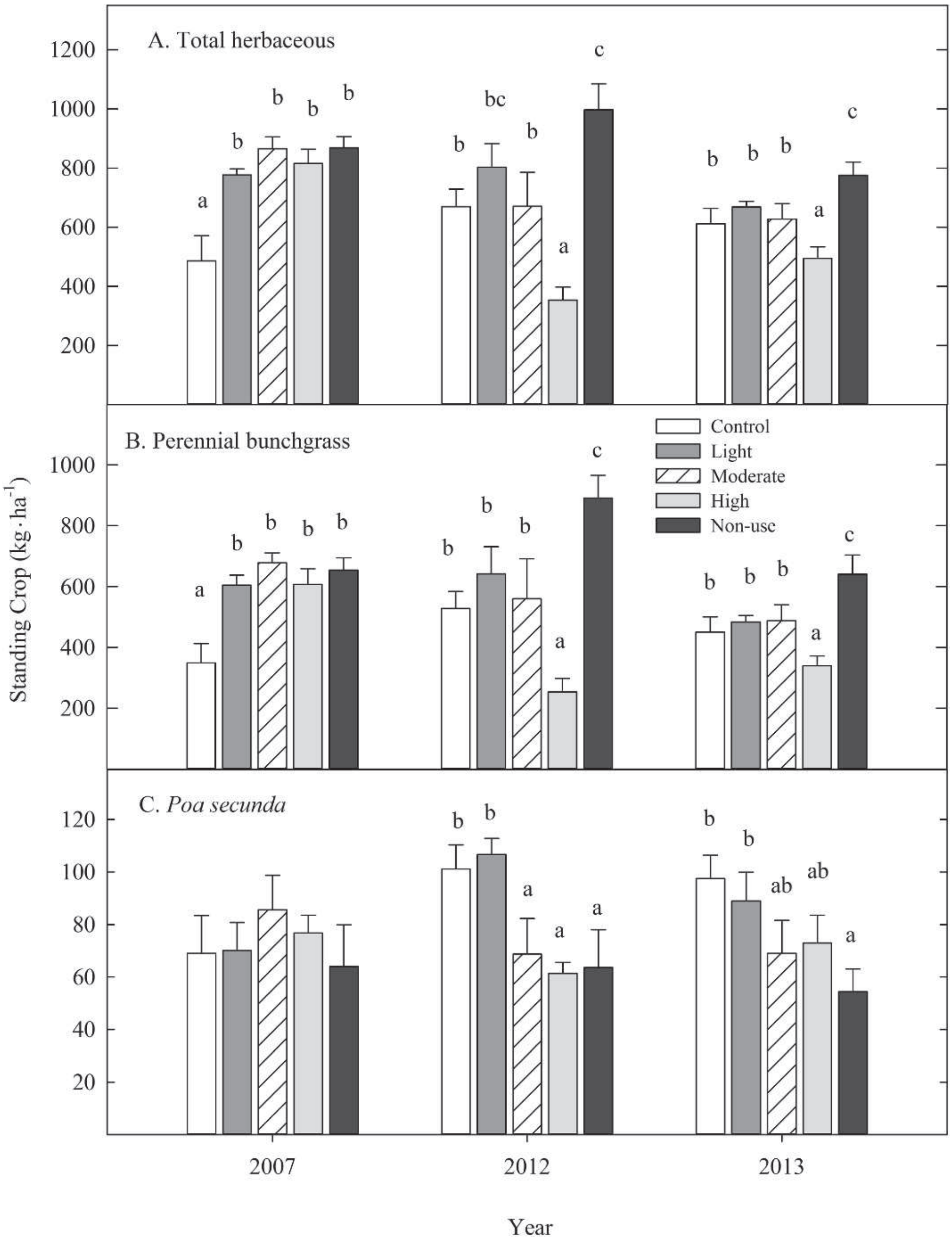

Figure 2. Herbaceous standing crop (kg · ha^{-1}) for **A,** total herbaceous, **B,** perennial bunchgrasses, and **C,** *Poa secunda* in light, moderate, high, and nonuse treatments and the control; Wyoming big sagebrush steppe, NGBER, Oregon, June, 2007, 2012, and 2013. Values represent means and 1 SE. Different letters indicate significant differences among the treatments within year.

blocks; df=3), year (2007, 2012, 2013; df=2), treatment (light, moderate, high, nonuse, control; df=4), and year×treatment interaction (df=4; error term df=30). Statistical significance of all tests was $P < 0.05$.

RESULTS

Standing Crop and Production

Herbaceous ($P=0.002$) and perennial bunchgrass ($P= 0.003$) standing crop were nearly 100% greater in the light, moderate, high, and nonuse treatments at the beginning of the study (2007) than the control (Figs. 2A and 2B). After 5 yr, grazing altered this relationship. In both 2012 and 2013, herbaceous ($P=0.006$) and perennial bunchgrass ($P=0.001$) standing crop was lowest in the high, intermediate in the control, light, and moderate, and greatest in the nonuse treatment. The greater standing crop in the nonuse than the three grazing treatments and control reflected the effect of herbage removal by livestock and the competitive influence of sagebrush, respectively. *Poa secunda* standing crop did not differ among the treatments at the start of the study (2007); however, by 2012 and 2013,

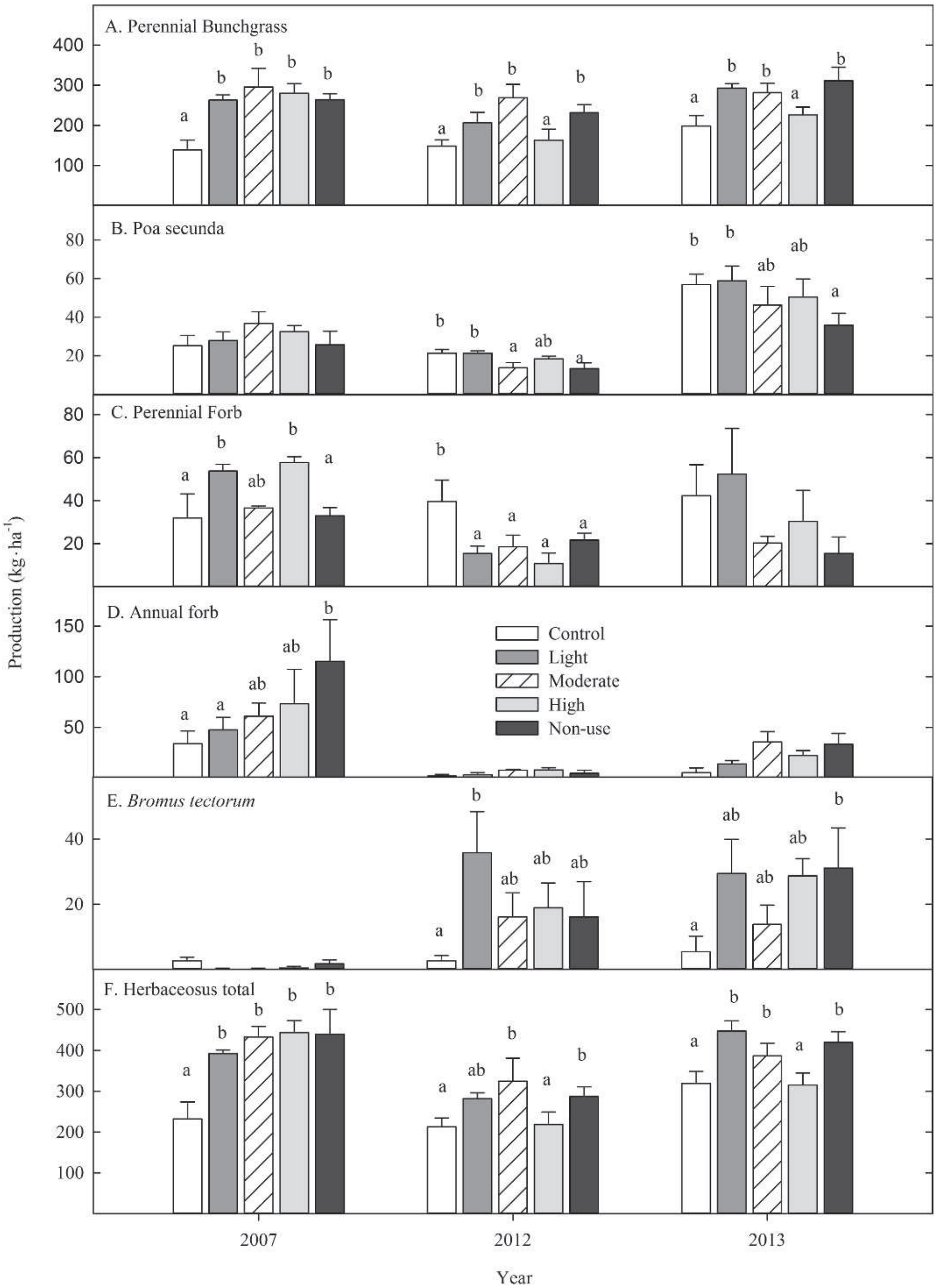

Figure 3. Production (kg · ha^{-1}) for **A,** perennial bunchgrasses, **B,** *Poa secunda*, **C,** perennial forbs, **D,** annual forbs, **E,** *Bromus tectorum,* and **F,** herbaceous total in the light, moderate, high, and nonuse treatments and the control; Wyoming big sagebrush steppe, NGBER, Oregon, June, 2007, 2012, and 2013. Values represent means and 1 SE. Different lower-case letters indicate significant differences among the treatments within year.

standing crop was 35–45% less in the nonuse compared to control and light (Fig. 2C; $P=0.017$).

Pretreatment (2007) perennial bunchgrass production was about 200 kg · ha^{-1} greater in the nonuse and all three grazing treatments than the control (Fig. 3A; $P < 0.001$). Posttreatment perennial bunchgrass production remained greater in the nonuse, light, and moderate treatments than the control ($P < 0.001$). In both posttreatment years, perennial bunchgrass production was lower in the high than the nonuse treatment ($P < 0.001$). *Poa secunda* production in the nonuse was less than the control and light treatments but did not differ from moderate and high treatments posttreatment (Fig. 3B; $P=0.044$). Perennial forb production exhibited no consistent patterns across years ($P=0.150$), though there were differences within individual years (Fig. 3C; $P=0.004$). Pretreatment annual forb production was greatest in the nonuse than the control and light treatments ($P=0.008$); however, by the end of the study annual forb production had declined ($P < 0.001$), and

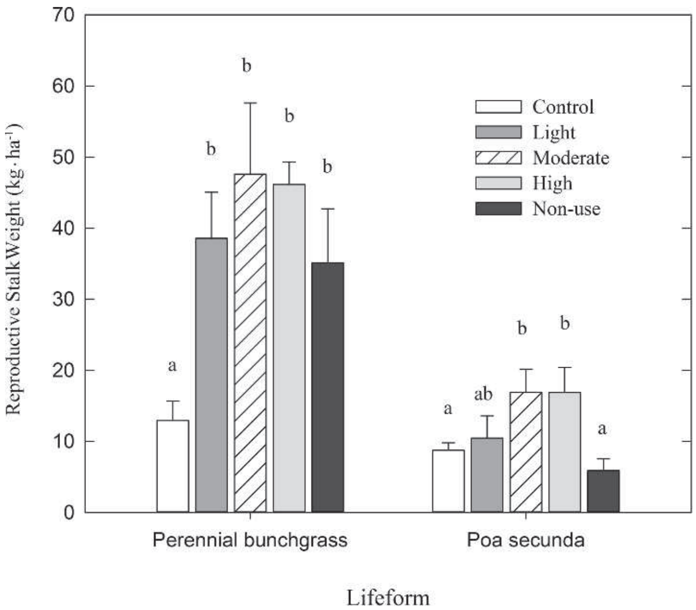

Figure 4. Reproductive stalk weight (kg · ha^{-1}) for perennial bunchgrasses and *Poa secunda* in the light, moderate, high, and nonuse treatments and the control; Wyoming big sagebrush steppe, NGBER, Oregon, June 2013. Values represent means and 1 SE. Different lower-case letters denote significant differences among the treatments within year.

there were no differences among treatments (Fig. 3D; $P=0.183$). *Bromus tectorum* productions increased over time for all treatments between 2007 and 2013 (Fig. 3E; $P < 0.001$). However, *B. tectorum* productions were highly variable, and no consistent trends developed. In 2012 *B. tectorum* production was greater in the light than the control and in 2013 was greater in the nonuse than the control ($P=0.028$).

In 2012 reproductive stalk weights of perennial bunchgrasses did not differ among the treatments and the control, averaging less than 5 kg · ha^{-1}. In 2013 perennial bunchgrass reproductive stalk weights were 180–275% greater in the burned (grazed and nonuse) treatments than the control (Fig. 4; $P=0.010$). *Poa secunda* reproductive stalk weight was about 100% greater in the moderate and high treatments than the nonuse and control in 2013 ($P=0.049$).

Canopy Cover, Basal Cover, and Density

Pretreatment (2007) perennial bunchgrass and *P. secunda* canopy cover did not differ among the treatments (Figs. 5A and 5B). Canopy cover of perennial bunchgrass ($P=0.006$) and *P. secunda* ($P=0.0062$) decreased over time in all treatments between 2007 and 2012. In 2012 perennial bunchgrass cover was less in the high than the nonuse ($P= 0.013$). *Poa secunda* canopy cover was lower in the nonuse than the three grazing treatments and the control in 2012 ($P=0.005$). Canopy cover of perennial forbs also decreased over time in all treatments between 2007 and 2012 (Fig. 5C; $P < 0.001$) and differences in perennial forb canopy cover that were measured prior to treatment were not present at the end of the study. Annual forb and *B. tectorum* canopy cover did not differ among the grazing treatments; however, both were affected by year. Annual forb canopy cover decreased ($P < 0.001$) and *B. tectorum* cover increased ($P < 0.001$) over time. *Bromus tectorum* canopy cover was greater in the burned treatments (grazed and nonuse) ranging from 2% to 3% compared to the control where cover averaged 0.2% ± 0.01% ($P=0.007$). Total herbaceous canopy cover did not differ among treatments ($P=0.1994$) and decreased across years in all the treatments and control (Fig. 5D; $P < 0.001$). Bare ground was lower in the control (54.7% ± 2.1%) and nonuse (56.5% ± 1.7%) than the light (59.6% ± 1.3%), moderate (60.1% ± 1.4%), and high (60.8% ± 0.9%) treatments in 2012 ($P=0.0175$). Litter cover increased by 3–4% in all treatments between 2007 and 2012 ($P=0.009$). A year × treatment interaction ($P=0.033$) indicated that litter cover changes did not respond similarly because cover was greatest in the nonuse (21.8% ± 2.1%) than the control (18.2% ± 1.4%), light (18.9% ± 0.8%), moderate (18.4% ± 0.6%), and high (18.6% ± 1.3%) treatments in 2012. Biological crust (moss and lichen) cover was greater in the control (4.5% ± 0.6%) than the nonuse (1.5% ± 0.4%), light (1.5% ± 0.2%), moderate (1.4% ± 0.2%), and high (1.2% ± 0.2%) treatments during the study ($P < 0.001$).

Cover of *A.t.* spp. *wyomingensis* was nearly 9.5 times greater in the control than the nonuse and three grazing treatments in 2007 and 2012 (Fig. 6A; $P < 0.0001$). Sagebrush density remained unchanged in all treatments over time ($P=0.743$), although density was greater ($P=0.001$) in the control (0.36 ± 0.04 plants m^{-2}) than the burned treatments (0.04 ± 0.009 plants m^{-2}). Cover of *C. viscidiflorus* had significant treatment ($P=0.022$) and year ($P < 0.001$) effects as treatment relationships shifted along with a general decline in cover between 2007 and 2012 (Fig. 6B). In 2007 *C. viscidiflorus* cover was about twice as great in nonuse and high treatments than the control ($P=0.006$). After 5 yr (2012) C. *viscidiflorus* cover, though declining by 1–3% across treatments, was 90–144% greater in light and high than the control and moderate treatments ($P=0.008$).

Basal cover of perennial grasses was affected by the various grazing treatments and year. In 2007 basal cover of perennial bunchgrasses and *P. secunda* did not differ among the treatments (Fig. 7A–7C). Perennial bunchgrass basal cover increased between 2007 and 2012 in the control, nonuse, light, and moderate treatments; however, the increase was greater in the nonuse ($P=0.009$). In 2012 perennial bunchgrass basal cover was 35–100% greater in the nonuse than the three grazing treatments and the control. Basal cover of bunchgrasses was also greater in the moderate and light than the control and high treatments. Basal cover of *P. secunda* increased between 2007 and 2012 for all treatments and the control ($P=0.015$). Increases were greatest in the light and high treatments, and both were about 70% greater than the nonuse treatment ($P=0.018$).

Density of perennial bunchgrasses did not differ among the treatments ($P=0.754$) nor change between pre- and posttreatment measurement years ($P=0.278$). Bunchgrass density averaged 9.1 ± 0.3 plants · m^{-2} among treatments and across years. The year × treatment interaction for *P. secunda* density indicated a shift in treatment relationships accompanied by about a 50% increase in densities in all but the nonuse treatment between 2007 and 2012 ($P=0.037$). *Poa secunda* density in the nonuse was 18.3 ± 4.0 plants · m^{-2} and less than control (28.1 ± 5.9), light (27.8 ± 4.5), moderate (29.7 ± 7.0), and high (28.4 ± 5.1) treatments in 2012.

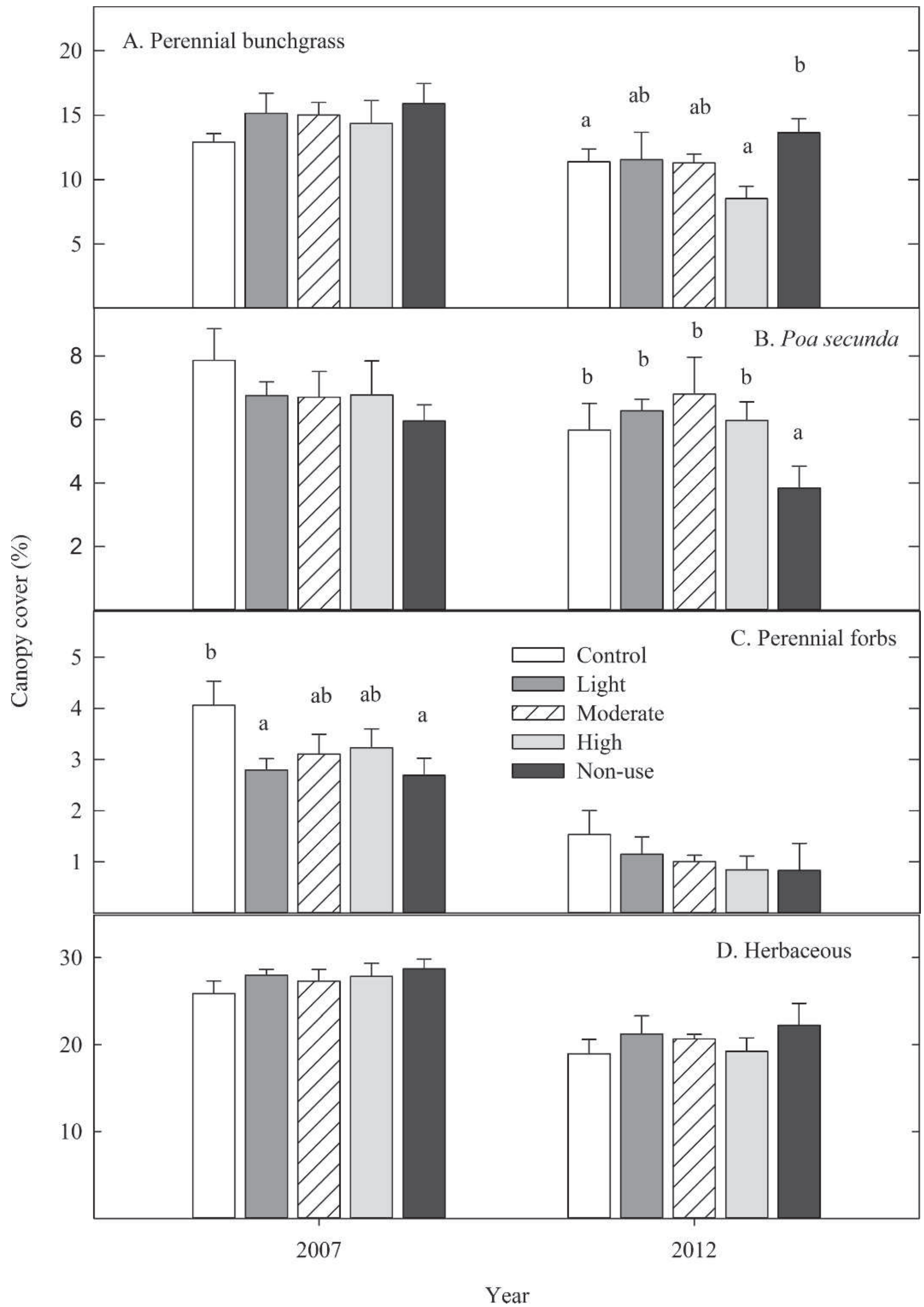

Figure 5. Canopy cover values (%) for **A,** perennial bunchgrasses, **B,** *Poa secunda*, **C,** perennial forbs, and **D,** herbaceous total in the light, moderate, high, and nonuse treatments and the Control; Wyoming big sagebrush steppe, NGBER, Oregon, June 2007 and 2012. Values represent means and 1 SE. Different lower-case letters indicate significant differences among the treatments within year.

Perennial forb density was not different prior to treatment, averaging 5.8 ± 0.5 plants $\cdot$ m^{-2} among the treatments in 2007. After 5 yr, perennial forb density had decreased by about 85% in the nonuse, which was 1/5 to 1/8 of the other treatments ($P=0.004$). Perennial forb density did not differ among the three grazing treatments and control.

DISCUSSION

There are several major threats to maintaining sagebrush steppe, particularly the *A.t.* spp. *wyomingensis* steppe. Two pressing and interrelated issues are the potential for *B. tectorum* and other invasive annual grass to dominate and

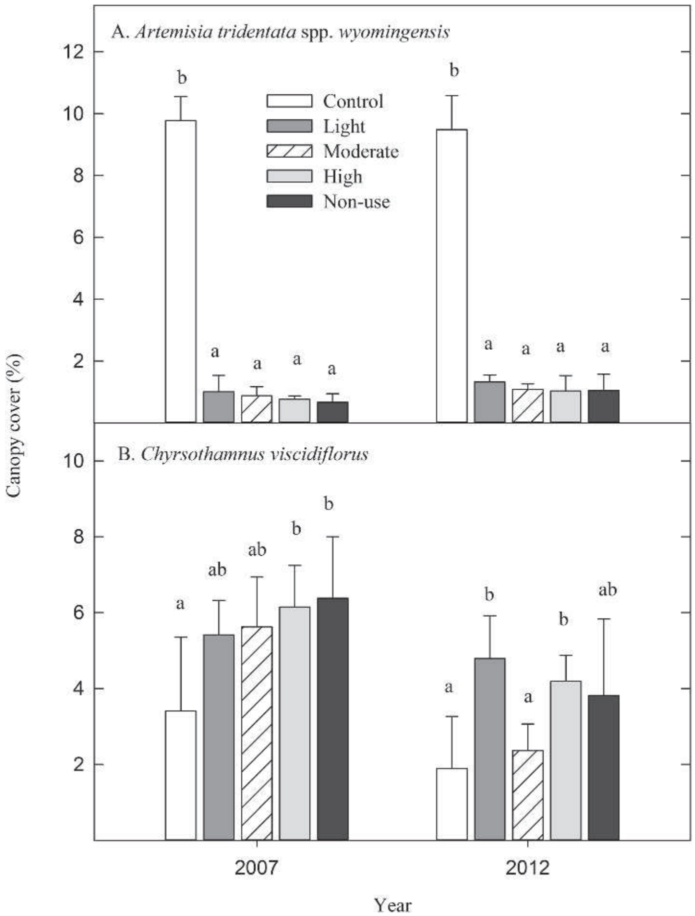

Figure 6. Canopy cover values (%) for **A,** *Artemisia tridentata* spp. *wyomingensis* and **B,** *Chrysothamnus viscidiflorus* in the light, moderate, high, and nonuse treatments and the control; Wyoming big sagebrush steppe, NGBER, Oregon, June 2007 and 2012. Values represent means and 1 SE. Different lower-case letters indicate significant differences among the treatments within year.

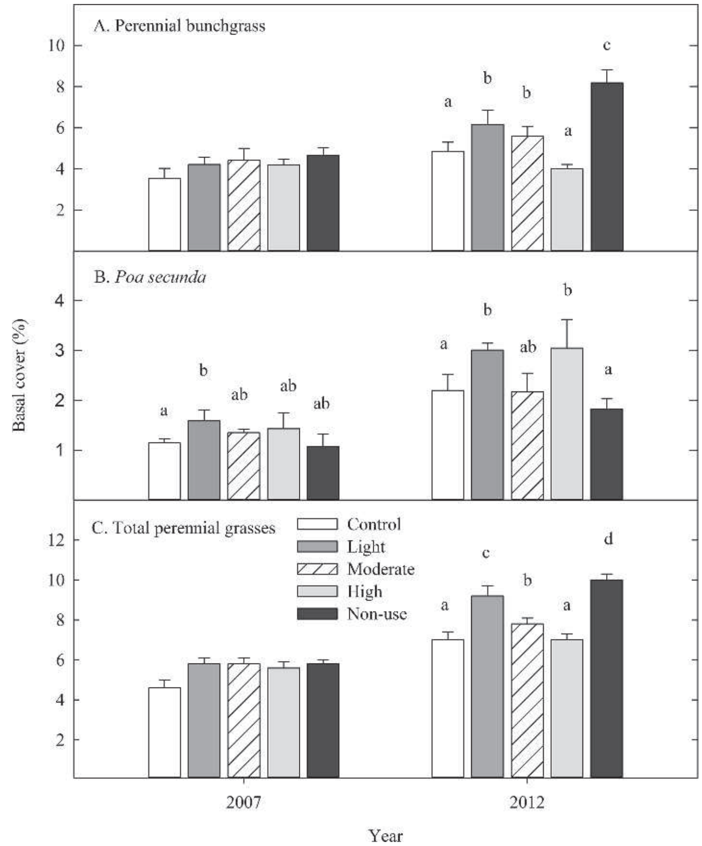

Figure 7. Basal cover values (%) for **A,** perennial bunchgrasses, **B,** *Poa secunda*, and **C,** total perennial grass in the light, moderate, high, and nonuse treatments and the control; Wyoming big sagebrush steppe, NGBER, Oregon, June 2007 and 2012. Values represent means and 1 SE. Different lower-case letters indicate significant differences among the treatments within year.

the loss of habitat for sage-grouse (Rowland and Wisdom 2005; Davies et al. 2011). As this study demonstrated, proper grazing management will maintain native herbaceous species composition and productivity. We found that herbaceous recovery 10 yr after fire in sagebrush steppe was largely unaffected by light and moderate grazing use, but high stocking did limit herbaceous productivity and cover. Maintaining a dominating presence of perennial vegetation prevents annual grasses from increasing and replacing sagebrush steppe (Chambers et al. 2007; Davies et al. 2008, 2010; Bates and Svejcar 2009; Bates et al. 2011). Furthermore, as this study and other studies (Davies et al. 2010) have shown grazing reduces the accumulation of cured herbage (i.e., fine fuels) within grass bunches which appears to increase bunchgrass survival chances when burned, thus decreasing the risk of replacement by invasive annuals (Davies et al. 2009). Standing crop (production and previous year's cured herbage) was 150 to 400 $kg \cdot ha^{-1}$ greater, in 2012 and 2013 in the nonuse than the grazing treatments.

The sagebrush steppe plant community in light and moderate treatments were demonstrably resilient because production, reproductive stalk weight, and canopy cover were similar to the nonuse treatment. Other researchers have documented no differences between species composition and production between ungrazed and areas of light to moderate use in sagebrush steppe grasslands (Sneva et al. 1984; West et al. 1984; Courtois et al. 2004; Manier and Hobbs 2006; Roselle et al. 2010). Despite frequent years of drought, bunchgrass basal cover continued to increase in light and moderate treatments, though values were less than the nonuse. However, because bunchgrass production did not differ, production per unit area of basal cover would be greater in light and moderate treatments.

Vegetation recovery was arrested by the high stocking treatment. The sagebrush community in the high treatment had lower cover, production, and standing crop than the other burned treatments (light, moderate, nonuse). This result is consistent with other results, because not only does grazing of bunchgrasses reduce cover and production within a season of use (Briske and Richards 1995; West and Yorks 2002; France et al. 2008; Kerns et al. 2011), but high defoliation lowers herbaceous production and tillering in subsequent growing seasons, even following a season of rest (Ganskopp 1988; Britton et al. 1990). However, bunchgrass basal cover and density remained unchanged from pretreatment levels in the high treatment, and reproductive stalk weight did not differ from the other treatments. This suggests the high treatment retained its capacity to recover bunchgrass cover and productivity should stocking be lowered, and that in the short term (less than 5 yr), high grazing levels may not cause major changes in sagebrush steppe communities.

All grazing treatments benefited *P. secunda* and perennial forbs. *Poa secunda* is considered an increaser with grazing (Blaisdell et al. 1982; NRCS 2013), and density, production, and basal cover were greater in the grazed treatments than the nonuse. The higher density of perennial forbs in the grazing treatments (and control) may indicate that grazing disturbance and reduced perennial bunchgrass cover are necessary for perennial forb recruitment and establishment. Despite the reduction in perennial forb density in the nonuse, production and canopy cover did not differ among treatments, suggesting that individual forbs were larger. The higher density of forbs in all grazed treatments and the control may permit forbs on these areas to respond better when growing conditions are more favorable than the nonuse. The lack of a grazing effect on perennial forb production and cover in our study contrasts with other researchers who have measured decreased cover of perennial forbs with grazing (West and Yorks 2002; Kerns et al. 2011).

Burned plots, whether grazed or not, tended to have higher *B. tectorum* production than the control, indicating that the presence of sagebrush in combination with intact native understories impedes establishment and growth of invasive annual grasses. However, in the burned plots *B. tectorum* production represented only 7–10% of total production, which indicates that native herbaceous species were effective at limiting this species influence. Greater cover and density of perennial herbaceous vegetation is key to preventing annual grasses from dominating in sagebrush steppe (Chambers et al. 2007; Davies and Svejcar 2008; Bates and Svejcar 2009; Davies et al. 2009; Condon et al. 2011). The increase in *B. tectorum* in the burned treatments was at the expense of *Alyssum alyssoides* L. (pale alyssum), an invasive mustard, which had been the primary annual on the site the first 6 yr after burning (Rhodes et al. 2010).

Cover of biological crust in the nonuse and grazing treatments remained well below the control indicating that recovery is likely a long-term prospect. The effects of fire persisted for 10 yr, and grazing had no effect on recovery of biological crust cover because nonuse and grazing treatments did not differ. On other big sagebrush sites in Oregon and Idaho, lichens and tall mosses have not recovered 8–10 yr after fire (Hilty et al. 2004; Bates et al. 2011). The recovery of tall mosses and sagebrush are likely synonymous. *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).

Between 5 and 10 yr after the fire *A.t.* spp. *wyomingensis* cover and density were stable and remained about 10% of the control in the nonuse and all grazing treatments. Sagebrush cover in the burned nonuse and grazed treatments was provided by surviving plants because recruitment of new individuals was absent. The slow postfire recovery of *A.t.* spp. *wyomingensis* is not unusual, and our results correspond with other studies. Cover of *A.t.* spp. *wyomingensis* was only 10% and 16% of associated unburned control 14 yr and 18 yr, respectively, after fire (Wambolt and Payne 1986; Lesica et al. 2007; Beck et al. 2009). The lack of establishment of new plants in the treatments may be a combination of herbaceous interference as well as the prevailing drought conditions.

The general decline of *C. viscidiflorus* cover appeared to be reduction and die-back of foliage rather than plant death or browsing. The likely explanation for this is that *C. viscidiflorus* was sensitive to the multiple years of drought that occurred between 2007 and 2012. Some subspecies of *C. viscidiflorus* are palatable to livestock and *Lepus californicus* Gray (black-tailed jack rabbit) (McArthur et al. 1977); however, there were no indications of browsing in our study.

IMPLICATIONS

Differences among light, moderate, and nonuse treatments were minor, producing no major community changes, reinforcing knowledge that light to moderate stocking rates are applicable to sustainable grazing of sagebrush steppe rangelands. The high treatment had lower herbaceous cover and production; however, because density was unchanged and reproductive effort was comparable to the other treatments, it appears these areas would respond favorably to rest or reduced stocking. Nevertheless, high defoliation, drought, or their combined effects are capable of producing significant mortality of bunchgrasses and potentially disrupting recruitment of new plants (Jirik and Bunting 1994; O'Connor 1994; Hodgkinson and Miller 2005; Hacker et al. 2006). Although we did not detect any such changes, perhaps 5 yr of high stocking use is too short a time to begin shifting composition from perennial bunchgrass dominance to other life forms such as invasive annuals. The lifespan of perennial bunchgrasses is variable, and individuals that survive past their first year of establishment may live 6 to 35 yr, with an average of 10 yr considered typical (West et al. 1979; Lauenroth and Adler 2008). Thus, monitoring of bunchgrass demography over longer time periods in response to various stocking levels would be useful for forecasting change in herbaceous composition in sagebrush steppe.

It is important to emphasize our results apply to sagebrush steppe supporting a healthy composition of native herbaceous species before and after fire. Areas with a significant weed component in the understory are likely to require different forms of management. However, our site is representative of a large part of the sagebrush steppe (Passey et al. 1982; Davies et al. 2006), which suggests that the principle of light to moderate stocking and use is likely to maintain both herbaceous productivity and community composition.

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