Rangeland Ecology & Management 72 (2019) 28–35

Contents lists available at ScienceDirect

Rangeland Ecology & Management

journal homepage: http://www.elsevier.com/locate/rama

Herbaceous Biomass Response to Prescribed Fire in Juniper-Encroached Sagebrush Steppe☆

Jonathan D. Bates [a,*], Kirk W. Davies [a], Justin Bournoville [b,1], Chad Boyd [c], Rory O'Connor [d,1], Tony J. Svejcar [e]

[a] Range Scientists, US Department of Agriculture (USDA)—Agricultural Research Service (ARS), Eastern Oregon Agricultural Research Center (EOARC), Burns, OR 97720, USA
[b] Former Range Technicians at EOARC, Botanist, US Forest Service, Eagle River, WI 54521, USA
[c] Research Leader, US Department of Agriculture (USDA)—Agricultural Research Service (ARS), Eastern Oregon Agricultural Research Center (EOARC), Burns, OR 97720, USA
[d] Former Range Technicians at EOARC, Ph.D. Candidate, Kansas State University, Manhattan, KS 66506, USA
[e] Rangeland Ecologist, EOARC-Oregon State University, Burns, OR 97720, USA.

ARTICLE INFO

Article history:
Received 15 June 2018
Accepted 8 August 2018

Key Words:
bunchgrass
cheatgrass
forbs
Great Basin
piñon-juniper
prescribed fire

ABSTRACT

Western juniper (*Juniperus occidentalis* Hook.) has expanded into sagebrush steppe plant communities the past 130 – 150 yr in the northern Great Basin. The increase in juniper reduces herbage and browse for livestock and big game. Information on herbaceous yield response to juniper control with fire is limited. We measured herbaceous standing crop and yield by life form in two mountain big sagebrush communities (MTN1, MTN2) and a Wyoming/basin big sagebrush (WYOBAS) community for 6 yrs following prescribed fire treatments to control western juniper. MTN1 and WYOBAS communities were early-successional (phase 1) and MTN2 communities were midsuccessional (phase 2) woodlands before treatment. Prescribed fires killed all juniper and sagebrush in the burn units. Total herbaceous and perennial bunchgrass yields increased 2 to 2.5-fold in burn treatments compared with unburned controls. Total perennial forb yield did not differ between burns and controls in all three plant communities. However, tall perennial forb yield was 1.6- and 2.5-fold greater in the WYOBAS and MTN2 burned sites than controls. Mat-forming perennial forb yields declined by 80 – 90% after burning compared with controls. Cheatgrass yield increased in burned WYOBAS and MTN2 communities and at the end of the study represented 10% and 22% of total yield, respectively. Annual forbs increased with burning and were mainly composed of native species in MTN1 and MTN2 communities and non-natives in WYOBAS communities. Forage availability for livestock and wild ungulates more than doubled after burning. The additional forage provided on burned areas affords managers greater flexibility to rest and treat additional sagebrush steppe where juniper is expanding, as well as rest or defer critical seasonal habitat for wildlife.

Published by Elsevier Inc. on behalf of The Society for Range Management.

Introduction

Piñon-juniper woodland expansion in sagebrush steppe plant communities has a number of adverse effects including increased soil erosion, loss of wildlife habitat, and reduced herbaceous and shrub productivity (Miller et al., 2005). The root cause of woodland expansion and infilling is a consequence of reduced fire across millions of hectares of sagebrush steppe (Johnson and Miller, 2006; Miller et al., 2008). Other dry forests of the western United States have undergone similar expansions and increases in tree densities with accompanying declines in shrub and herbaceous understories (Clary et al., 1968; Moore and Deiter, 1992; Covington and Moore, 1994).

In ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson) forests, it's been well documented that fire treatments to reduce tree density increase herbage yields (Ffolliott et al., 1977; Andariese and Covington, 1986) and that severe fire effects may increase the abundance of exotic species (Crawford et al., 2001; Griffis et al., 2001). Similar dynamics have been described for herbaceous cover following fire in developing piñon-juniper woodlands (Bates et al., 2013; Miller et al., 2014; Roundy et al., 2014a). Effects of fire treatments on herbage yield in these woodlands have not garnered similar attention and have been limited to short-term studies (Bates et al., 2011a; Davies et al., 2012). Because early-successional piñon-juniper woodlands retain the characteristics of sagebrush steppe, herbage yield following fire might be expected to increase twofold to threefold (Harniss and Murray, 1973; Bates et al., 2009; Davies et al., 2012). Herbaceous yield composition in mid- and late-successional woodland is likely to be less predictable because

☆ The EOARC is jointly funded by the USDA-ARS and Oregon State Agricultural Experiment Station. USDA-ARS and Oregon State University are equal opportunity providers and employers. Mention of a proprietary product does not constitute a guarantee or warranty of the product by USDA-ARS, Oregon State University, or the authors and does not imply approval to the exclusion of other products.

* Correspondence: Jon Bates, USDA-ARS, EOARC, 67826-A Hwy 205, Burns, OR 97720, USA.

E-mail address: jon.bates@ars.usda.gov (J.D. Bates).

[1] Former range technicians at EOARC.

https://doi.org/10.1016/j.rama.2018.08.003
1550-7424/Published by Elsevier Inc. on behalf of The Society for Range Management.

greater fire severity increases the potential for invasive species to establish (Bates et al., 2011a, 2013; Condon et al., 2011). Because livestock grazing remains a primary use in these areas, it is important for managers to understand postfire forage yield dynamics when developing grazing plans.

We gathered herbaceous yield response for 6 yrs after burning early- and midsuccessional western juniper (*Juniperus occidentalis* Hook.) woodlands encroaching in sagebrush steppe. Three plant communities were studied: two in mountain big sagebrush (*Artemisia tridentata* Nutt. spp. *vaseyana* [Rydb.] Beetle) and one in Wyoming-basin big sagebrush (*A. t.* Nutt. spp. *wyomingensis* [Rydb.] Beetle and *A. t.* Nutt. spp. *tridentata* [Rydb.] Beetle) steppe plant communities. Herbaceous composition at all sites consisted of mostly native perennials. Studies on similar sites indicated that cover of perennial grasses and forbs increased and dominated postfire herbaceous composition (Davies et al., 2007; Bates et al., 2009, 2014; Bates and Davies, 2014). Therefore, our expectations following prescribed fire were that perennial grasses and forbs would comprise the bulk of herbaceous yield increases. Previous studies indicated annual forb cover in burned Wyoming and basin big sagebrush communities were mostly non-native species (Rhodes et al., 2010; Bates et al., 2017), and in burned mountain big sagebrush communities they were native species (Bates et al., 2011a, 2011b, 2013). Thus, we anticipated that annual forb yields would follow similar patterns in the respective sagebrush communities after fire. Cheatgrass (*Bromus tectorum* L.) has typically increased in these communities (Bates et al., 2009, 2011a, 2014) after fire, but because of dominance by perennial herbaceous species we anticipated that cheatgrass would be a minor component of herbaceous yield.

Study Sites and Methods

The study was located at the Northern Great Basin Experimental Range (NGBER), Harney County, Oregon (43.491953 N, 119.712377 W). Vegetation communities were MTN1 (mountain big sagebrush/Idaho fescue [*Festuca idahoensis* Elmer]; $n = 5$), MTN2 (mountain big sagebrush/Idaho fescue; $n = 4$) and WYOBAS (Wyoming and basin big sagebrush/Idaho fescue-bluebunch wheatgrass—Thurber's needlegrass [*Festuca idahoensis*—*Pseudoroegneria spicata* {Pursh} A. Löve—*Achnatherum thurberianum* {Piper} Barkworth]; $n = 4$). Before fire, the MTN1 and WYOBAS communities were both encroached by western juniper and were classed as phase 1 woodlands (early succession) on the basis of tree dominance indices presented by Roundy et al. (2015) (Table 1). The MTN2 communities encroached by western juniper were classed as phase 2 (midsuccession) woodlands. Before burning, native herbaceous understories at all sites were intact and were dominated by perennial bunchgrasses and forbs. Invasive species, primarily cheatgrass, represented < 0.5—1% of herbaceous biomass across the sites, before treatment.

Annual precipitation at the NGBER averaged 284 mm since measurements began in the 1930s, and precipitation distribution has been 60% from October to March, 30% from April to July, and 10% in September (Fig. 1). Elevation was 1 400 to 1 490 m at WYOBAS sites and 1 500 m to 1 560 m at MTN1 and MTN2 sites. Slope at the WYOBAS sites was 1—3% and east to west facing. Slopes at MTN1 and MTN 2 sites were 0—15% and generally west or north facing. WYOBAS communities receive 280 mm in annual precipitation, with frost-free periods of 80—100 d (Lentz and Simonson, 1986). The MTN1 and MTN2 sites receive 330—356 mm of annual precipitation and with frost-free periods of 70—90 d. The WYOBAS communities are therefore slightly drier and warmer than the MTN1 and MTN2 communities. Soils all tend to be moderately well drained and have sandy loam surface textures (Lentz and Simonson, 1986).

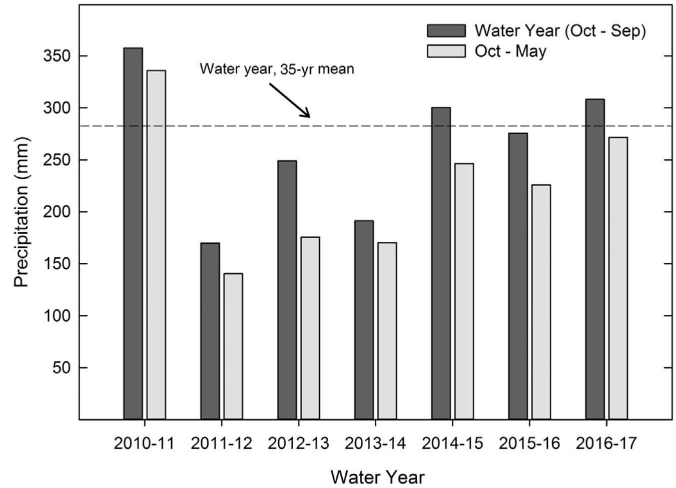

Figure 1. Water year (1 October–30 September) and October–May precipitation at the Northern Great Basin Experimental Range, 2011–2017. The 80-yr average is 284 mm.

In the MTN2 communities about 20—25% of the juniper trees (> 2 m height) were cut in March 2011, six mo before prescribed burning. The cut trees assist in carrying fire and killing remaining live trees (Bates et al., 2011a). The MTN1 and WYOBAS communities had adequate fine fuels and shrub cover to carry fire and kill juniper and, therefore, required no juniper cutting. Treatments were prescribed broadcast burns applied by NGBER personnel in September 2011. Burns were conducted by head-fire ignition and applied individually to each unit. Burn units varied from 10 ha to 75 ha. Unburned controls (Control) were adjacent to burn units. Burns were complete, killing all juniper and sagebrush within each unit. Wind speeds varied between 5 km-hr^{-1} and 20 km-hr^{-1}, air temperatures were 18—25°C, and relative humidity varied from 16% to 35% during the prescribed burns. Moisture content of fine fuels (herbaceous vegetation) was between 8% and 12%, and fine fuel loads ranged between 350 kg ha^{-1} and 480 kg ha^{-1}.

Vegetation sampling was conducted each June (peak growth), from 2011 to 2017, of which 6 yr were post treatment (2012—2017). Sampling was done in representative plots of about 1 ha in each burned and unburned unit. Plant communities were not grazed between 2010 and 2013. Plant communities were grazed after July 1, each year, beginning in 2014. Understory measurements were completed before livestock entry and grazing utilization was evaluated using methods described by Anderson and Currier (1973). Grazing use was rated light on controls and moderate on burned treatments.

Standing crop biomass was determined by herbaceous life-form by clipping 15, 1-m^2 frames per treatment and control unit. Life-forms were Sandberg's bluegrass (*Poa secunda* J. Presl), perennial

Table 1
Vegetation cover characteristics,[1] woodland phase, and tree dominance indexes[2] (TDIs) for the western juniper control sites at the Northern Great Basin Experimental Range, Harney County, Oregon.

Site	Sagebrush cover (%)	Herbaceous cover (%)	Juniper cover (%)	Woodland phase at time of treatment	TDI
WYOBAS	10.6 ± 0.4	20.2 ± 0.6	2.5 ± 0.2	Phase 1	0.08
MTN1	13.8 ± 0.6	18.6 ± 0.5	7.9 ± 0.5	Phase 1	0.20
MTN2	8.2 ± 0.6	18.3 ± 0.7	20.8 ± 0.3	Phase 2	0.44

1 File data, US Department of Agriculture—Agriculture Research Service, Eastern Oregon Agricultural Research Center, Harney County.
2 TDI—0.0—0.34 for Phase 1 woodlands; 0.34—0.67 for Phase 2 woodlands; > 0.67 for Phase 3 woodlands. TDI = Juniper cover/(shrub cover + herbaceous cover + juniper cover). This index is sourced from Roundy et al. (2015). Woodland phase classification was developed by Miller et al. (2005).

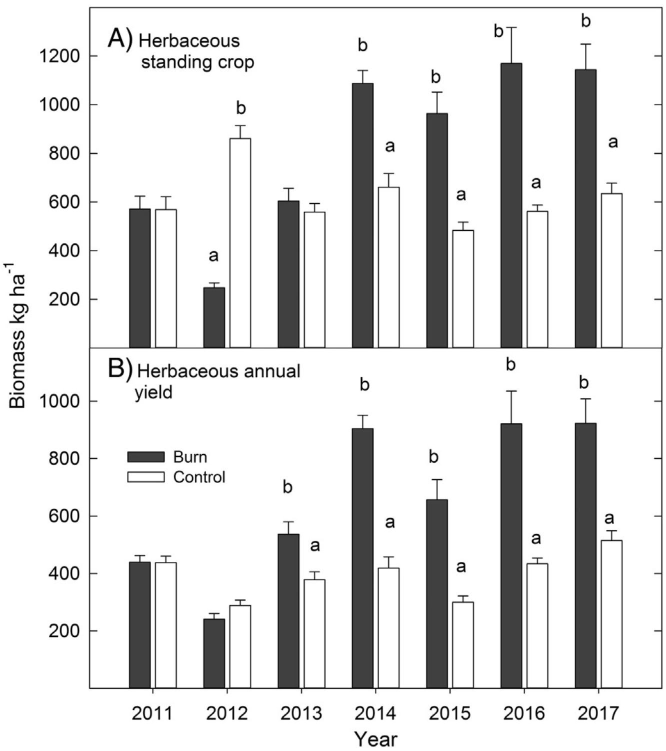

Figure 2. Herbaceous (A) standing crop (kg ha^{-1}) and (**B**) annual yield (kg ha^{-1}) for the juniper-encroached sagebrush sites (WYOBAS, MTN1, MTN2), Northern Great Basin Experimental Range, 2011—2017. Values for 2011 are preburn data. Prescribed fires were applied in September 2011. *Asterisks* indicate significant differences between burned and control treatments within year ($P < 0.05$).

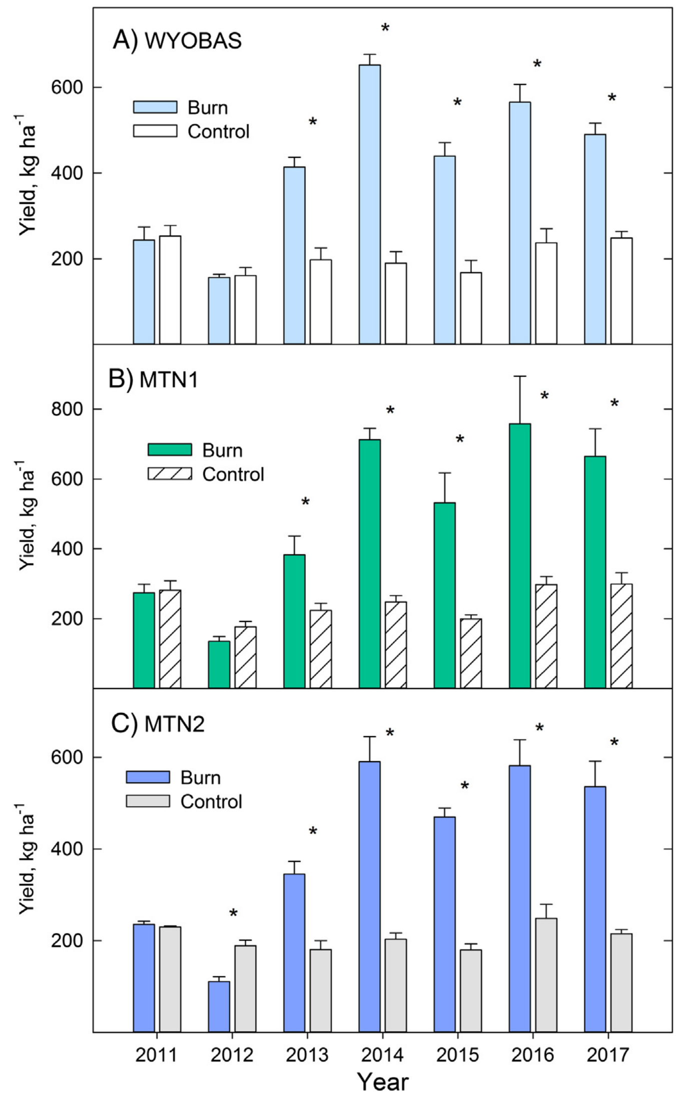

Figure 3. Perennial bunchgrass yield (kg ha^{-1}) for (**A**) WYOBAS, (**B**) MTN1, and (**C**) MTN2, juniper-encroached sagebrush sites, Northern Great Basin Experimental Range, 2011—2017, for burned and control treatments. Values for 2011 are preburn data. Prescribed fires were done in September 2011. *Asterisks* indicate significant differences between burned and control treatments within year ($P < 0.05$).

bunchgrasses (e.g., Idaho fescue, bluebunch wheatgrass), cheatgrass, perennial forbs, and annual forbs. Perennial bunchgrasses were clipped to 2.5-cm stubble height. Other life-forms were clipped to near ground level. Harvested herbage was dried at 48°C for 72 h before weighing. Yield of perennial grasses and *P. secunda* was determined by sorting current year's growth from standing crop. Standing crop included current year's growth and standing biomass from previous year's growth. Yields for perennial forbs, annual forbs, and cheatgrass were equivalent to their standing crop values and required no sorting. Perennial forbs were sorted into mat-forming forbs and tall forbs. Mat-forming forbs were fleabanes (*Erigeron* spp. L.), rosy pussy-toes (*Antennaria microphylla* Rydb.), and Hood's phlox (*Phlox hoodii* Rich.). Tall forbs, forbs generally taller than 10 cm or not forming mats, included milkvetchs (*Astragalus* spp. L.), hawksbeards (*Crepis* spp. L.), lupines (*Lupinus* spp. L.), false-agoseris (*Microseris troximoides* Gray), beardtongues (*Penstemon* spp. Mitch.), long-leaf phlox (*Phlox longifolia* Nutt.), long-leaf fleabane (*Erigeron corymbosus* Nutt.), and groundsels (*Senecio* spp. L.). The growth points of the tall forbs are mainly found below the soil surface, which makes them less susceptible to fire damage than mat-forming forbs (Brown and Smith, 2000).

Repeated measures analysis of variance using the PROC MIXED or PROC GLIMMIX procedures for randomized complete block designs were used to test year, plant community, treatment, and the interactions for the herbaceous response variables (SAS 9.3, SAS Institute, Cary, North Carolina). If communities were different, communities were analyzed separately for a randomized complete block design for year, treatment, and the interaction. An autoregressive order one covariance structure was used because it provided the best model fit (Littell et al., 1996). Data were tested for normality using the SAS univariate procedure. Data not normally distributed were square root or log transformed to stabilize variance. Because of significant year effects, years were also analyzed separately using a generalized model (Proc GLM, SAS Institute) to simplify presentation of the results and to assist in explaining interactions. Statistical significance of all tests were set at $P < 0.05$.

Results

Herbaceous biomass increased after prescribed fire was used to control juniper in all three communities. It required 3 and 2 yr post fire, respectively, for total herbaceous standing crop and yield to exceed controls (Fig. 2, A and B). This resulted in a significant *treatment × year* interaction for standing crop ($P < 0.001$; $F = 34.7$) and yield ($P < 0.001$; $F = 30.11$). Between the third and sixth yr after fire, herbaceous standing crop and yield were 2 to 2.5 times greater in the burned treatments than controls. Yields of functional groups, especially after treatment, differed among the plant communities. For example, in burned sites perennial bunchgrass yield was greater in MTN1 communities (504 ± 37 kg ha^{-1}) than the MTN2 (410 ± 32 kg ha^{-1}) and WYOBAS (423 ± 29 kg ha^{-1}) communities ($P < 0.001$; $F = 10.6$). Perennial forb yield was greater in MTN2 communities (173 ± 9 kg ha^{-1}) than the MTN1 (96 ± 8 kg ha^{-1}) and WYOBAS (71 ± 7 kg ha^{-1}) communities ($P < 0.001$; $F = 31.0$). *P. secunda* yield was greater in WYOBAS communities (60 ± 7 kg ha^{-1}) than the MTN1 (43 ± 4 kg ha^{-1}) and MTN2 (37

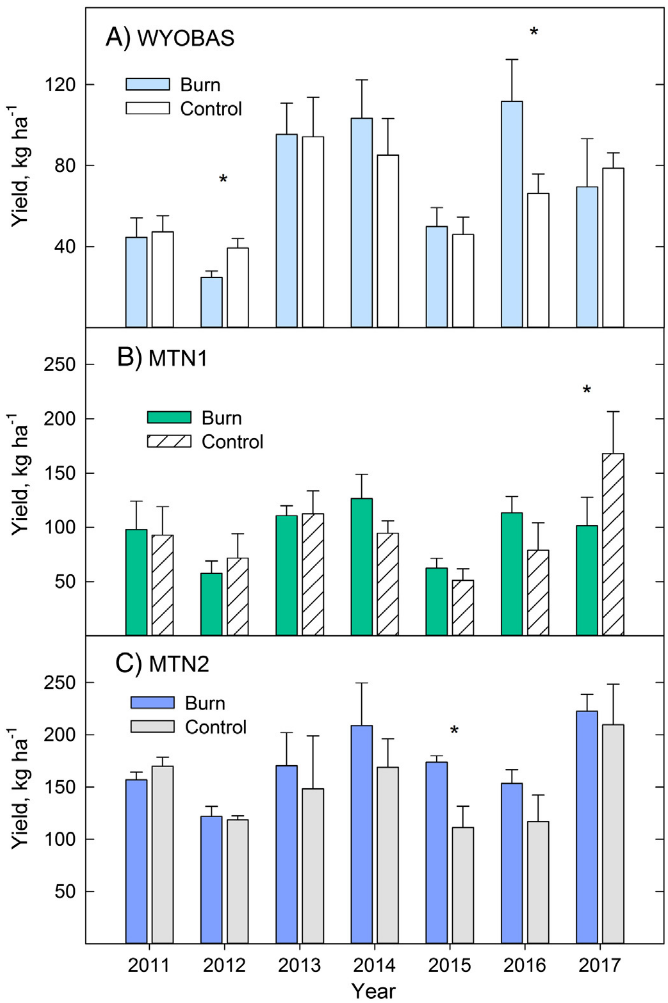

Figure 4. Perennial forb yield (kg ha^{-1}) for (**A**) WYOBAS, (**B**) MTN1, and (**C**) MTN2 sites, Northern Great Basin Experimental Range, 2011−2017, for burned and control treatments. Values for 2011 are preburn data. Prescribed fires were applied in September 2011. *Asterisks* indicate significant differences between burned and control treatments within year ($P<0.05$).

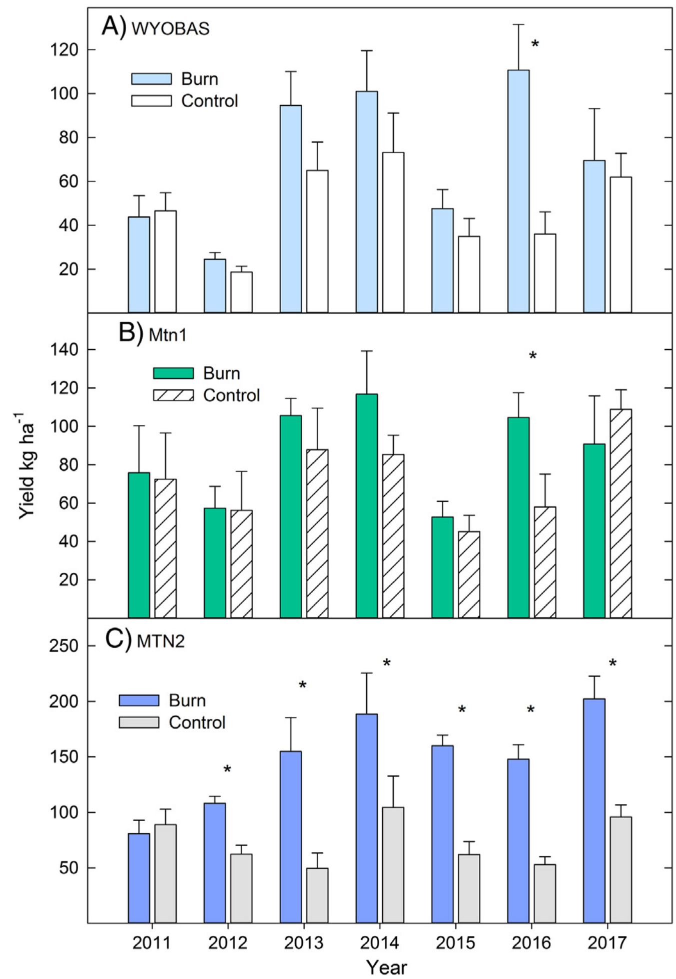

Figure 5. Perennial tall-forb yield (kg ha^{-1}) for (**A**) WYOBAS, (**B**) MTN1, and (**C**) MTN2 sites, Northern Great Basin Experimental Range, 2011−2017, for burned and control treatments. Values for 2011 are preburn data. Prescribed fires were applied in September 2011. *Asterisks* indicate significant differences between burned and control treatments within year ($P<0.05$).

$\pm$ 2 kg ha^{-1}) communities ($P<0.001$; F $=23.0$). Cheatgrass yield was greater in MTN2 communities (53 ± 15 kg ha^{-1}) than the WYOBAS (24 ± 6 kg ha^{-1}) and MTN1 (10 ± 5 kg ha^{-1}) communities ($P<0.001$; F $=10.5$). Annual forb yield was greater in WYOBAS communities (56 ± 11 kg ha^{-1}) compared with MTN1 (10 ± 3 kg ha^{-1}) and MTN2 (10 ± 2 kg ha^{-1}) communities ($P<0.001$; F $=22.5$). Because of site differences, treatment, year, and the interaction results for the functional groups are reported by the community.

Perennial Bunchgrass

In all three communities, response was influenced by *treatment × year* interaction (WYOBAS, $P<0.001$, F $=48.7$; MTN1, $P<0.001$, F $=6.38$; MTN2, $P<0.001$, F $=17.8$). In all communities, perennial grass yield was twofold to threefold greater in the burned treatments compared with the control, beginning the second year after fire (Fig. 3A−C).

Perennial Forb

Total perennial forb yield was influenced by year in all three communities (WYOBAS, $P<0.001$, F $=6.8$; MTN1, $P=0.004$, F $=3.7$; MTN2, $P=0.007$, F $=3.3$). In all communities, perennial forb yield varied 1.5- to 3-fold depending on year. Years of higher yields tended to correspond to greater winter and spring precipitation. Although treatments overall did not differ, there were years, on one or two occasions in each community, when treatments differed from controls (Fig. 4A−C).

At all sites, yield of tall forbs was similar between treatment and control units before prescribed fires (Fig. 5A−C). After fire, yield of tall forbs was significantly different for treatment and year main effects in the WYOBAS (Year, $P<0.001$, F $=6.0$; Treatment, $P=0.004$, F $=9.2$) and MTN2 (Year, $P=0.010$, F $=3.2$; Treatment, $P<0.001$, F $=44.0$) communities. This indicated that year influenced tall forb production and that fire treatments increased tall forb yield (Fig. 5A and C). Yield of tall forbs in the MTN1 sites was significantly different for the year main effect (Year, $P=0.002$, F $=2.9$), although in 2017, treatments did differ (Fig. 5B).

Yield of mat forbs varied after fire in all three communities (Fig. 6A−C). Yield of mat forbs differed by *treatment × year* interactions in WYOBAS ($P=0.002$, F $=2.9$) and MTN1 ($P=0.027$, F $=2.6$) communities. Generally, mat forb yield was greater in control plots of WYOBAS and MTN1 communities than the burn treatments. Yield of mat forbs in the MTN2 sites was 6- to 10-fold greater in the control than the burn treatment following fire ($P<0.001$, F $=23.0$).

P. secunda

Yield of *P. secunda* varied in all three communities (Fig. 7A−C). Yields were significantly different for treatment and year main effects

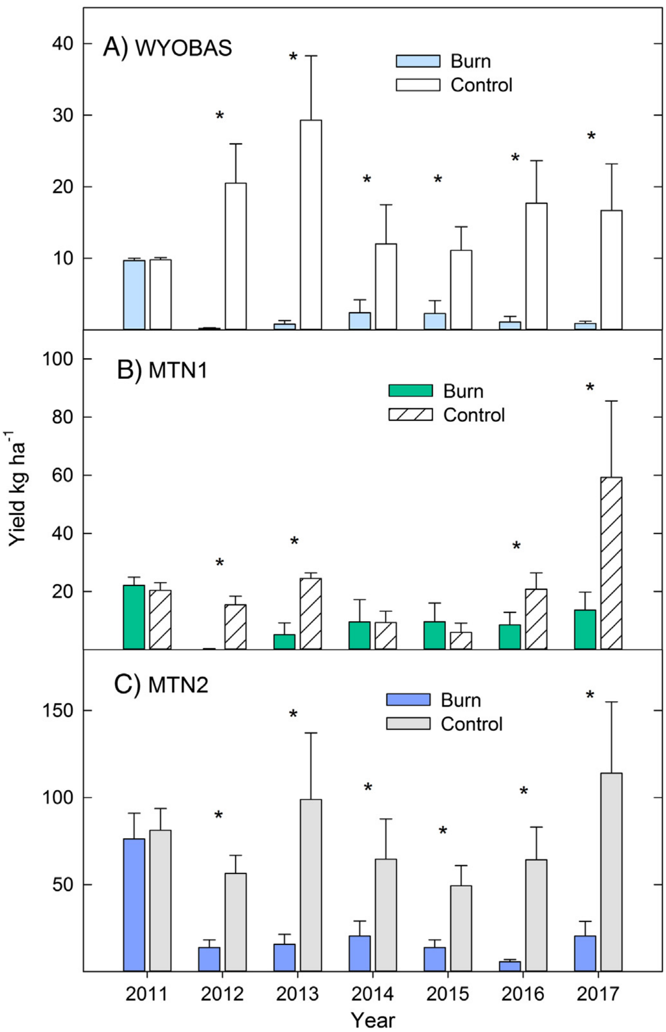

Figure 6. Perennial mat forb yield (kg ha^{-1}) for (**A**) WYOBAS, (**B**) MTN1, and (**C**) MTN2 sites, Northern Great Basin Experimental Range, 2011 – 2017, for burned and control treatments. Values for 2011 are preburn data. Prescribed fires were applied in September 2011. *Asterisks* indicate significant differences between burned and control treatments within year ($P < 0.05$).

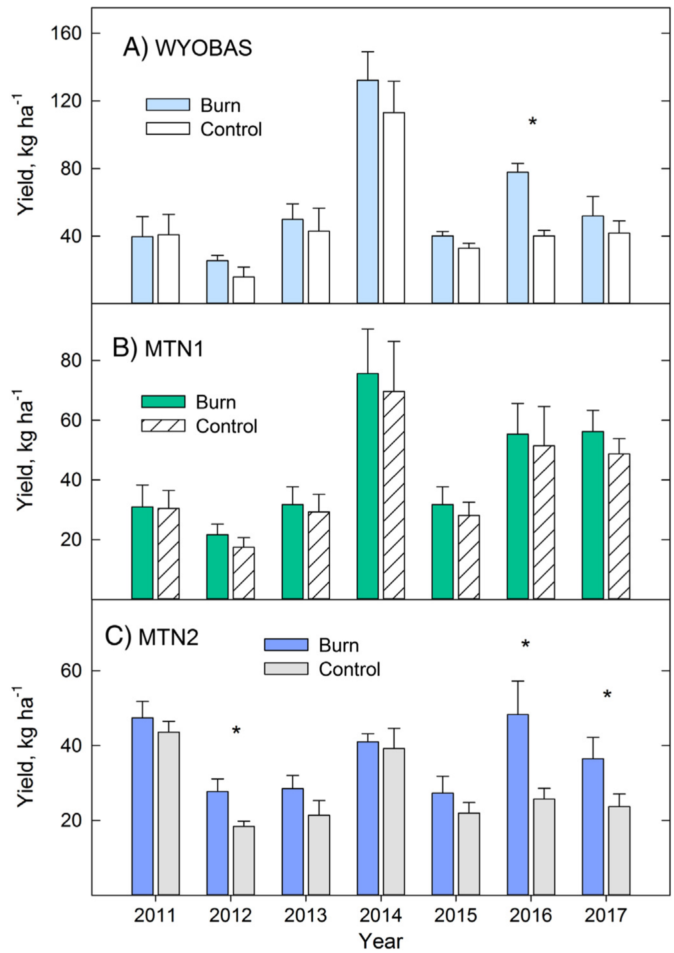

Figure 7. Sandberg's bluegrass yield (kg ha^{-1}) for (**A**) WYOBAS, (**B**) MTN1, and (**C**) MTN2 sites, Northern Great Basin Experimental Range, 2011 – 2017, for burned and control treatments. Values for 2011 are preburn data. Prescribed fires were applied in September 2011. *Asterisks* indicate significant differences between burned and control treatments within year ($P < 0.05$).

in the WYOBAS (Year, $P < 0.001$, F = 20.2; Treatment, $P = 0.024$, F = 5.4) and MTN2 (Year, $P < 0.001$, F = 15.1; treatment, $P = 0.002$, F = 8.2) communities. Fire treatments were effective at increasing *P. secunda* yield (Fig. 7A and 7C). Yield of *P. secunda* in the MTN1 sites varied only by year ($P < 0.001$, F = 8.8; Fig. 7B).

Cheatgrass

Yield of cheatgrass varied in all three communities (Fig. 8A – C). Yields were significantly different for the *treatment × year* interaction on the WYOBAS ($P < 0.001$, F = 10.2) and MTN2 ($P < 0.001$, F = 23.4) communities. These results indicated cheatgrass yield increased in the burn treatments, over time, relative to controls (Fig. 8A and C). Treatment differences in the WYOBAS and MTN2 communities were apparent the sixth yr after fire where cheatgrass yield was 10% and 22% of total yield, respectively. Yield of cheatgrass in the MTN1 communities was unaffected for the model main effects and interaction and rarely represented > 1% of total yield (Fig. 7B).

Annual Forb

Annual forb yields varied in all three communities (Fig. 9A – C). Yields were significantly affected by the *treatment × year* interaction on the WYOBAS ($P < 0.001$, F = 10.2), MTN1 ($P = 0.035$, F = 2.5), and MTN2 ($P < 0.001$, F = 23.4) communities. These results indicated annual forb yield increased after fire compared with the controls. Annual forb composition on MTN1 and MTN2 plant communities was composed mainly of native species including blue-eyed Mary (*Collinsia parviflora* Lindl.), slender phlox (*Microsteris gracilis* [Hook.] Greene), tiny trumpet (*Collomia linearis* Nutt.), and tall willowherb (*Epilobium brachycarpum* C. Presl.). Annual forb composition on the WYOBAS plant communities was dominated by the non-native mustard, pale madwort (*Alyssum alyssoides* L.).

Discussion

The fire treatments in phase 1 and phase 2 juniper woodlands were all effective at increasing herbaceous yield and standing crop, 2 to 2.5-fold, by the second year following prescribed fire. These increases in herbaceous production are similar to results following burning of Wyoming big sagebrush (Wright and Klemmedson, 1965; Davies et al., 2007; Rhodes et al., 2010) and mountain big sagebrush steppe (Harniss and Murray, 1973; Davies et al., 2012). All three communities reached herbaceous yield potentials the third year after fire. Longer-term studies indicate that herbaceous yield and canopy cover potentials are reached 2 to 3 yr after fire in sagebrush steppe (Harniss and Murray, 1973; Bates and Davies, 2014; Bates et al., 2014; Miller et al., 2013, 2014). Recovery of herbaceous yield may take longer when more developed woodland sites are burned, especially when the understory is depleted either

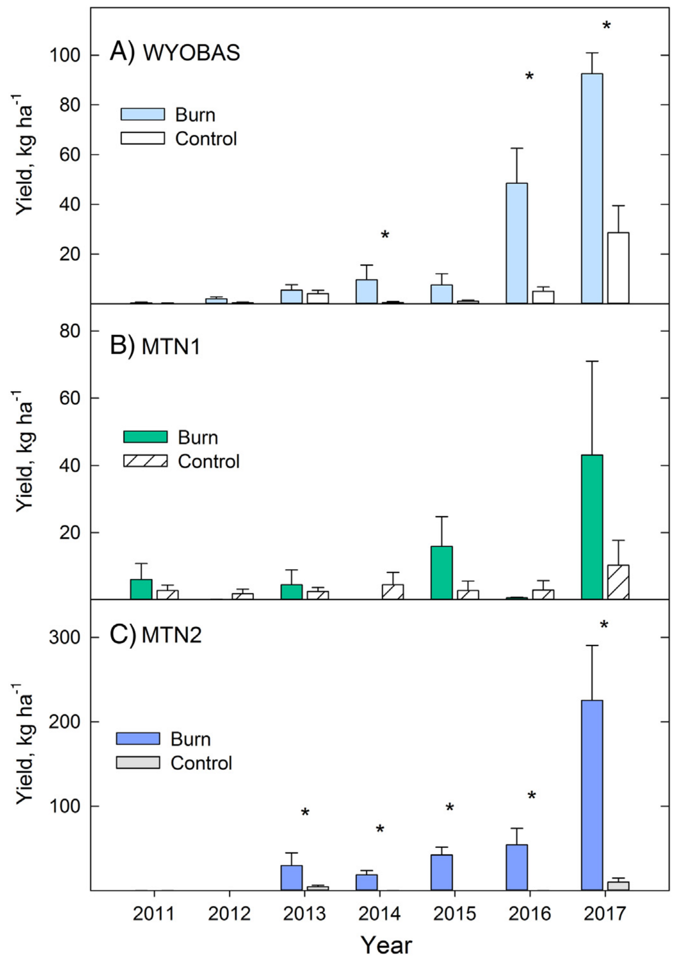

Figure 8. Cheatgrass yield (kg ha^{-1}) for (**A**) WYOBAS, (**B**) MTN1, and (**C**) MTN2 sites, Northern Great Basin Experimental Range, 2011 – 2017, for burned and control treatments. Values for 2011 are preburn data. Prescribed fires were applied in September 2011. *Asterisks* indicate significant differences between burned and control treatments within year ($P < 0.05$).

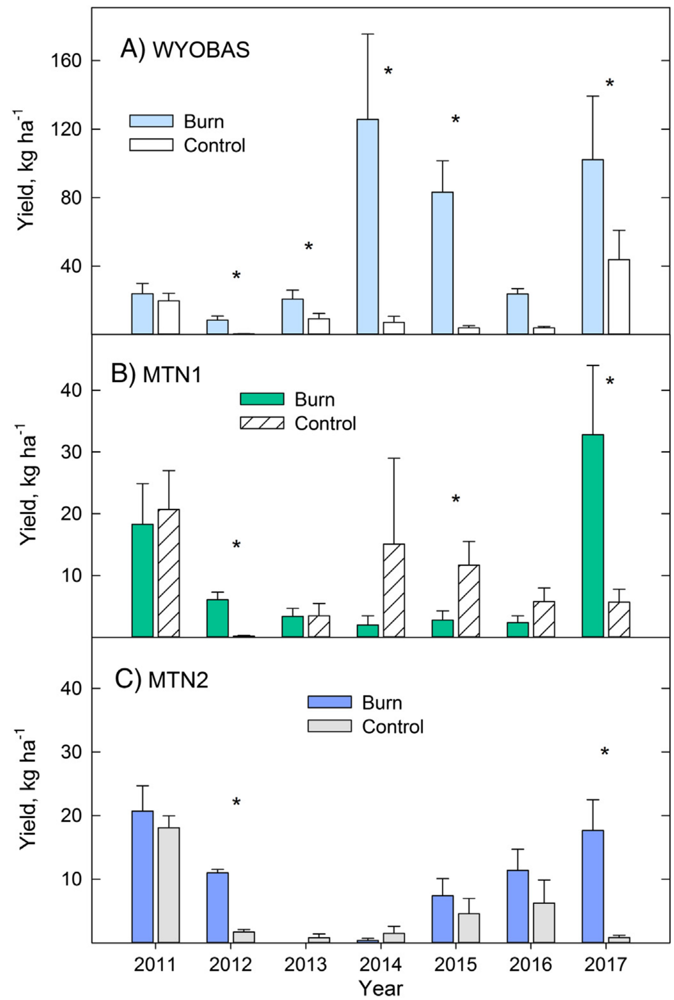

Figure 9. Annual forb yield (kg ha^{-1}) for (**A**) WYOBAS, (**B**) MTN1, and (**C**) MTN2 sites, Northern Great Basin Experimental Range, 2011 – 2017, for burned and control treatments. Values for 2011 are preburn data. Prescribed fires were applied in September 2011. *Asterisks* indicate significant differences between burned and control treatments within year ($P < 0.05$).

before tree control or because the fire treatment caused high mortality of native perennials (Bates et al., 2011a, 2013). In burned phase 3 western juniper woodlands, herbaceous yield was only 50 – 60% of site potential 4 yrs after fire (Bates et al., 2011a) and 6 yrs were required for herbaceous yield to reach site potential after tree cutting (Bates et al., 2005).

Herbaceous yields increased despite below-average precipitation the first 3 yrs after fire, including 2 yrs of drought. Yields increase because reduction of sagebrush and piñon-juniper following fire or mechanical treatments increases available soil water and nutrients (Bates et al., 2000, 2002; Roundy et al., 2014b; Bates and Davies, 2017).

Perennial Bunchgrass

Perennial bunchgrass yield dynamics mirrored the responses of total yield because bunchgrasses comprised the bulk of herbaceous yield after fire. After fire, perennial bunchgrass yield was 64%, 67%, and 79% of total yield in MTN2, WYOBAS, and MTN2, respectively. Most studies in sagebrush steppe and Phase 1 and 2 woodlands in the Great Basin report that increased yield and canopy cover of perennial bunchgrasses occur in the second or third yr following fire (Rhodes et al., 2010; Bates et al., 2013, 2014, 2016; Miller et al., 2013, 2014).

Perennial Forbs

Total perennial forb yield did not differ between burning and the controls in all three plant communities. Lack of perennial forb response to fire is common in the sagebrush steppe. Other studies have failed to detect any increase in perennial forb diversity (Fischer et al., 1996; Beck et al., 2009), abundance (Wrobleski and Kauffman, 2003), or cover and yield (Rhodes et al., 2010; Bates et al., 2011b, 2017) after burning in Wyoming big sagebrush communities. Also, burning of mountain big sagebrush communities does not always result in increased perennial forb cover, density, or yield (Fischer et al., 1996; Nelle et al., 2000; Bates et al., 2011a, 2014; Davies et al., 2012).

Lack of perennial forb response to burning in sagebrush steppe and juniper woodlands can result from 1) site characteristics or method of woodland treatment (Koniak, 1985; Bates et al., 2011a, 2014, 2017; Miller et al., 2014) or 2) specific responses by individual or groups of species (Pyle and Crawford, 1996; Wrobleski and Kauffman, 2003). This was evident when evaluating the response to fire of tall and mat-forming perennial forbs. The tall forb group is generally not vulnerable to fire damage because its growth points are protected below the soil surface (Brown and Smith, 2000; Miller et al., 2013). Tall forbs in MTN1 communities recovered after fire and, although their yields did not statistically differ from the controls, means did average 15 kg ha^{-1} more in the burned sites. The WYOBAS and MTN2 sites had a greater capacity for increased tall forb yields because yields were 1.6- and 2.5-fold greater after burning than the controls, respectively. Although tall forbs were not weighed by species or groups, it was observable that *Cichoreae* species and tailcup lupine (*Lupinus caudatus*

Kellogg) were the main increasers at all sites and long-leaf fleabane was also a major increaser on the MTN2 sites. Others have noted that burning of sagebrush steppe may increase a specific forb species or species assemblages (Pyle and Crawford, 1996; Wrobleski and Kauffman, 2003; Rhodes et al., 2010; Bates et al., 2011b).

Mat-forming perennial forbs are moderately to severely reduced by fire (Brown and Smith, 2000; Bates et al., 2011b; Miller et al., 2013), and this was evident in our study where yields of mat-forming forbs declined dramatically. This was particularly the case in the MTN2 community where mat-forming forbs typically represented about 50% of total perennial forb yield but after burning only averaged 9% of total yield. Mat-forming forbs on MTN2 sites were mainly represented by rosy pussytoes. Yields of mat-forming forbs have only slowly begun to recover in burned MTN1 and MTN2 communities and in the WYOBAS community since fire.

P. secunda

Response of *P. secunda* after fire in sagebrush steppe and juniper woodlands varies widely from severe reductions to large increases in cover and yield (Bates et al., 2009, 2011b, 2014). In our study, *P. secunda* yield increased on two sites, WYOBAS and MTN2, by 30% and 40%, respectively. *P. secunda* yield on the MTN1 community was unresponsive to treatment and, similar to the other two communities, was highly responsive to year. Others have reported high annual variability in *P. secunda* yield as a result of precipitation and temperature effects (Passey et al., 1982; Sneva, 1982; Bates et al., 2009).

Cheatgrass

Cheatgrass has become an established, naturalized component of sagebrush steppe understories. On intact steppe communities, with understories dominated by native perennials, cheatgrass is generally present, though in trace amounts (Davies et al., 2007; Davies et al., 2012; Miller et al., 2014). After fire the level of cheatgrass response varies considerably but is especially influenced by herbaceous perennial composition and abundance, as well as site characteristics (Chambers et al., 2007; Bates et al., 2013, 2014). In our study, cheatgrass yield increased in WYOBAS and MTN2 communities as a result of the fire treatment. On the WYOBAS community this is a typical response following fire (Bates et al., 2011b; Miller et al., 2014), as site characteristics leave areas open to colonization and expansion by annual grasses (Chambers et al., 2007, 2014). Cheatgrass was observed to be fairly well distributed and will likely remain a minor component of herbaceous yield in the WYOBAS community because herbaceous perennial composition and abundance remained intact after fire. Similar patterns of herbaceous perennial and cheatgrass yield and abundance were measured in burned Wyoming big sagebrush communities 11 yr after fire (Bates and Davies, 2014).

The increase of cheatgrass on the MTN2 sites was confined to severely burned patches, representing about 15% of total area, beneath fire-killed juniper and under burned cut trees. The dominance of cheatgrass in these zones resulted from 1) complete removal of perennial grasses (bunchgrasses and *P. secunda*) and a high percentage of the perennial forbs and 2) the lack of perennials recolonizing these areas after 6 yr. The increase of cheatgrass, as well as other non-native weeds, in severely burned areas has been measured after fire in midsuccessional juniper woodlands (Haskins and Gehring, 2004; Bates et al., 2016) and ponderosa pine forests (Crawford et al., 2001; Griffis et al., 2001; Dodson and Fiedler, 2006; McGlone et al., 2009; Sabo et al., 2009). It remains to be seen whether herbaceous perennials will displace cheatgrass in the severely burned patches. Studies indicate cheatgrass is less competitive with native perennials on similar sites because temperatures are cooler and soil water availability is higher (Chambers et al., 2007). In addition, we observed cheatgrass yield in the intercanopy of the burned MTN2 communities was low and similar to the MTN1 community sites. This indicates the value of burning woodlands in the earliest successional phase because as woodlands progress into phases 2 and 3, more area may be severely impacted by fire, resulting in more openings for cheatgrass and other weeds to exploit.

Cheatgrass took several years to respond to the fire treatments. The delayed response is typical of cheatgrass dynamics reported in other studies (Bates et al., 2011a, 2011b, 2013, 2014) and may result from lack of sufficient seed availability and dispersal the first few years after fire. In addition, in our study, cheatgrass response may have been limited because precipitation was below average the first 3 yr after fire. Cheatgrass productivity is positively linked to precipitation with yields varying as much as 12-fold between years of low and high precipitation (Ganskopp and Bedell, 1979; Sneva, 1982).

Annual Forbs

The increase in annual forbs after fire in plant communities is a response common to many other studies on burned sagebrush steppe and early-successional to midsuccessional piñon-juniper woodlands (Miller et al., 2014; Roundy et al., 2014a, 2014b; Bates et al., 2017). Annual forbs were almost entirely native species on the MTN1 and MTN2 communities. In other mountain big sagebrush sites, postfire annual forb cover has been dominated by native species (Bates et al., 2017). In the WYOBAS community, non-native pale alyssum was the main annual forb that increased after fire. Non-native annuals have also been the main annual forbs on other burned Wyoming and Basin big sagebrush communities (Bates et al., 2009, 2011a, 2017; Miller et al., 2014).

Management Implications

Prescribed fire in phase 1 and phase 2 western juniper woodlands more than doubled herbaceous forage for livestock and wild ungulates. The additional forage provided on burned areas affords managers greater flexibility to rest and treat additional sagebrush steppe where juniper is expanding, as well as rest or defer critical seasonal habitat for wildlife, such as sage grouse. Prescribed fire is a necessary tool to curtail and rollback the development of juniper woodlands in sagebrush steppe because mechanical treatments alone will likely fail to keep pace with current woodland expansion and infilling (Boyd et al., 2017). In addition, mechanical treatment of phase 1 juniper woodlands will not increase forage production and, at best, will yield but a 50% increase in phase 2 woodlands (Bates et al., 2016), which may limit grazing flexibility and management options at landscape levels.

Until sagebrush recovers on MTN1 and MTN2 communities, elevated herbaceous production may persist for up to 20 yr, which we base on forage dynamics reported by Harniss and Murray (1973). Herbaceous production will decline as mountain big sagebrush recovers, which has been measured to take between 20 and 40 yr (Harniss and Murray, 1973; Lesica et al., 2007; Ziegenhagen and Miller, 2009). On MTN1 and MTN2 communities, sagebrush seedlings were noticeable the first year post fire and those that established were producing seed by the second and third yr after fire. Wyoming big sagebrush may require 50 − 100 yr to recover (Baker, 2006; Lesica et al., 2007), although recovery can be faster when fires are not stand replacing and contain scattered individuals and pockets of sagebrush that provide a nearby seed source (Wambolt et al., 2001; Beck et al., 2009; Bates and Davies, 2014). The fires in WYOBAS communities were stand replacing, and there was no measurable establishment of sagebrush within the burns 6 yr after fire; thus, the higher herbaceous yields are likely to persist for many years.

Acknowledgments

The authors gratefully recognize the summer crews over the years for their hard work in collecting field data. The prescribed burn crew included Aleta Nafus, Rory and Emily O'Connor, Tony Runnels, Matt Madsen, and Jon Bates.

References

Andariese, S.W., Covington, W.W., 1986. Changes in understory production for three prescribed burns of different ages in ponderosa pine. Forest Ecology and Management 14, 193–203.

Anderson, E.W., Currier, W.F., 1973. Evaluating zones of utilization. Journal of Range Management 26, 87–91.

Baker, W.L., 2006. Fire and restoration of sagebrush ecosystems. Wildlife Society Bulletin 34, 177–185.

Bates, J.D., Davies, K.W., 2014. Cattle grazing and vegetation succession in burned sagebrush steppe. Rangeland Ecology & Management 67, 412–422.

Bates, J.D., Davies, K.W., 2017. Effects of juniper slash treatments on soil nutrient availability and plant composition in sagebrush steppe. Forest Ecology and Management 400, 631–644.

Bates, J., Miller, R.F., Svejcar, T.J., 2000. Understory dynamics in cut and uncut western juniper woodlands. Journal of Range Management 53, 119–126.

Bates, J., Svejcar, T.J., Miller, R.F., 2002. Effects of juniper cutting on nitrogen mineralization. Journal of Arid Environments 51, 221–234.

Bates, J., Miller, R., Svejcar, T., 2005. Long-term successional trends following western juniper cutting. Range Ecology and Management 58, 533–541.

Bates, J.D., Rhodes, E.C., Davies, K.W., Sharp, R.N., 2009. Post-fire succession in big sagebrush steppe with livestock grazing. Rangeland Ecology & Management 61, 98–110.

Bates, J.D., Davies, K.W., Sharp, R.N., 2011a. Shrub-steppe early succession following juniper cutting and prescribed fire. Environmental Management 47, 468–481.

Bates, J.D., Rhodes, E.C., Davies, K., 2011b. Impacts of fire on sage-grouse habitat and diet resources. In: Monaco, T. (Ed.), Proceedings of 16th Wildland Shrub Symposium, Logan, Utah, 20—24 May 2010; Natural Resources and Environmental Issues. Vol. 17 Article 15.

Bates, J.D., Davies, K.W., Sharp, R.N., 2013. Sagebrush steppe recovery after fire varies by development phase of *Juniperus occidentalis* woodland. International Journal of Wildland Fire 23, 117–130.

Bates, J.D., O'Conner, R., Davies, K.W., 2014. Vegetation response to seasonal burning of western juniper slash. Fire Ecology 10, 27–48.

Bates, J., Davies, K., and Svejcar, T. 2016. Juniper treatments and herbaceous production. *In:* Ochoa, C., and DeBoodt, T. [compilers]. Range field day, June 2016, Ecology and hydrology of western juniper, special report. Corvallis, OR, USA: Oregon State University, Agricultural Experiment Station. p. 46—53.

Bates, J.D., Davies, K.W., Hulet, A., Miller, R.F., Roundy, B., 2017. Sage-grouse groceries; forb response to piñon-juniper treatments. Rangeland Ecology & Management 70, 106–115.

Beck, J.L., Connelly, J.W., Reese, K.P., 2009. Recovery of greater sage-grouse habitat features in Wyoming big sagebrush following prescribed fire. Restoration Ecology 17, 393–403.

Boyd, C., Kerby, J., Svejcar, T.J., Bates, J.D., Davies, K.W., 2017. The sage-grouse habitat mortgage: effective conifer management in space and time. Rangeland Ecology & Management 70, 141–148.

Brown, J.K., Smith, J.K., 2000. Wildland fire in ecosystems: effects of fire on flora. General Technical Report RMRS-GTR-42-vol. 2. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, UT, USA 257 p.

Chambers, J.C., Roundy, B.A., Blank, R.R., Meyer, S.E., Whittaker, A., 2007. What makes Great Basin sagebrush ecosystems invasible by *Bromus tectorum*? Ecological Monographs 77, 117–145.

Chambers, J.C., Bradley, B.A., Brown, C.A., D'Antonio, C., Germino, M.J., Hardegree, S.P., Grace, J.B., Miller, R.F., Pyke, D.A., 2014. Resilience to stress and disturbance, and resistance to *Bromus tectorum* L. invasion in the cold desert shrublands of western North America. Ecosystems 17, 360–375.

Clary, W.P., Ffolliott, P.F., Jameson, D.A., 1968. Relationship of different forest floor layers to herbage production. General Technical Report RM-123. USDA, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO, USA 3 p.

Condon, L., Weisberg, P.J., Chambers, J.C., 2011. Abiotic and biotic influences on *Bromus tectorum* invasion and *Artemisia tridentata* recovery after fire. International Journal of Wildland Fire 20, 597–604.

Covington, W.W., Moore, M.M., 1994. Southwestern ponderosa forest structure changes since Euro-American settlement. Journal of Forestry 92, 39–47.

Crawford, J.A., Wahren, C.H., Kyle, S., Moir, W.H., 2001. Responses of exotic plant species to fires in *Pinus ponderosa* forests in northern Arizona. Journal of Vegetation Science 12, 261–268.

Davies, K.W., Bates, J.D., Miller, R.F., 2007. Short-term effects of burning Wyoming big sagebrush steppe in southeast Oregon. Rangeland Ecology & Management 60, 515–522.

Davies, K.W., Bates, J.D., Nafus, A.M., 2012. Comparing burning and mowing treatments in mountain sagebrush steppe. Environmental Management 50, 451–461.

Dodson, E.K., Fiedler, C.E., 2006. Impacts of restoration treatments on alien plant invasion in Pinus ponderosa forests, Montana, USA. Journal of Applied Ecology 43, 887–897.

Ffolliott, P.F., Clary, W.P., Larson, F.R., 1977. Effects of a prescribed fire in an Arizona ponderosa pine forest. USDA, Forest Service, Rocky Mountain Research Forest and Range Experiment Station, Fort Collins, CO, USA Research Note RM-336. 4 p.

Fischer, R.A., Reese, K.P., Connelly, J.W., 1996. An investigation on fire effects within xeric sage grouse brood habitat. Journal of Range Management 49, 194–198.

Ganskopp, D.C., Bedell, T.E., 1979. Cheatgrass and its relationship to climate: a review. Technical Report, no. 562. Oregon State University, Agricultural Experiment Station, Corvallis, OR, USA Available at:. http://ir.library.oregonstate.edu/concern/administrative_report_or_publications/h989r709x, Accessed date: 1 April 2018.

Griffis, K.L., Crawford, J.A., Wagner, M.R., Moir, W.H., 2001. Understory response to management treatments in northern Arizona ponderosa pine forest. Forest Ecology & Management 146, 239–245.

Harniss, R.O., Murray, R.B., 1973. 30 years of vegetal change following burning of sagebrush-grass range. Journal of Range Management 26, 322–325.

Haskins, K.E., Gehring, C.A., 2004. Long-term effects of burning slash on plant communities and *Arbuscular mycorrhizae* in a semi-arid woodland. Journal of Applied Ecology 41, 379–388.

Johnson, D.D., Miller, R.F., 2006. Structure and development of expanding western juniper woodlands as influenced by two topographic variables. Forest Ecology and Management 229, 7–15.

Koniak, S., 1985. Succession in pinyon-juniper woodlands following wildfire in the Great Basin. Great Basin Naturalist 45, 556–566.

Lesica, P., Cooper, S.V., Kudray, G., 2007. Recovery of big sagebrush following fire in southwest Montana. Rangeland Ecology & Management 60, 261–269.

Lentz, D.R., Simonson, G.H., 1986. A detailed soils inventory and associated vegetation of Squaw Butte Range Experiment Station. Special Report 760. Agricultural Experiment Station, Oregon State University, Corvallis, OR, USA 184 p.

Littell, R.C., Milliken, G.A., Stroup, W.W., Wolfinger, R.D., 1996. SAS system for mixed models. SAS Institute, Cary, NC, USA.

McGlone, C.M., Springer, J., Covington, W.W., 2009. Cheatgrass encroachment on a ponderosa pine ecological restoration project in northern Arizona. Ecological Restoration 27, 37–46.

Miller, R.F., Bates, J.D., Svejcar, T.J., Pierson, F.B., Eddleman, L.E., 2005. Biology, ecology, and management of western juniper. Oregon State University Agricultural Experiment Station, Corvallis, OR, USA Technical Bulletin 152, June 2005. 77 p.

Miller, R.F., Chambers, J.C., Pyke, D.A., Pierson, F.B., Williams, J.C., 2013. Fire effects on vegetation and soils in the Great Basin Region and the role of site characteristics. US Department of Agriculture, Forest Service, Rocky Mountain Station, Fort Collins, CO, USA RMRS-GTR-308. 136 p.

Miller, R.F., Ratchford, J., Roundy, B.A., Tausch, R.J., Hulet, A., Chambers, J., 2014. Response of conifer-encroached shrublands in the Great Basin to prescribed fire and mechanical treatments. Rangeland Ecology & Management 67, 468–481.

Miller, R.F., Tausch, R.J., McArthur, E.D., Johnson, D.D., Sanderson, S.C., 2008. Age structure and expansion of piñon-juniper woodlands: a regional perspective in the Intermountain West. Research Paper RMRS-RP-69. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO, USA 15 p.

Moore, M.M., Deiter, D.A., 1992. Stand density index as a predictor of forage production in northern Arizona ponderosa pine forest. Journal of Range Management 45, 267–271.

Nelle, P.J., Reese, K.P., Connolly, J.W., 2000. Long-term effects of fire on sage-grouse habitat. Journal of Range Management 53, 586–591.

Passey, H.B., Hugie, V.K., Williams, E.W., Ball, D.E., 1982. Relationships between soil, plant community, and climate on rangelands of the intermountain west. US Department of Agriculture Soil Conservation Service, Washington, DC, USA Technical Bulletin 1662. 52 p.

Pyle, W.H., Crawford, J.A., 1996. Availability of foods of sage grouse chicks following prescribed fire in sagebrush-bitterbrush. Journal of Range Management 49, 320–324.

Rhodes, E.C., Bates, J.D., Sharp, R.N., Davies, K.W., 2010. Fire effects on cover and dietary resources of sage-grouse habitat. Journal of Wildlife Management 74, 755–764.

Roundy, B.R., Miller, R.F., Tausch, R.J., Young, K., Hulet, A., Rau, B., Jessop, B., Chambers, J.C., Egget, D., 2014a. Understory cover responses to pinon-juniper treatments across tree dominance gradients in the Great Basin. Rangeland Ecology & Management 67, 482–494.

Roundy, B.A., Young, K., Cline, N., Hulet, A., Miller, R.F., Tausch, R.J., Rau, B., 2014b. Piñon-juniper reduction increases soil water availability of the resource growth pool. Rangeland Ecology & Management 67, 495–505.

Roundy, B.A., Hulet, A., Cline, N.L., Rau, B., Miller, R., Tausch, R., Chambers, J., 2015. Successional trends after treating pinyon-juniper encroached sagebrush steppe to reduce fuels. Society for Range Management 68th annual meeting. 31 January—6 February, 2015. SRM, Sacramento, CA, USA.

Sabo, K.E., Hull-Sieg, C., Hart, S.C., Bailey, J.D., 2009. The role of disturbance severity and canopy closure on standing crop of understory plant species in ponderosa pine stands in northern Arizona, USA. Forest Ecology & Management 257, 1656–1662.

Sneva, F., 1982. Relation of precipitation and temperature with yield of herbaceous plants in eastern Oregon. International Journal of Biometeorology 26, 263–276.

Wambolt, C.L., Walhof, K.S., Frisina, M.R., 2001. Recovery of big sagebrush communities after burning in southwestern Montana. Journal of Environmental Management 61, 243–252.

Wright, H.A., Klemmedson, J.O., 1965. Effect of fire on bunchgrasses of the sagebrush-grass region in southern Idaho. Ecology 46, 680–688.

Wrobleski, D.W., Kauffman, J.B., 2003. Initial effects of prescribed fire on morphology, abundance, and phenology of forbs in big sagebrush communities in southeastern Oregon. Restoration Ecology 11, 82–90.

Ziegenhagen, L.L., Miller, R.F., 2009. Post-fire recovery of two shrubs in the interiors of large burns in the Intermountain West. Western North American Naturalist 69, 195–205.