#918

Rangeland Ecology & Management 70 (2017) 356–362

Contents lists available at ScienceDirect

Rangeland Ecology & Management

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

Original Research

Plant Community Dynamics 25 Years After Juniper Control☆

Jon D. Bates [a,*], Tony Svejcar [b], Rick Miller [c], Kirk W. Davies [a]

[a] Rangeland Scientist, US Department of Agriculture, Agricultural Research Service (ARS), Burns, OR 97720, USA
[b] Rangeland Ecologist, Oregon State University, Eastern Oregon ARS, La Grande, OR 97850
[c] Professor Emeritus, Department of Animal and Rangeland Sciences, Oregon State University, Burns, OR 97720, USA

ARTICLE INFO

Article history:
Received 2 September 2016
Received in revised form 25 October 2016
Accepted 7 November 2016

Key Words:
Bromus tectorum
invasive annual grass
sagebrush-steppe
western juniper

ABSTRACT

The expansion of piñon-juniper woodlands over the past 100 − 150 yr in the western United States has resulted in large-scale efforts to kill trees and recover sagebrush steppe rangelands. Western juniper (*Juniperus occidentalis* spp. *occidentalis* Hook.) expansion in the northern Great Basin has reduced sagebrush-steppe productivity and habitat. Chainsaw cutting of western juniper woodlands is a commonly applied practice to kill trees and restore shrub-understory composition. Studies reporting vegetation response following juniper cutting have been limited to early successional stages. This study assessed successional dynamics spanning 25 yr following tree cutting on Steens Mountain, southeast Oregon. Herbaceous standing crop and yield and plant densities were compared between chainsaw cut (Cut) and uncut woodland (Control) treatments. Cut plots were treated in 1991. In the Cut, total standing crop and yield have remained fairly consistent since 1996 and on average were 8 times greater than the Control. Perennial grass yield was 2- to 20-fold greater in the Cut than the Control across measurement years and peaked 14 yr (2005) after treatment. Perennial bunchgrass yield declined to 30 − 40% of its peak value, and bunchgrass density declined from about 11 plants m^{-2} in 2005 to 7 plants m^{-2} between 2005 and 2016. Invasive annual grasses increased in yield and as a percentage of total yield from 3% to 20%, between 2005 and 2016. Juniper and shrub cover and density increases and greater annual grass yields in the Cut have likely contributed to declines in perennial bunchgrass density and yields. Juniper control will be necessary within 5 yr to maintain progression to sagebrush steppe, indicating a treatment longevity of about 25 − 30 yr. To lengthen the life expectancy of cutting and other mechanical control of piñon-juniper woodlands requires that all age classes of trees be controlled in the initial treatment.

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

Introduction

Juniper (*Juniperus* spp.) and piñon (*Pinus* spp.) coniferous woodlands have expanded and increased 2- to 10-fold across the Intermountain region of the western United States over the past 150 yr (Romme et al., 2009). Nearly 90% of the expansion has occurred in the sagebrush (*Artemisia* spp.) steppe (Miller et al., 2011). Woodland dominance reduces herbaceous productivity and diversity of shrub-steppe communities (Miller et al. 2000; Miller et al., 2014a; Miller et al., 2014b; Roundy et al., 2014), compromises diverse wildlife habitats (Baruch-Mordo et al., 2013; Noson et al., 2006; Reinkensmeyer et al., 2007), and may negatively impact hydrologic processes (Kormos et al., 2016; Peterson and Stringham, 2008; Pierson et al., 2007; Williams et al., 2016). To maintain or recover sagebrush steppe and other plant communities, piñon-juniper woodlands have been controlled by various mechanical treatments and prescribed fire since the 1950s. Vegetation response to woodland treatments are varied, and the literature has concentrated on reporting short-term (< 3 − 8 yr) herbaceous results. Evaluation of long term vegetation response is limited to a handful of studies, and despite many lacking adjacent untreated comparisons, they have been invaluable in describing woodland treatment effectiveness and major compositional and structural changes across multiple decades (Barney and Frischknecht, 1974; Bristow et al., 2014; Huffman et al., 2012; Koniak, 1985; Redmond et al., 2013; Skousen et al., 1989; Tausch and West, 1988). Long-term treatment evaluations have been located in single-leaf piñon *(Pinus monophylla)*, two-needle piñon *(Pinus edulis)*, and Utah juniper *(Juniperus osteosperma)* woodlands. In these systems, fire typically results in trees not significantly reestablishing on sites for 40 − 60 yr (Barney and Frischknecht, 1974; Koniak, 1985). Mechanical treatments tend to have shorter life expectancy, although with more complete tree control herbaceous production and cover can be maintained for nearly as long as fire (Clary, 1989; Redmond et al., 2013). Similar assessments have been absent for western juniper (*Juniperus*

☆ The Eastern Oregon Agricultural Research Center (ARS) is jointly funded by the US Department of Agriculture (USDA)-ARS and Oregon State Agricultural Experiment Station. Mention of a proprietary product does not constitute a guarantee or warranty of the product by the USDA, Oregon State University, or the authors and does not imply approval to the exclusion of other products. The USDA is an equal opportunity provider and employer.
* Correspondence: Jon D. Bates, Eastern Oregon Agricultural Research Center, 67826-A Hwy 205, Burns, OR 97720, USA.
E-mail address: jon.bates@oregonstate.edu (J.D. Bates).

http://dx.doi.org/10.1016/j.rama.2016.11.003
1550-7424/Published by Elsevier Inc. on behalf of The Society for Range Management.

occidentalis spp. *occidentalis*) woodlands of the northern Great Basin and Columbia Plateau.

We evaluated tree, shrub, and herbaceous composition responses over a period spanning 25 yr after cutting 90-yr-old western juniper stands in southeast Oregon. Previously, vegetation dynamics at this site were described 2 yr (Bates et al., 2000) and 13 yr after cutting (Bates et al., 2005a). These earlier evaluations indicated tree cutting was effective at increasing understory biomass, cover, and diversity (Bates et al., 2000). Perennial bunchgrass density and herbaceous cover and yield peaked and leveled off between the 6th and 13th yr after treatment (Bates et al., 2005a). Cheatgrass cover and yield peaked the 6th yr after cutting and declined to a minor understory component the 12th yr after treatment as perennial grass biomass and cover increased. Shrubs were slower to recover, and though juniper cover was < 1%, juniper density had increased to effectively restock the site.

We hypothesized that 25 yr after cutting, 1) shrub and juniper cover and density would have increased in the Cut treatment, 2) shrub cover and density would be greater in Cut versus Control, 3) juniper cover would be greater in Control but tree density would not differ between treatments, 4) herbaceous yield would be greater in Cut versus Control but would have declined as a result of increasing shrub and juniper presence, and 5) perennial herbaceous density would be greater in Cut than Control.

Materials and Methods

Site Description and Experimental Design

The study site was located on Steens Mountain in southeastern Oregon (118°36'E, 42°55'N). Elevation at the site is 1550 m, and aspect is west-southwest with a 22% slope. Precipitation occurs mostly in the winter through midspring. Summers are warm and dry. Water year precipitation at the site averaged 373 mm the past 12 yr and ranged from 243 to 566 mm (Fig. 1). Before cutting, juniper canopy cover averaged 27% and mature tree density was about 250 trees ha^{-1} (Bates et al., 2000). The plant association was basin big sagebrush/bluebunch wheatgrass-Thurber's needlegrass (*Artemisia tridentata* Nutt. spp. *tridentata* (Rydb.) Beetle/*Pseudoroegneria spicata (Pursh) A. Löve*—*Achnatherum thurberianum (Piper)* Barkworth. The interspace zone was 95% bare ground, shrub cover was < 1%, and Sandberg bluegrass (*P. secunda* Vasey) was the dominant understory species (Bates et al., 2000). This woodland would be classed a Phase 3 or late invasive stage because trees dominated the site (Miller et al., 2005). The site most closely fits a DROUGHTY SOUTH SLOPE 11-13 (280—330 mm) PZ (precipitation zone) ecological site (NRCS, 2016). Soils are shallow (40—50 cm deep), and the soil temperature regime is classed as frigid, though given the aspect and elevation the temperature regime tends toward a warmer range of frigid. The potential for this site is 15—20% sagebrush cover, and herbaceous production averages 830 kg ha^{-1} (NRCS, 2016). Site resilience and resistance were considered moderate on the basis of the classification system developed by Miller et al. (2014a) and Miller et al. (2014b).

Eight 0.9-ha blocks were established in June 1991. Each block was divided into two 0.45-ha—sized plots. One plot within each block was randomly assigned the cutting treatment (Cut), and the remaining plot was left as woodland (Control). In the Cut treatment, all mature trees and saplings > 20 cm in height were felled using chainsaws and loppers in August 1991. Felled trees were left in place (Bates et al., 2000). After 1993, four blocks were put back into pasture and the remaining four blocks were fenced and have not been grazed. Only ungrazed plots were measured for this study.

Vegetation Measurements

Understory measurements included density, standing crop, and yield at the functional group level. Functional groups were composed of *P. secunda*, perennial bunchgrasses (e.g., Thurber's needlegrass and bluebunch wheatgrass, invasive annual grass (cheatgrass [*Bromus tectorum* L.] and field brome [*Bromus arvensis* L.]), perennial forbs, and annual forbs. Criteria for grouping species in functional groups were described in Bates et al. (2000).

Density of perennial herbaceous species was measured inside 0.2-m^2 (0.4 × 0.5 m) frames. Plant density was estimated spatially by zone in 1991—1993, 1997, and 2003—2004. Cut areas were stratified into interspace, canopy (litter area formerly beneath standing trees), and debris (under cut trees) zones. In the Control, zones were stratified into interspace and canopy (within tree canopy dripline). Zonal measurement descriptions are referenced in Bates et al. (2000). Plant densities in 1994 and 2005, 2009, and 2016 were not stratified by zone. In these sample years, frames were placed every 2 m along five permanent 30.5-m transects.

Shrub and tree canopy cover was measured by line intercept along five, 30.5-m transect lines. Zonal areas (canopy, interspace, and debris) were also determined by line intercept along each transect. Shrubs and juniper seedlings and saplings (< 1 m tall) were counted in 2 × 30.5 m belt transects. Junipers (> 1 m height) were counted in 6 × 30.5 m belt transects.

In early June 1992, 1993, 1997, 2003, 2004, 2005, 2009, 2015, and 2016 herbaceous standing crop was harvested by functional group inside 25, 1-m^2 frames per experimental unit. Perennial bunchgrass was harvested to a 2-cm stubble height. *P. secunda* and other functional groups were clipped to near ground level. Harvested herbage was dried at 48°C for 2 d before weighing. Yield for *P. secunda* and perennial bunchgrasses was determined by sorting the current year's growth from standing crop (Bates et al., 2005a; Bates et al., 2005b). Standing

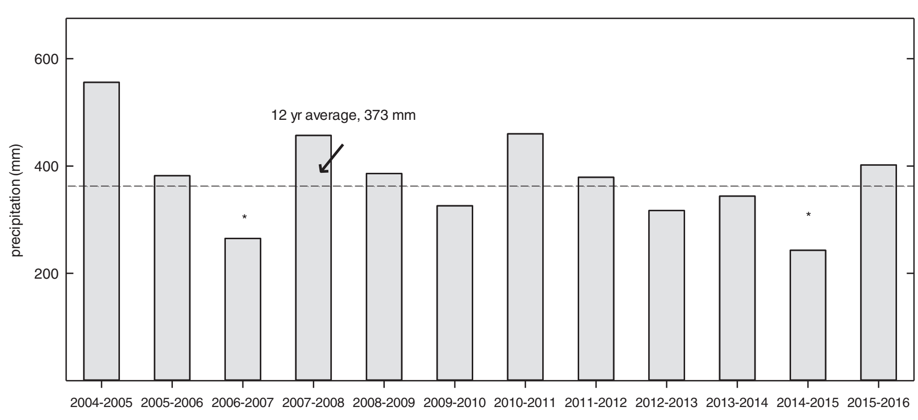

Figure 1. Water year (1 October to 30 September) precipitation at the study site, Steens Mountain, Oregon. Years marked with an asterisk are drought years when precipitation was below 75% of average.

crop includes current (yield) and past years' growth. Yield of perennial forbs, annual forbs, and cheatgrass were equivalent to their respective standing crop and required no sorting.

Statistical Analysis

Repeated measures using the PROC MIXED procedure (SAS 9.3) for a randomized complete block design was used to test year, treatment, and year by treatment effects. Response variables were herbaceous standing crop and yield, perennial herbaceous density, and woody canopy cover and density. An autoregressive order one covariance structure was used because it provided the best fit for data analysis (Littell et al., 1996). Statistical significance of all tests was set at $P < 0.05$. Zonal means for density response variables (for those years measured) were weighted by the relative area of each zone (interspace, debris, canopy). Interspace zones averaged 54% and 73%, and canopy zones were 25% and 27% of the area in Cut and Control treatments, respectively. The debris zone in the Cut treatment averaged 21% of the area. Weighted means for zones were summed to obtain pooled plot averages for response variables (Bates et al., 2000, 2005a). Data were tested for normality using the SAS univariate procedure, and data not normally distributed were arcsine square root transformed to stabilize variance. Back transformed means are reported. For brevity, data from some years were not shown as they are available in other articles (Bates et al., 1998, 2000, 2005a, 2007).

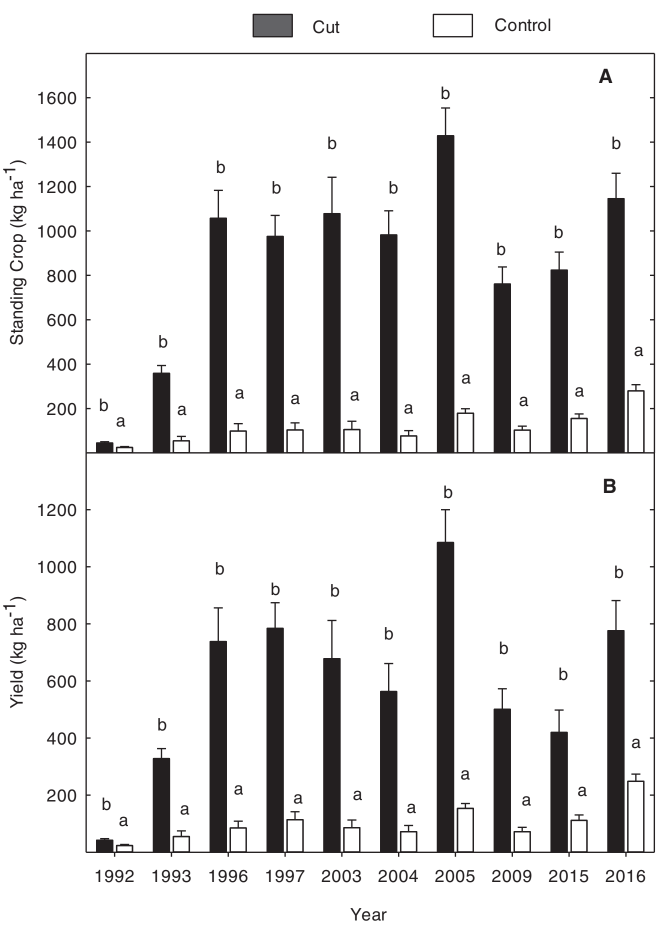

Figure 2. Biomass (kg ha^{-1}) in Cut and Control treatments from 1992 to 2016 (Steens Mountain, Oregon). **A,** Total standing crop and B. total herbaceous yield from 1992 to 2016. Values are means + one standard error. Different lowercase letters indicate significant differences ($P > 0.05$) between treatments within a year.

Results

Herbaceous Biomass

Herbaceous standing crop and yield were greater in the Cut compared with the Control after treatment. Main effects (year, treatment) and the interaction (year × treatment) were significant for total and functional group standing crop and yield (Fig. 2A and B; Table 1). Standing crop and yield increased in the Cut treatment between 1992 (first-year post cutting) and 1996 (fifth year post cutting). Total standing crop in the Cut fluctuated between 800 and 1400 kg ha from 1996 to 2016 and was 6 − 12 times greater compared with the Control. Standing crop and yield of herbaceous functional groups was also greater in the Cut than the Control, although for several of the functional groups this relationship was not consistent among years (Fig. 3A-E). Perennial grass yield was 2- to 20-fold greater in the Cut than the Control across measurement years (see Fig. 3A). Perennial grass standing crop and yield appear to have peaked in in the Cut in 2005, which also was an exceptionally high precipitation year. In years since, perennial grass yield in the Cut has been 30 − 40% of its peak value obtained in 2005. Invasive annual grass yield was greater in the Cut than in the Control (see Fig. 3B). Annual grass yield declined significantly in the Cut between 1997 and 2005, as perennial grass yield increased. In 2005, annual grass yield represented only 3% of total herbaceous yield. After 2005, annual grass yield again increased and represented about 20% of total herbaceous yield in 2015 and 2016. Yields of *P. secunda*, perennial forbs, and annual forbs were greater in the Cut compared with the Control (see Table 1), though within individual years, differences between the Cut and Control were, on occasion, not significantly different (see Fig. 3C-E). *P. secunda* yield over time has declined and become a less significant portion of total yield. During the last three measurement years, *P. secunda* represented about 3% of total herbaceous yield. Aside from 2016, perennial forb yields were 2- to 10-fold greater in the Cut than the Control (see Fig. 3D; Table 2). Annual forb yield, in most years, was 2-fold greater in the Cut compared with the Control. Annual forb

Table 1
Response variable *P* values from mixed-model analysis for the western juniper cutting study on Steens Mountain, southeast Oregon (1991 − 2016). Values in bold indicate significant treatment (Cut, Control) differences for main (treatment, year) effects and the interaction (treatment × year).

Response variables	Treatment	Yr	Treatment x Yr
Standing crop (SC)			
Perennial bunchgrass	< **0.001**	< **0.001**	< **0.001**
Poa secunda	< **0.001**	< **0.001**	< **0.001**
Total SC	< **0.001**	< **0.001**	< **0.001**
Yield			
Perennial bunchgrass	< **0.001**	< **0.001**	< **0.001**
Poa secunda	< **0.001**	< **0.001**	< **0.001**
Invasive annual grass[1]	**0.007**	< **0.001**	< **0.001**
Perennial forb[1]	< **0.001**	< **0.001**	0.080
Annual forb[1]	< **0.010**	< **0.001**	< **0.001**
Total yield	< **0.001**	< **0.001**	< **0.001**
Density			
Perennial bunchgrass	< **0.001**	**0.020**	**0.029**
Poa secunda	0.093	0.071	0.489
Perennial Forb	**0.013**	**0.045**	0.718
Basin big sagebrush	**0.008**	0.585	0.487
Rabbitbrush	**0.026**	0.066	0.089
Other shrubs	**0.004**	0.506	0.534
Western juniper	0.318	0.540	0.277
Woody Cover			
Basin big sagebrush	**0.004**	0.919	0.638
Rabbitbrush	**0.023**	0.253	0.894
Other shrubs	**0.042**	0.934	0.588
Western juniper	< **0.001**	0.087	0.473

[1] Standing crop and yield are equivalent for invasive annual grass, perennial forb, and annual forb life-forms.

yield was highly variable across years, representing 2 − 14% and 1 − 47% of total herbaceous yield in the Cut and Control treatments, respectively. Annual forbs were primarily composed of *Alyssum alyssoides* L. (pale alyssum), an old world species.

Herbaceous Density

Perennial bunchgrass density was greater in the Cut than the Control by the second growing season (1993) post treatment (Fig. 4A). Perennial bunchgrass density increased nearly sixfold by 1997. Between 1997 and 2005 bunchgrass density was fivefold to sixfold greater in the Cut than the Control. Between 2005 and 2016, bunchgrass density declined by about 30% in the Cut and density was about threefold greater in the Cut than the Control. Density of *P. secunda* was not different between treatments until 2005 (Fig. 4B). Since 2005, *P. secunda* density declined in the Cut while slightly increasing in the Control, thus accounting for the higher density values in the Control. Aside from one year (1997), perennial forb densities were not different between the Cut and Control treatments (Fig. 4C).

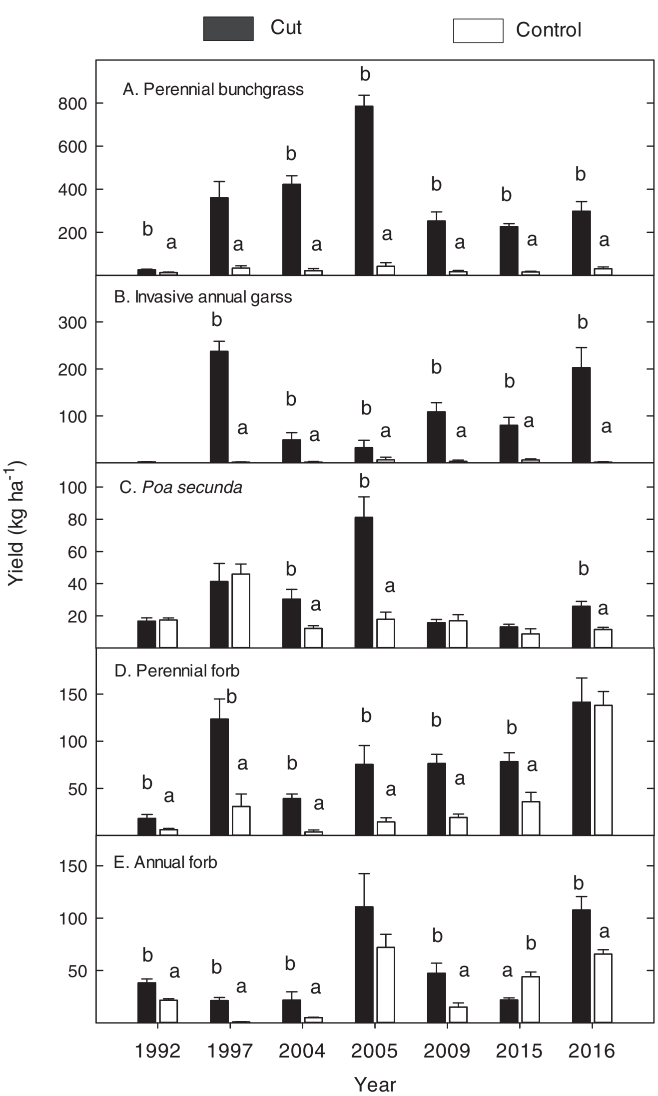

Figure 3. Yield (kg ha^{-1}) by functional group for Cut and Control treatments 1992 − 2016 (Steens Mountain, Oregon). **A,** Perennial bunchgrass. **B,** Invasive annual "grass". **C,** *Poa secunda*. **D,** Perennial forb. **E,** Annual forb. Data are means + one standard error. Significant differences ($P < 0.05$) between the treatments within year are indicated by different lowercase letters.

Table 2
Comparisons of tree and shrub cover and density values collected on Steens Mountain, Oregon (1991 − 2016), as affected by the juniper cutting treatment. Values are means ± one standard error. Different lowercase letters indicate significant differences between treatment means within a year and column ($P < 0.05$).

Yr & treatment	Tree cover	Shrub cover	Tree density[1]	Shrub density
	%	%	# ha^{-1}	# ha^{-1}
1991[2]				
Cut	24.4 ± 4.4	0.0 ± 0.0	316.2 ± 24.7	15.2 ± 12.3
Control	27.3 ± 1.0	0.0 ± 0.0	325.5 ± 20.7	13.2 ± 10.8
1992				
Cut	0.0 ± 0.0 a	0.0 ± 0.0	79.3 ± 23.5 a	13.4 ± 12.1
Control	25.6 ± 1.8 b	0.0 ± 0.0	328.3 ± 21.3 b	12.6 ± 9.4
1993				
Cut	0.0 ± 0.0 a	0.0 ± 0.0	85.4 ± 30.5 a	24.4 ± 22.1
Control	27.6 ± 1.6 b	0.0 ± 0.0	318.5 ± 27.3 b	11.2 ± 8.9
1997				
Cut	0.2 ± 0.2 a	1.4 ± 1.0	129.7 ± 29.3 a	887.5 ± 686.4 b
Control	24.7 ± 2.0 b	0.0 ± 0.0	335.4 ± 39.1 b	14.8 ± 14.8 a
2004				
Cut	0.8 ± 0.3 a	1.2 ± 0.9	268.2 ± 45.0	489.5 ± 159.7 b
Control	29.6 ± 4.0 b	0.0 ± 0.0	370.3 ± 44.3	8.3 ± 3.6 a
2009				
Cut	2.0 ± 0.8 a	4.2 ± 0.9 b	312.7 ± 26.7	1690.3 ± 540.1 b
Control	27.1 ± 2.2 b	0.2 ± 0.2 a	319.0 ± 24.6	6.3 ± 3.1 a
2016				
Cut	3.8 ± 0.5 a	5.5 ± 1.3 b	327.4 ± 49.5	1791.7 ± 490.4 b
Control	29.8 ± 2.7 b	0.2 ± 0.2 a	305.9 ± 23.4	6.0 ± 4.0 a

[1] Tree density includes all trees from seedling to large mature trees. Mature tree density averaged 230 trees ha^{-1} in woodland controls.
[2] Pretreatment data are presented for readers to compare treatment dynamics over the 25-yr study period.

Shrubs and Juniper

Basin big sagebrush and other shrub species increased in cover and density in the Cut, and establishment was highly variable because half the plots required complete recolonization by sagebrush (see Tables 1-2; Fig. 5A-C). Other species that established after cutting included yellow rabbitbrush (*Chrysothamnus viscidiflorus* [Hook.] Nutt.), rubber rabbitbrush (*Ericameria nauseosa* (Pall. ex Pursh) G. L. Nesom & Baird), Wood's rose (*Rosa woodsii* Lindl.), golden currant (*Ribes aureum* Pursh), squaw currant (*Ribes cereum* Dougl.), and gray horse-brush (*Tetradymia canescens* DC.). In 2016, sagebrush cover was 4.4% ± 0.7% in the Cut treatment and zero in the Control. Density of sagebrush has been stable at about 700 plants ha^{-1} since 2009 (see Fig. 5A). Rabbitbrush was the second most numerous shrub in the Cut treatment (see Fig. 5B), and cover was 0.9% ± 0.4%. Density of other shrub species, listed previously, that established after cutting, were greater in the Cut than the Control (see Fig. 5C). Combined, other shrub cover was about 0.1%.

Juniper cover since cutting has remained greater in the Control (Table 1 and 2). Juniper cover appears to recovering at an increasing rate in the Cut. Thirteen yr after cutting (2004), juniper cover was < 1% (see Table 2). In the past 12 yr (2004 to 2016), juniper cover has increased to 3.8%, which is about 13% of the Control. Density of juniper steadily increased in the Cut following treatment and by 2009 had equaled precutting values. Since 2004, tree density in the Cut has not differed from the Control.

Discussion

Herbaceous Dynamics

Twenty-five yr after cutting, herbaceous standing crop, herbaceous yield, and bunchgrass density remained greater in the Cut compared with Control woodlands. In the Cut, total standing crop and yield have remained fairly consistent since 1996 and on average are 8 times greater than the Control. This level of biomass response in the Cut is within the range of increases that may be expected following conifer control. In

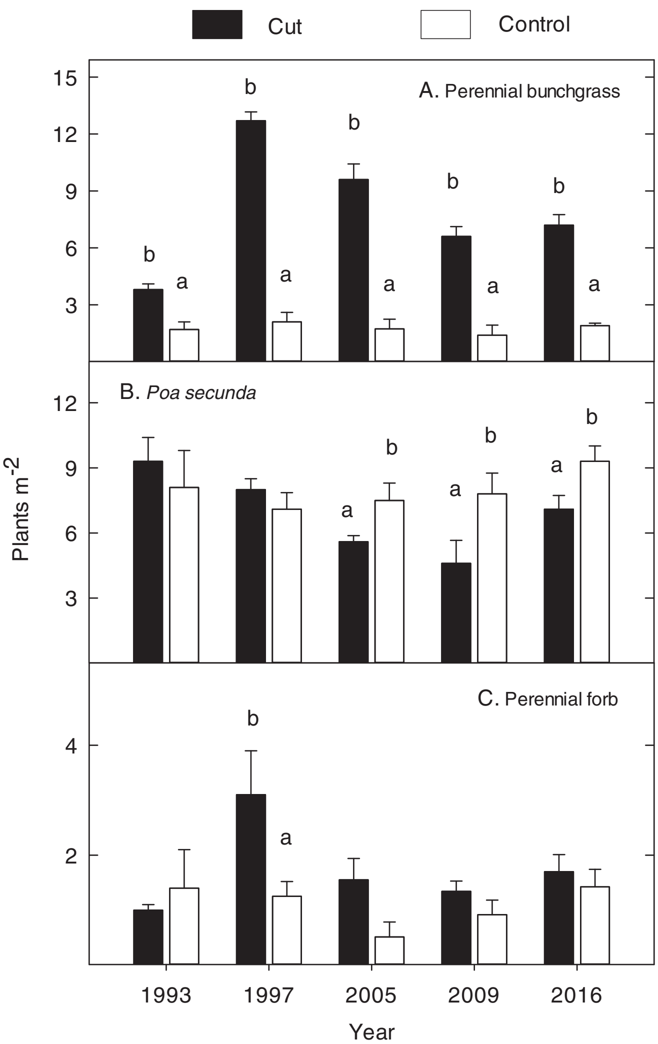

Figure 4. Herbaceous perennial densities (plants m^{-2}) for Cut and Control treatments, 1992 – 2016 (Steens Mountain, Oregon). **A,** Perennial bunchgrasses. **B,** *Poa secunda*. **C,** Perennial forbs. Values are means + one standard error. Significant differences ($P < 0.05$) between treatments within a year for each response variable are indicated by different lowercase letters.

western juniper and pinyon-juniper woodlands, 2- to 10-fold increases in herbaceous standing crop and yield have been measured following juniper control with peak levels typically beginning 2 – 6 yr following treatment (Young et al. 1985; Clary, 1987, 1989; Bates et al., 2005a, 2016). The variable response of standing crop and yield are influenced by site potential, woodland phase, residual herbaceous composition, woodland removal method, time since treatment, and annual weather events.

Although total herbaceous standing crop and yield remained stable for 20 yr, there were several shifts in composition. Perennial bunchgrass standing crop and yield had increased through 2005, the 14th yr after treatment, and increasingly represented the largest proportion of total yield (75% in 2005). The past three measurement years' (2009, 2015, 2016) standing crop and yield of perennial bunchgrasses declined by over 50% (compared with 1997, 2003-2005), and bunchgrass yield only represented 25% of total yield. The decline in perennial bunchgrass standing crop and yield coincided with the 30% decrease in bunchgrass density. Fewer bunchgrass plants and lower bunchgrass yield may have been a response to the continued presence of invasive annual grasses and increasing cover of shrubs and juniper. Interference by invasive annual grasses can limit the recruitment of perennial bunchgrasses (Eiswerth et al., 2009; Svejcar et al., 2014). Total woody cover for our study increased from about 2% in 2004 to 9.3% in 2016. Negative relationships between woody cover and herbaceous cover or yield are well established on similar ecological sites. For each 1% increase in sagebrush crown cover, crested wheatgrass production decreased by about 50 kg ha^{-1} (Rittenhouse and Sneva, 1976). Canopy cover of herbaceous species also decreased steeply with small increases in juniper and piñon cover on areas in the early stages of woodland development (Tausch and Tuellar, 1977; Miller et al. 2000). Maintaining herbaceous cover and productivity is important for forage production and is essential for minimizing runoff and erosion, which typically increase as woodlands develop (Pierson et al., 2007, 2014; Roundy et al., 2016).

The large increase in the yield of annual forbs, invasive annual grasses, and perennial forbs in 2016 likely resulted from ideal growth conditions. Temperatures were favorable and soil water remained near field capacity into the late spring (late May) of 2016, providing a combination of conditions that favor the growth of these life-forms (Bates et al., 2005b; Ganskopp and Bedell, 1979; Passey et al., 1982; Sneva, 1982).

Juniper and Shrub Dynamics

After 25 yr, the cutting treatment remained effective at slowing the recovery of tree cover but was not effective at preventing juniper

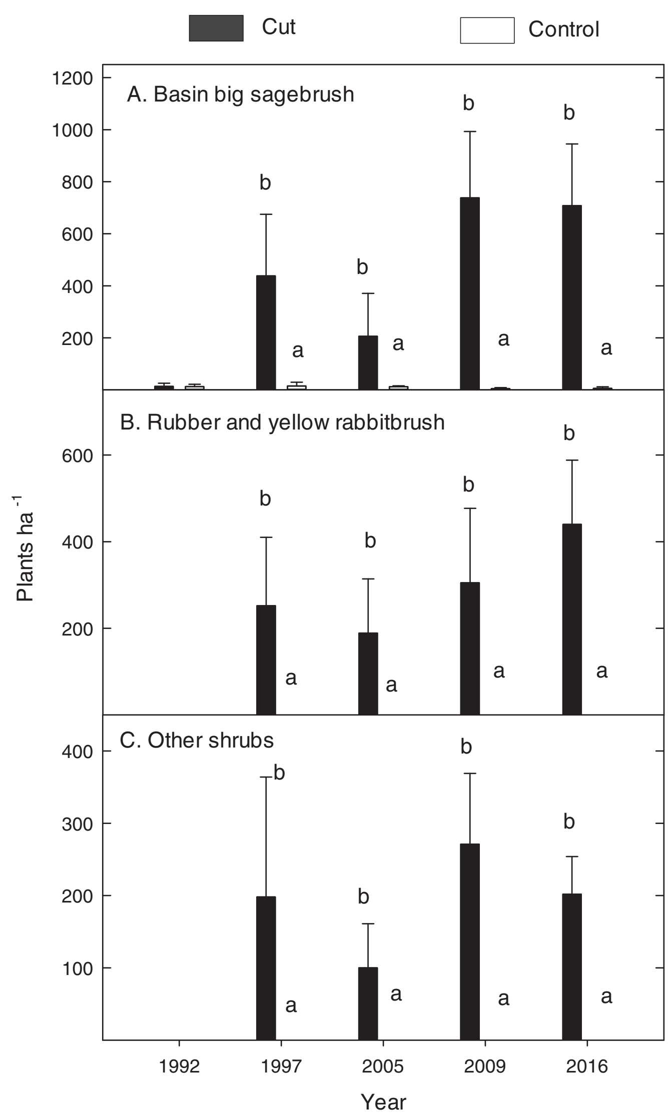

Figure 5. Shrub densities (plants ha^{-1}) for Cut and Control treatments, 1992 – 2016 (Steens Mountain, Oregon). **A,** Basin big sagebrush. **B,** Rubber and yellow rabbitbrush. **C,** Other shrub. Values are in means + one standard error. Significant differences ($P < 0.05$) between treatments within a year for each response variable are indicated by different lowercase letters.

density from recovering. Within 15 yr, juniper density in the Cut treatment had restocked to pretreatment values. About three-quarters of these junipers established from seed because one-quarter were small individuals (< 20 cm) that were not controlled in the 1991 treatment application (Bates et al., 2005a). Compared with fire, mechanical treatments such as cutting and chaining often result in low mortality of saplings and fail to deplete the seed bank, thus permitting more rapid returns to woodland dominance (Chambers et al., 1999). How quickly trees redominate appears to be related to the effectiveness of mechanical treatments at reducing tree cover. In our study, cutting reduced tree canopy cover by nearly 100% and post-treatment recovery juniper cover has been slowed as evidenced by total herbaceous productivity remaining fairly stable for 2 decades. In Utah, greater control of trees when chaining piñon-juniper woodlands was effective at maintaining shrub and herbaceous dominance for 18 − 40 yr following treatment across multiple sites (Clary, 1989; Redmond et al., 2013). However, others have measured rapid woodland recovery and declines in shrub and herbaceous components following treatments that were less effective at reducing tree cover and density (Skousen et al., 1989; Tausch and Tuellar, 1977). In Nevada, Tausch and Tuellar (1977) measured steady declines in understory cover and production within 5 − 8 yr after chaining of pinyon-juniper woodlands, as shrubs and trees reoccupied these sites.

Sagebrush and other shrub cover increased but remained far below site potential on the basis of the ecological site description (NRCS, 2016). For our site, total shrub cover typically ranges between 15% and 20%. The response of shrubs in this study has been slower than in other long-term studies in pinyon-juniper woodlands where shrub cover increased rapidly within 10 yr following chaining and cabling treatments (Redmond et al., 2013; Skousen et al., 1989; Tausch and Tuellar, 1977). Better shrub recovery appears to be associated with greater residual shrub cover or densities at the time of treatment. Compared with these studies, shrub cover and density on our site were extremely low before cutting and, for sagebrush and other species, required recolonization.

Implications

The success of vegetation management treatments depends on how well preferred plant communities recover and are maintained over time. The key to extending the life expectancy of cutting and other mechanical piñon-juniper woodland treatments, first recognized by Tausch and Tuellar (1977), is that almost all trees and saplings must be controlled. On our site, to maintain total herbaceous production for 2 decades, it was crucial to eliminate all mature western juniper as they composed almost 100% of the tree cover. Because juniper establishment and expansion rates are variable as a result of differing site characteristics (Johnson and Miller, 2006), the longevity of mechanical woodland treatments will also vary across sites (Chambers et al., 1999). However, maximizing the elimination of juniper and reducing tree cover, to extend treatment longevity, is likely to remain essential regardless of site and woodland characteristics.

Because mechanical methods are generally not successful at eliminating all piñon-juniper trees and because recruitment from the seedbank and recolonization continues, treated areas require follow-up tree control to retain or recover desired plant communities. Ideally this would be scheduled before trees begin impacting the preferred plant community. This typically occurs when tree cover is about one-fifth to one-third of a site's maximum potential tree cover (Tausch and Tuellar, 1977; Miller et al. 2000), which for our study is about 5%−10%. For our site, tree control is necessary within the next 5 yr to maintain progression to sagebrush steppe, indicating a cutting treatment longevity of about 25 − 30 yr.

Acknowledgments

We thank Otley Brothers Inc. for using their property during the study. Thanks to all the summer field crew members, across the years, who collected and entered data. We appreciate the comments and suggestions on the manuscript contributed by Dave Ganskopp, David Bates, and anonymous reviewers.

References

Barney, M.A., Frischknecht, N.C., 1974. Vegetation changes following fire in the pinyon-juniper type of west-central Utah. Journal of Range Management 27, 91–96.

Baruch-Mordo, S., Evans, J.S., Severson, J.P., Naugle, D.E., Maestas, J.D., Kiesecker, J.M., Falkowski, M.J., Hagen, C.A., Reese, K.P., 2013. Saving sage-grouse from the trees: a proactive solution to reducing a key threat to a candidate species. Biological Conservation 167, 233–241.

Bates J. D., K. W. Davies, and T. Svejcar. 2016. Juniper treatments and herbaceous production. pp. 46-53. *In:* C. Ochoa, and T. DeBoodt [compilers]. Range Field Day 2016 Progress Report, Ecology and Hydrology of Western Juniper, Special Report. Brothers, Oregon, June 2016. Oregon State University, Agricultural Experiment Station, Corvallis. 54 p. (Technical Bulletin). Available at: http://ecohydrology.oregonstate.edu/sites/labs/files/Ecology%20and%20Hydrology%20of%20Western%20Juniper_Special%20Report_OSU%20Range%20Field%20Day%202016_4.pdf. Accessed 20 August 2016.

Bates, J.D., Miller, R.F., Svejcar, T.J., 1998. Understory patterns in cut western juniper (*Juniperus occidentalis* spp. *occidentalis* Hook.) woodlands. Great Basin Naturalist 58, 363–374.

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

Bates, J.D., Miller, R.F., Svejcar, T., 2005a. Long-term successional trends following western juniper cutting. Rangeland Ecology & Management 58, 533–541.

Bates, J.D., Miller, R.F., Svejcar, T., 2007. Long-term vegetation dynamics in cut western juniper woodland. Western North American Naturalist 67, 549–561.

Bates, J., Svejcar, T.J., Miller, R.F., Angell, R., 2005b. The effects of precipitation timing on sagebrush steppe vegetation. Journal of Aridland Environments 64, 670–697.

Bristow, N.A., Weisberg, P.J., Tausch, R.J., 2014. A 40-year record of tree establishment following chaining and prescribed fire treatments in singleleaf pinyon (*Pinus monophylla*) and Utah Juniper *(Juniperus osteosperma)* woodlands. Rangeland Ecology & Management 67, 389–396.

Chambers, J.C., Vander Wall, S.B., Schupp, E.W., 1999. Seed and seedling ecology of piñon and juniper species in the pygmy woodlands of western North America. Botanical Review 65, 1–38.

Clary, W.P., 1987. Herbage production and livestock grazing on pinyon-juniper woodlands. In: Everett, R.L. (Ed.), Proceedings—Pinyon-Juniper Conference, Intermountain Research Station, USDA-Forest Service General Technical Report INT-215; 13-16 January 1986. USDA, Ogden, UT, USA 581 pp.

Clary, W.P., 1989. Test of RPA production coefficients and local assumptions for the pinyon-juniper ecosystem in central Utah. Intermountain Research Station, USDA-Forest Service, Research Rep. INT-403. USDA, Ogden, UT, USA 11 pp.

Eiswerth, M.E., Krauter, K., Swanson, S.R., Zielinski, M., 2009. Post-fire seeding on Wyoming big sagebrush ecological sites: regression analyses of seeded nonnative and native species densities. Journal of Environmental Management 90, 1320–1325.

Ganskopp, D.C., Bedell, T.E., 1979. Cheatgrass *(Bromus tectorum)* and its relationship to climate: a review. Special Report 562, Oct 1979. Oregon Agricultural Experiment Station, Corvallis, OR, USA 13 pp.

Huffman, D.A., Crouse, J.E., Chancellor, W.W., Fulé, P.Z., 2012. Influence of time since fire on pinyon–juniper woodland structure. Forest Ecology and Management 274, 29–37.

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.

Kormos, P.R., Marks, D., Pierson, F.B., Williams, C.J., Hardegree, S.P., Havens, S., Hedrick, A., Bates, J.D., Svejcar, T.J., 2016. Ecosystem water availability in juniper versus sagebrush snow-dominated rangelands. Rangeland Ecology & Management Available at: www.ScienceDirect.com. Accessed 7 July 2016.

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

Miller, R.F., Svejcar, T.J., Rose, J.R., 2000. Impacts of western juniper on plant community composition and structure. Journal of Range Management 53, 574–585.

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 Technical Bulletin 152. OSU, Corvallis, OR, USA Available at: http://extension.oregonstate.edu/catalog/html/tb/tb152/. Accessed 20 August 2016.

Miller, R.F., Chambers, J.C., Pellant, M., 2014a. A field guide for selecting the most appropriate treatment in sagebrush and piñon-juniper ecosystems in the Great Basin: evaluating resilience to disturbance and resistance to invasive annual grasses, and predicting vegetation response. General Technical Repoirt RMRS-GTR-322-rev. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO, USA 68 pp.

Miller, R.F., Knick, S.T., Pyke, D.A., Meinke, C.W., Hanser, S.E., Wisdom, M.J., Hild, A.L., 2011. Characteristics of sagebrush habitat and limitations to long-term conservation. In: Knick, S.T., Connelly, J.W. (Eds.), Greater sage-grouse: ecology and conservation of a landscape species and its habitat. Studies in Avian Biology 38. University of California Press, Berkeley, CA, USA, pp. 145–184.

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

Noson, A.C., Schmitz, R.F., Miller, R.F., 2006. Influence of fire and juniper encroachment on birds in high elevation sagebrush steppe. Western North American Naturalist 66, 343–353.

NRCS, 2016. Ecological site description. USDA Natural Resource Conservation Service, Washington, District of Columbia, USA Available at: http://esis.sc.egov.usda.gov/Welcome/pgApprovedSelect.aspx?type=ESD>. Accessed 1 August 2016.

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. Washington, DC, USA: US Department of Agriculture Soil Conservation Service. Technical Bulletin 1662. 52 pp.

Peterson, S.L., Stringham, T.K., 2008. Infiltration, runoff, and sediment yield in response to western juniper encroachment in southeast Oregon. Rangeland Ecology & Management 61, 74–81.

Pierson, F.B., Bates, J.D., Svejcar, T.J., Hardegree, S., 2007. Runoff and erosion after cutting western juniper. Rangeland Ecology & Management 60, 285–292.

Pierson, F.B., Williams, C.J., Kormos, P.R., Al-Hamdan, O.Z., 2014. Short-term effects of tree removal on infiltration, runoff, and erosion in woodland-encroached sagebrush steppe. Rangeland Ecology & Management 67, 522–538.

Redmond, M.D., Cobb, N.S., Miller, M.E., Barger, N.N., 2013. Long-term effects of chaining treatments on vegetation structure in piñon–juniper woodlands of the Colorado Plateau. Forest Ecology and Management 305, 120–128.

Reinkensmeyer, D.P., Miller, R.F., Anthony, R.G., Marr, V.E., 2007. Avian community structure along a mountain big sagebrush successional gradient. Journal of Wildlife Management 71, 1057–1066.

Rittenhouse, L.R., Sneva, F.A., 1976. Expressing the competitive relationship between Wyoming big sagebrush and crested wheatgrass. Journal of Range Management 29, 326–327.

Romme, W.H., Allen, C.D., Bailey, J.D., Baker, W.L., Bestelmeyer, B.T., Brown, P.M., Eisenhart, K.S., Floyd, M.L., Huffman, D.W., Jacobs, B.F., Miller, R.F., Muldavin, E.H., Swetnam, T.W., Tausch, R.J., Weisberg, P.J., 2009. Historical and modern disturbance regimes, stand structures, and landscape dynamics in piñon: juniper vegetation of the western United States. Rangeland Ecology & Management 62, 203–222.

Roundy, B.A., Farmer, M., Olson, J., Petersen, S.L., Nelson, D.R., Davis, J., Vernon, J., 2016. Runoff and sediment response to tree control and seeding on a high soil erosion potential site in Utah: evidence for reversal of an abiotic threshold. Ecohydrology http://dx.doi.org/10.1002/eco.1775 Available at Wiley Online Library, September 2016.

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

Skousen, J.G., Davis, J.N., Brotherson, J.D., 1989. Pinyon–juniper chaining and seeding for big game in central Utah. Journal of Range Management 42, 98–104.

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

Svejcar, T.J., James, J., Hardegree, S., Sheley, R., 2014. Incorporating plant mortality and recruitment into rangeland management and assessment. Rangeland Ecology & Management 67, 603–613.

Tausch, R.J., Tuellar, P.T., 1977. Plant succession following chaining of pinyon–juniper woodlands in eastern Nevada. Journal of Range Management 30, 44–49.

Tausch, R., West, N., 1988. Differential establishment of pinyon and juniper following fire. American Midland Naturalist 119, 174–184.

Williams, C.J., Pierson, F.B., Spaeth, K.E., Brown Jr., J.R., Al-Hamdan, O.Z., Weltz, M.A., Nearing, M.A., Herrick, J.E., Boll, J., Robichaud, P.R., Goodrich, D.C., Heilman, P., Guertin, D.P., Hernandez, M., Wei, H., Hardegree, S.P., Strand, E.K., Bates, J.D., Metz, L.J., Nichols, M.H., 2016. Incorporating hydrologic data and ecohydrologic relationships in ecological site descriptions. Rangeland Ecology & Management 69, 4–19.