

Sage Grouse Groceries: Forb Response to Piñon-Juniper Treatments ☆

Authors: Bates, Jonathan D., Davies, Kirk W., Hulet, April, Miller, Richard F., and Roundy, Bruce

Source: Rangeland Ecology and Management, 70(1) : 106-115

Published By: Society for Range Management

URL: <https://doi.org/10.1016/j.rama.2016.04.004>

BioOne Complete (complete.BioOne.org) is a full-text database of 200 subscribed and open-access titles in the biological, ecological, and environmental sciences published by nonprofit societies, associations, museums, institutions, and presses.

Your use of this PDF, the BioOne Complete website, and all posted and associated content indicates your acceptance of BioOne's Terms of Use, available at www.bioone.org/terms-of-use.

Usage of BioOne Complete content is strictly limited to personal, educational, and non - commercial use. Commercial inquiries or rights and permissions requests should be directed to the individual publisher as copyright holder.

BioOne sees sustainable scholarly publishing as an inherently collaborative enterprise connecting authors, nonprofit publishers, academic institutions, research libraries, and research funders in the common goal of maximizing access to critical research.



Sage Grouse Groceries: Forb Response to Piñon-Juniper Treatments[☆]



Jonathan D. Bates^{a,*}, Kirk W. Davies^a, April Hulet^b, Richard F. Miller^c, Bruce Roundy^d

^a Rangeland Scientists, US Department of Agriculture – Agricultural Research Service, Eastern Oregon Agricultural Research Center, Burns, OR 97720, USA

^b Assistant Professor, Department of Forest, Rangeland, and Fire Sciences, University of Idaho, Moscow, ID, 83844, –1142, USA

^c Professor Emeritus, Department of Animal and Rangeland Sciences, Oregon State University, Corvallis, OR 97331, USA

^d Professor, Plant & Wildlife Sciences, Brigham Young University, Provo, UT 84601, USA

ARTICLE INFO

Article history:

Received 1 January 2016

Received in revised form 14 March 2016

Accepted 25 April 2016

Key Words:

conifer woodland
fuel reduction
juniper
prescribed fire
sagebrush

ABSTRACT

Juniper and piñon coniferous woodlands have increased 2- to 10-fold in nine ecoregions spanning the Intermountain Region of the western United States. Control of piñon-juniper woodlands by mechanical treatments and prescribed fire are commonly applied to recover sagebrush steppe rangelands. Recently, the Sage Grouse Initiative has made conifer removal a major part of its program to reestablish sagebrush habitat for sage grouse (*Centrocercus urophasianus*) and other species. We analyzed data sets from previous and ongoing studies across the Great Basin characterizing cover response of perennial and annual forbs that are consumed by sage grouse to mechanical, prescribed fire, and low-disturbance fuel reduction treatments. There were 11 sites in western juniper (*Juniperus occidentalis* Hook.) woodlands, 3 sites in singleleaf piñon (*Pinus monophylla* Torr. & Frém.) and Utah juniper (*Juniperus osteosperma* [Torr.] Little), 2 sites in Utah juniper, and 2 sites in Utah juniper and Colorado piñon (*Pinus edulis* Engelm.). Western juniper sites were located in mountain big sagebrush (*A. tridentata* ssp. *vaseyana*) steppe associations, and the other woodlands were located in Wyoming big sagebrush (*A. tridentata* ssp. *wyomingensis*) associations. Site potential appears to be a major determinant for increasing perennial forbs consumed by sage grouse following conifer control. The cover response of perennial forbs, whether increasing (1.5- to 6-fold) or exhibiting no change, was similar regardless of conifer treatment. Annual forbs favored by sage grouse benefitted most from prescribed fire treatments with smaller increases following mechanical and fuel reduction treatments. Though forb abundance may not consistently be enhanced, mechanical and fuel reduction conifer treatments remain good preventative measures, especially in phase 1 and 2 woodlands, which, at minimum, maintain forbs on the landscape. In addition, these two conifer control measures, in the short term, are superior to prescribed fire for maintaining the essential habitat characteristics of sagebrush steppe for sage grouse.

Published by Elsevier Inc. on behalf of The Society for Range Management. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Introduction

During the past 150 years, juniper (*Juniperus* spp.) and piñon (*Pinus* spp.) coniferous woodlands have increased 2- to 10-fold in 9 ecoregions (Omernik 1987) spanning the Intermountain Area of the western United States (Romme et al. 2009). Woodland expansion is especially well documented in the Great Basin and Oregon High Desert where woodlands are estimated to occupy about 12 million hectares (Miller et al. 2005; Suring et al. 2005; Weisberg et al. 2007; Miller et al. 2008). About 90% of woodland expansion has occurred in sagebrush (*Artemisia* spp.) steppe habitat (Miller et al. 2011). Control of piñon-

juniper woodlands by mechanical treatments and prescribed fire has been applied since the 1950s. The early objectives of woodland control were to increase forage for livestock, restore big-game habitat, and improve watershed function (Tidwell 1987). These objectives remain a component of current woodland control programs; however, over time others have been added to address multiple resource priorities. Most recently, targeted conifer removal has been conducted on large scales to restore sagebrush habitat for greater sage grouse (*Centrocercus urophasianus*) and other shrub steppe species through private-public land partnerships associated with the Sage Grouse Initiative (SGI) (SGI 2014; NRCS 2015). Sage grouse are sensitive to conifer presence, abandoning lek sites when tree cover exceeds 4% and avoiding sites when trees begin exceeding 1 m in height (Casazza et al. 2011; Baruch-Mordo et al. 2013). Increases in conifer cover and density cause declines in cover and structure provided by sagebrush and bunchgrasses, as well as reducing the abundance of perennial and annual forbs (Miller et al. 2000, 2005; Casazza et al. 2011; Knick et al. 2013a, 2013b; Roundy et al. 2014). Forbs are seasonally important,

[☆] The Eastern Oregon Agricultural Research Center is jointly funded by the US Department of Agriculture – Agricultural Research Service and Oregon State Agricultural Experiment Station.

* Correspondence: Jonathan D. Bates, US Dept of Agriculture – Agricultural Research Service, Eastern Oregon Agricultural Research Center, Burns, OR 97720, USA. Tel.: +1-541-573-8932.

E-mail address: jon.bates@oregonstate.edu (J.D. Bates).

amounting to 50–80% of the diet of sage grouse during prenesting and brood-rearing in the spring and summer (Barnett and Crawford 1994, Drut et al. 1994).

There is no information on how conifer treatments directly benefit sage grouse, although some inferences can be made on the basis of treatment method and the woodland phase treated. For example, mechanical control of conifers in phase 1 and 2 woodlands will maintain or quickly recover the major characteristics of shrub-steppe habitat, as treatment disturbance is minimal compared to fire (Maestas et al. 2015). Prescribed fire in these two woodland phases removes sagebrush with recovery taking 20 to 40 years on mountain big sagebrush (*A. tridentata* ssp. *vaseyana* [Rydb.] Beetle) sites (Harniss and Murray 1973; Lesica et al. 2007; Ziegenhagen and Miller 2009) and likely longer periods of time on Wyoming big sagebrush (*A. tridentata* ssp. *wyomingensis* Beetle and A. Young) steppe (Baker 2006; Beck et al. 2009; Wambolt and Payne 1986). Fire may enhance the response of forbs used by sage grouse, although published data are limited and often conflicting. Burning in Wyoming big sagebrush communities has not been effective at increasing perennial forb abundance, and the responses of annual forbs have mainly been dominated by invasive species (Fischer et al. 1996; Bates et al. 2009; Beck et al. 2009). In mountain big sagebrush communities, perennial and annual forbs have increased or not changed after fires and cutting (Bates et al. 2009, 2014; Davies et al., 2011a, 2011b). Information on the response of species and genera specifically consumed by sage grouse has, however, been limited (Nelle et al. 2000; Miller et al. 2014).

We analyzed data sets from previous and ongoing studies that contain detailed forb genera and species response to conifer treatments in sagebrush steppe. Specifically, we evaluated the cover response of perennial and annual forbs, consumed by sage grouse, to mechanical, prescribed fire (landscape level), and fuel reduction treatments. Here, fuel reduction treatments are winter and spring burning of cut trees and slash with minimal site disturbance to shrub and herbaceous components. Treatments were conducted in woodlands in five western states spanning all three woodland expansion phases (for phase descriptions see Miller et al. 2005; Romme et al. 2009). We hypothesized that 1) fire treatments would have greater forb cover response compared with fuel reduction or mechanical tree control and untreated controls, 2) perennial forb response would be greater following prescribed fire treatments in phase 1 and 2 woodlands compared with phase 3 woodlands and controls, 3) in mechanical treatments, perennial forb cover in phase 1 and phase 2 woodland treatments would not differ from untreated controls and would be greater than treated phase 3 woodlands, and 4) annual forb cover would be greater in phase 3 woodlands than phase 1 and 2 woodlands after mechanical treatment.

Methods

Study Sites

Sites were located in southwest Idaho, Nevada, California, eastern Oregon, and Utah. Studies included woodland treatments performed on single sites and others spanning multiple sites. Data collections ranged from the first 3 to 10 years post treatment (Table 1). Commonalities among the studies were that 1) conifer treatments were applied to woodlands expanding into big sagebrush steppe and sage grouse habitat and 2) before treatment, the understory was largely composed of native grasses and forbs and exotic invasive species were either absent or minor components of the herb layer. There were 11 sites in western juniper (*Juniperus occidentalis* spp. *occidentalis* Hook.) woodlands, 3 sites in singleleaf piñon (*Pinus monophylla* Torr. & Frém.) and Utah juniper (*Juniperus osteosperma* [Torr.] Little), 2 sites in Utah juniper, and 2 sites in Utah juniper and Colorado piñon (*Pinus edulis* Engelm.). Western juniper sites were in northwestern California, eastern Oregon, and southwestern Idaho and were located in mountain big sagebrush steppe associations (Table 1). These sites were the Hart

Mountain (Hart Mt), Northern Great Basin Experimental Range (NGBER), High Desert (two sites; Otley Ranch, Squaw Butte), Joint Fire Science mountain big sagebrush (JFSMTN), South Mountain (Owyhee), and Steens Mountain (Steens Mt.) studies. Sites for the other woodlands were in eastern Nevada and western Utah and were located in Wyoming big sagebrush steppe associations and were the Joint Fire Science Wyoming big sagebrush (JFSWYO) sites. Further site descriptions are referenced in the associated literature (see Table 1), except for the NGBER study, which was new. The NGBER site is a mountain big sagebrush/Idaho fescue (*Festuca idahoensis*) association located on north- and east-facing slopes (10–20%) at 1500–1650 m. The ecological site is a Droughty Loam 11–13 PZ (NRCS 2006; 2010). Before treatment, juniper canopy cover averaged 15% and tree density (>1.5 m tall) averaged 145 trees ha⁻¹. The intercanopy was 51% bare ground, sagebrush cover was 6.1%, and Idaho fescue and perennial forbs were the main herbaceous species. The site was classified as a phase 2 woodland because trees codominated with shrub and perennial herbaceous plants. For woodland phase classification we used criteria developed by Miller et al. (2000, 2005).

Experimental Design and Treatment Application

The Owyhee, High Desert, Hart Mt, NGBER, JFSMTN, and JFSWYO studies were randomized complete block designs, and the Steens Mt. study was a completely randomized design (see Table 1). Treatment applications are briefly described in Table 1, and, aside from the NGBER study, further details can be referenced in the citations for each study.

The NGBER site included prescribed fire and fuel reduction treatments, as well as untreated controls, each replicated five times. Treatment plots were 0.4 ha–1.0 ha. In the prescribed fire treatment, 10–20% of the trees were cut in October 2010 and left to dry for 11 months before the fire application. The felled trees were used to augment shrub and herbaceous fuels to maximize killing of remaining live trees. Prescribed fire plots were burned 19 September, 2011 using strip head fires. All remaining live trees and sagebrush were killed by the fires. All fine surface fuels were consumed, and few sagebrush skeletons remained. Burning of felled juniper consumed all 1-hr, 10-hr, and 100-hr fuels and partly consumed 1000-hr fuels. Large perennial bunchgrass density was reduced by almost 30% from 19.2 ± 0.7 to 13.8 ± 1.1 plants m⁻². All trees in the fuel reduction treatment were felled in June 2011. After 8 months all felled trees were burned individually on 8–9 February, 2012 using drip torches with 50:50 diesel and gas mixture. Fuel consumption was confined to the felled juniper, and burning consumed 1-hr and 10-hr fuels. Sagebrush cover and perennial plant densities were unaffected. Fuel reduction treatments referenced in this article were similarly of low disturbance, with felled trees burned in the winter and spring.

Vegetation Measurements

Canopy cover of perennial and annual forbs was measured inside 0.2-m² (0.4 × 0.5 m) frames at 3-m intervals along 50-m transects in the Steens Mt., Owyhee, Hart Mt, and NGBER studies. The number of transects were four or five in each treatment replicate depending on the study. Canopy cover in the High Desert studies was sampled in three zones (interspace, beneath felled tree, around the stump) and pooled by weighted average to determine whole-plot effects for juniper control treatments (Bates et al. 2014). Canopy cover in the JFSMTN and JFSWYO was sampled with the point-intercept method along 30-m transects (Herrick et al. 2009; Miller et al. 2014) between 2006 and 2014. Additional sampling detail is provided in the references provided in Table 1.

Analysis

Cover of perennial and annual forbs was sorted to species and genera known to be consumed by sage grouse as reported by Klebenow and

Table 1
Piñon-juniper control studies providing site, plant community, source, woodland phase treated, woodland treatment method and replication, years post treatment, tree species, treatment application, and fire severity.

Study, plant community, and site description source	Woodland phase treated	Woodland treatments and treatment reps	Years post treatment	Tree species	Treatment application	Fire severity
Hart Mt Mountain big sagebrush/grassland (Davies et al. 2012)	Phase 1	Brush-beating (8 reps), Rx fire (6 reps)	4 (2008–2011)	Western juniper	10/2007 10–11/2007	Light Light to moderate
NGBER Mountain big sagebrush/Idaho fescue (this article)	Phase 2	Rx fire (5 reps), fuel reduction (5 reps)	4 (2012–2015)	Western juniper	Cut 10/2010; Rx fire 9/2011 Fuel reduction 2/2012	High Light
Steens Mt. Mountain big sagebrush/Idaho fescue (Bates et al. 2013)	Phases 2 and 3	Prescribed (Rx) fire ^{1,a} (11 phase 2 reps; 8 phase 3 reps)	8 (2004–2012)	Western juniper	Cut 5/2003 and burned 9/2003	High both treatments
Owhyee Mountain big sagebrush/Letterman's needleglass Mountain big sagebrush/Columbia needleglass (Bates et al. 2009)	Phase 3	Rx fire	4 (2003–2006)	Western juniper	Both cut 10/2002 and burned 10/2003	High both treatments
High Desert Mountain big sagebrush/Idaho fescue (2 sites; Otley Ranch; Squaw Butte) (Bates et al. 2014)	Phases 2 and 3	Cutting ² Rx fire Fuel reduction ³ (4 to 5 reps per treatment at each site)	6 (2007–2012)	Western juniper	Cut 6/2006 Cut 7/2006 Fuel reduction 1/2007 Rx fire 9/2006	None (cut) None to light High
JFSMTN Mountain big sagebrush (3 sites)	Phases 1, 2, & 3 Phases 1, 2, & 3	Cutting Rx fire Cutting	6–8 (2007–2014) 6–8	Western juniper Utah juniper, singleleaf piñon, Colorado piñon	Cut, Rx fire and mastication were conducted across 3 yr (2006–2008) at the various sites	None (Cut, mastication) Moderate to severe for Rx fires
JFSWYO Wyoming big sagebrush steppe (6 sites) (Miller et al. 2014; Roundy et al. 2014)		Rx fire Mastication	(2007–2014)			

¹ Prescribed fires were done in the fall, September and October. Fire severity is moderate to high.

² Clear-cutting treatments done with the use of chainsaws; cut trees were left in place.

³ Fuel reduction treatments were clear-cutting followed by winter and spring burning of cut trees.

⁴ Sites are treated as replications (Miller et al. 2014).

^a No untreated controls for this study.

Gray (1968), Peterson (1970), Wallestad et al. (1975), Barnett and Crawford (1994), Drut et al. (1994), Pyle and Crawford (1996), Gregg et al. (2008), and Gregg and Crawford (2009) (Table 2). Perennial and annual forbs were also sorted for forbs not used by sage grouse and life-form totals. For analysis, variables tested were perennial forbs consumed by sage grouse, annual forbs consumed by sage grouse, other perennial forbs, other annual forbs, and total perennial and annual forbs. For Owyhee, High Desert, Hart Mt., and NGBER studies, repeated measures analysis of variance (ANOVA) for a completely randomized design using a mixed model (PROC MIX; SAS Institute, Cary, NC, USA) was used to test for year, treatment, and year-by-treatment interactions for the forb response variables (Bates et al. 2011a, 2013; Davies et al. 2012). Data analysis for Steens Mt. was by repeated measures ANOVA for a completely randomized design using a mixed model (Bates et al. 2013). An autoregressive order one covariance structure was used in the models as it provided the best fit for data analysis (Littell et al. 1996). Mean separation involved comparison of least squares using the LSMEANS statement (SAS Institute, Cary, NC, USA). JFSMTN (three sites) and JFSWYO (six sites) forb data were averaged for each site for all years (2007/2008–2014) following treatment. Forb response variables were analyzed using mixed-model ANOVA (JFSWYO) and GLM (JFSMTN) procedures for a randomized block (blocked by site) design to test for differences among prescribed fire, clear-cutting, mastication

Table 2

List of the common greater sage grouse—relevant forb genera and species (in italics) for the conifer control sites.

Perennial forbs	Annual forbs
<i>Achillea millefolium</i>	<i>Blepharipappus scaber</i>
<i>Agoseris</i> spp.	<i>Collomia</i> spp.
<i>Antennaria</i> spp.	<i>Collinsia parviflora</i>
<i>Arabis</i> spp.	<i>Epilobium</i> spp.
<i>Arnica</i> spp.	<i>Eriastum</i> spp.
<i>Astragalus</i> spp.	<i>Gayophytum</i> spp.
<i>Calochortus</i> spp.	<i>Gilia</i> spp.
<i>Castilleja</i> spp.	<i>Lactuca serriola</i> *
<i>Crepis</i> spp.	<i>Linanthus</i> spp.
<i>Eriogonum</i> spp.	<i>Microsteris</i> spp.
<i>Lomatium</i> spp.	<i>Mimulus</i> spp.
<i>Mertensia</i> spp.	<i>Phacelia</i> spp.
<i>Microseris</i> spp.	<i>Tragopogon dubius</i> *
<i>Phacelia</i> spp.	
<i>Phlox longifolia</i>	
<i>Potentilla</i> spp.	
<i>Taraxacum officinale</i> *	
<i>Trifolium</i> spp.	
<i>Vicia americana</i>	
<i>Viola</i> spp.	

* Indicates non-native.

(JFSWYO only), and control treatments. All data were tested for normality using the Shapiro-Wilk test (Shapiro and Wilk 1965) and were log transformed before analyses when necessary. Significant interactions were followed by tests of simple effects at $\alpha = 0.05$.

Results

General Tendencies

Forb response was variable and influenced by several factors including site characteristics, woodland phase, forb life-form (perennial, annual), and treatment method. One strong tendency among the studies was that annual forbs consumed by sage grouse, and total annual forbs in general, had greater increases in cover following fire than mechanical (mastication, cutting) and fuel reduction treatments. Sage grouse perennial forb cover was generally 45–60% of total perennial forb cover, and when perennial forb cover increased, this occurred within the first 3 years post treatment.

Hart Mt. Study

In this study, perennial forb cover increased equally in the treatments and control over time ($P = 0.011$). Consequently, cover did not differ among treatments and controls ($P = 0.458$; Fig. 1A). Sage grouse annual forbs increased, and treatments were greater than controls post treatment ($P = 0.001$; Fig. 1B).

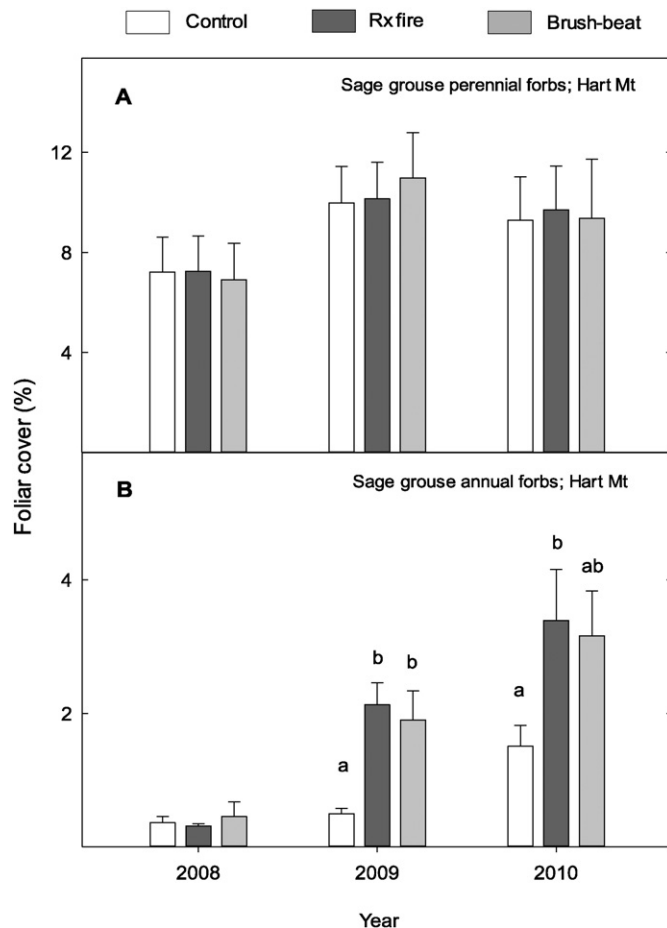


Figure 1. Canopy cover of (A) sage grouse—relevant perennial forbs and (B) sage grouse relevant annual forbs, at Hart Mountain (mountain big sagebrush/Idaho fescue association), Oregon, 2008–2010, following prescribed fire (Rx fire) and brush beating in phase 1 western juniper woodlands. Data are in means + one standard error. Means sharing a common lowercase letter are not significantly different ($P > 0.05$). The pretreatment year was 2007.

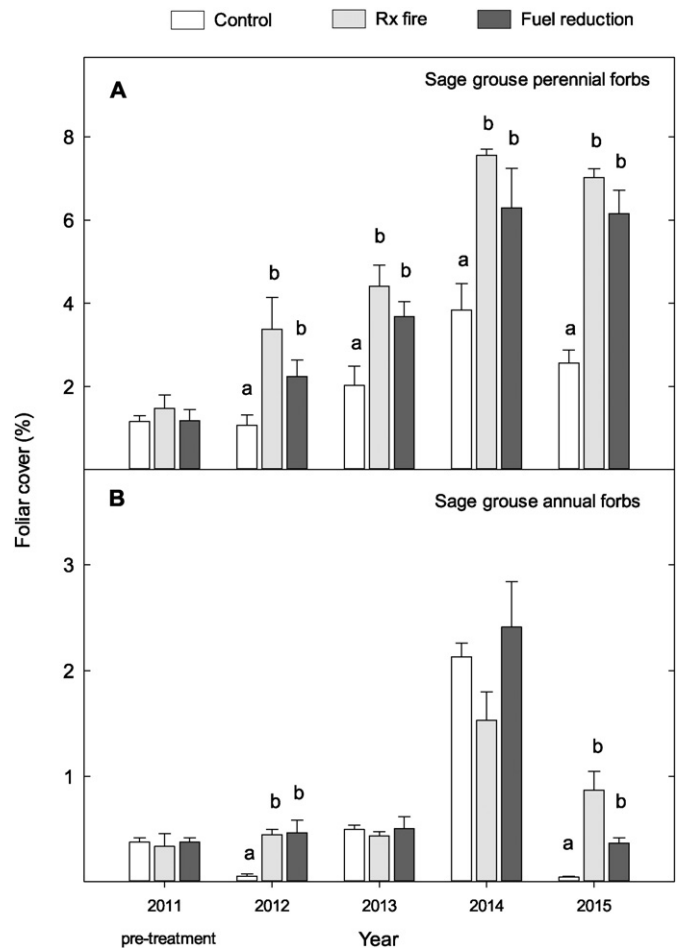


Figure 2. Canopy cover of (A) sage grouse—relevant perennial forbs and (B) sage grouse—relevant annual forbs, NGBER (mountain big sagebrush/Idaho fescue association), Oregon, 2011–2015, following prescribed fire (Rx fire) and fuel reduction treatments in phase 2 western juniper woodlands. Data are in means + one standard error. Means sharing a common lowercase letter are not significantly different ($P > 0.05$). The pretreatment year was 2011.

Northern Great Basin Experimental Range Study

At the NGBER site, sage grouse perennial forb cover increased in prescribed fire and fuel reduction treatments ($P < 0.001$) and was nearly three times greater than the controls ($P < 0.001$; Fig. 2A). Sage grouse annual forb cover did not increase in either treatment compared with controls ($P = 0.623$; Fig. 2B). In 2 individual years (2012, 2015) sage grouse annual forbs were greater in the treatments than the control; however, cover did not exceed 1% in the treatments and was less than 0.1% in the controls.

Steens Mt.

In the Steens Mt. study, woodland phase had a major effect on perennial forb cover before and after prescribed fire. Sage grouse perennial forb cover was 6 times greater in phase 2 than in phase 3 sites before treatment ($P < 0.001$; Fig. 3A). After fire, forb cover increased and was three to six times greater in phase 2 than in phase 3 sites ($P = 0.006$). Sage grouse annual forb cover was greater in phase 2 than phase 3 sites after fire, though not for all years, resulting in a phase-year interaction ($P = 0.028$).

Owyhee

In the Owyhee study, sage grouse perennial forbs increased about threefold ($P < 0.001$) and were two times greater in both cut-burn

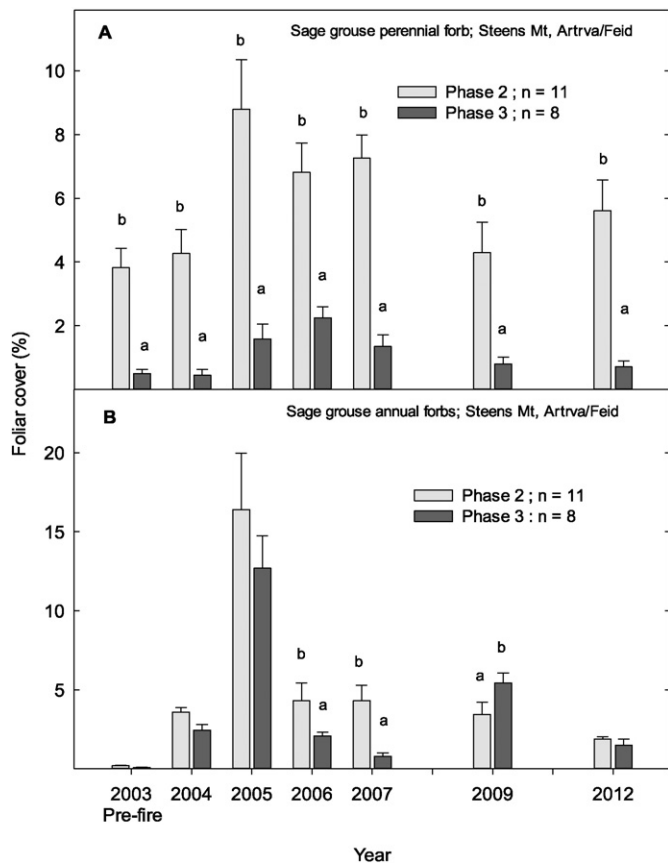


Figure 3. Canopy cover of (A) sage grouse—relevant perennial forbs and (B) sage grouse—relevant annual forbs, Steens Mountain (mountain big sagebrush/Idaho fescue association), Oregon, 2011–2015, following prescribed fire (Rx fire) treatments in phase 2 and 3 western juniper woodlands. Data are in means + one standard error. Means sharing a common lowercase letter are not significantly different ($P > 0.05$). The pretreatment year was 2003.

treatments of the mountain big sagebrush/Letterman's needlegrass (*Achnatherum lemmonii* [Vasey] Barkworth var. *lemmonii*; Artrva/Acle) site post fire than the control (Fig. 4A; $P = 0.038$). Sage grouse perennial forbs about doubled in both cut-burn treatments on the mountain big sagebrush/Columbia needlegrass (*Achnatherum nelsonii* [Scribn.] Barkworth subsp. *nelsonii* Show; Artrva/Acle) site post fire ($P < 0.001$; Fig. 4B), but treatments did not differ from the control ($P = 0.407$; Fig. 4B). Sage grouse annual forbs increased and were significantly greater at the Artrva/Acle ($P < 0.001$; Fig. 4C) and Artrva/Acle ($P < 0.001$; Fig. 4D) sites than their respective controls post fire.

High Desert

Sage grouse perennial forb cover at the Otley Ranch site increased in the treatments (clear-cut, prescribed fire, fuel reduction) and control over time ($P < 0.001$; Fig. 5A). Following treatment, sage grouse perennial forb cover was 1.5 times greater in the treatments than the control ($P < 0.001$). Sage grouse perennial forb cover at the Squaw Butte site increased in all treatments over time ($P < 0.001$) but was significantly greater in clear-cut and fuel reduction treatments than prescribed fire ($P < 0.001$; Fig. 5B). Sage grouse annual forb cover at the Otley Ranch site increased in all treatments and control over time; however, the increase was greatest in the prescribed fire treatment (year-by-treatment interaction, $P < 0.001$; Fig. 5C). The treatments had greater cover than the controls between 2008 and 2012 (only 2009 and 2012 shown). Sage grouse annual forb cover at the Squaw Butte site increased in all treatments, yet the increase was greatest in the prescribed fire treatment (year-by-treatment interaction, $P = 0.002$; Fig. 5D). Cover was

greater in the prescribed fire than clear-cut and fuel reduction treatments between 2008 and 2012 (only 2009 and 2012 shown).

Joint Fire Science Mountain Big Sagebrush

Sage grouse perennial forb cover for JFSMTN type was unaffected by phase ($P = 0.190$) and treatment ($P = 0.057$) (Fig. 6A). Total perennial forb cover also did not differ among phase ($P = 0.136$) and treatment ($P = 0.182$) (Fig. 6B). Lack of cover differences for phase and treatment may be due to limited and variable site potential at the three sites. At two of the sites, sage grouse perennial forb cover barely exceeded 1% or 2%, even after treatment (Fig. S1 in the online version at <http://dx.doi.org/10.1016/j.rama.2016.04.004>). Sage grouse annual forb and total annual forb cover was three to five times greater in prescribed fire treatments than the control and clear-cut treatments ($P < 0.001$; Fig. 6C and D). Phase did not influence sage grouse and total annual forb covers ($P = 0.638$ and $P = 0.485$, respectively). Sage grouse annual forb cover represented 50–83% of total annual forb cover.

JFSWYO

Sage grouse perennial forb cover for JFSWYO was greater in clear-cut and prescribed fire treatments than the mastication treatment, especially in phase 1 woodland ($P = 0.007$; Fig. 7A). Cover of sage grouse and total perennial forbs was also greater in phase 1 and 2 than phase 3 woodlands ($P = 0.005$; $P < 0.001$, respectively). Sage grouse annual forb and total annual forb cover were greater for prescribed fire than the control and clear-cut and mastication treatments ($P < 0.001$, $P < 0.001$; Fig. 7B). Sage grouse annual forb cover represented only 6–17% of total annual forb cover. The majority of annual forbs were represented by four non-native species (curveseed butterwort, *Ceratocephala testiculata* [Crantz] Roth; desert madwort, *Alyssum desertorum* Stapf; pale madwort, *Alyssum alyssoides* [L.]; redstem stork's bill, *Erodium cicutarium* [L.] L'Hér. ex Aiton).

Discussion

An overall result of treating piñon-juniper woodlands is that herbaceous cover and production increase significantly, usually between two-fold and sevenfold depending on site characteristics and potentials (Miller et al. 2005, 2013; Bates et al. 2014). However, the response of herbaceous life-forms (e.g., bunchgrasses, perennial forbs, annual forbs) to conifer treatments is also sensitive to woodland phase treated and method of conifer control (Koniak 1985; Bates and Svejcar 2009; Bates et al. 2013, 2014; Miller et al. 2014; Roundy et al. 2014; Bybee et al. 2016). For perennial and annual forbs consumed by sage grouse, their response was influenced by treatment method, particularly after prescribed fire and cutting (Table 3).

Treatment Responses

We hypothesized that prescribed fire treatments would develop greater forb cover compared with fuel reduction or mechanical tree control and untreated controls. On only three of the studies were sage grouse perennial forbs greater after fire than controls (High Desert, NGBER, Owyhee-Artrva/stle), and only one study measured higher sage grouse perennial forb cover after fire than a mechanical treatment (JFSWYO—mastication). Results from other studies measured increased, no change, or decreased perennial forb cover following piñon-juniper cutting and fuel reduction (Vaitkus and Eddleman 1987; Bates et al. 2005, 2006; Baughman et al. 2010; Ross et al. 2012; O'Conner et al., 2013). This mixed response of perennial forbs to conifer treatments parallels results measured in burned or mechanically treated sagebrush steppe free of tree encroachment. Sage grouse perennial forbs did not increase after fire or mechanical treatments in several studies

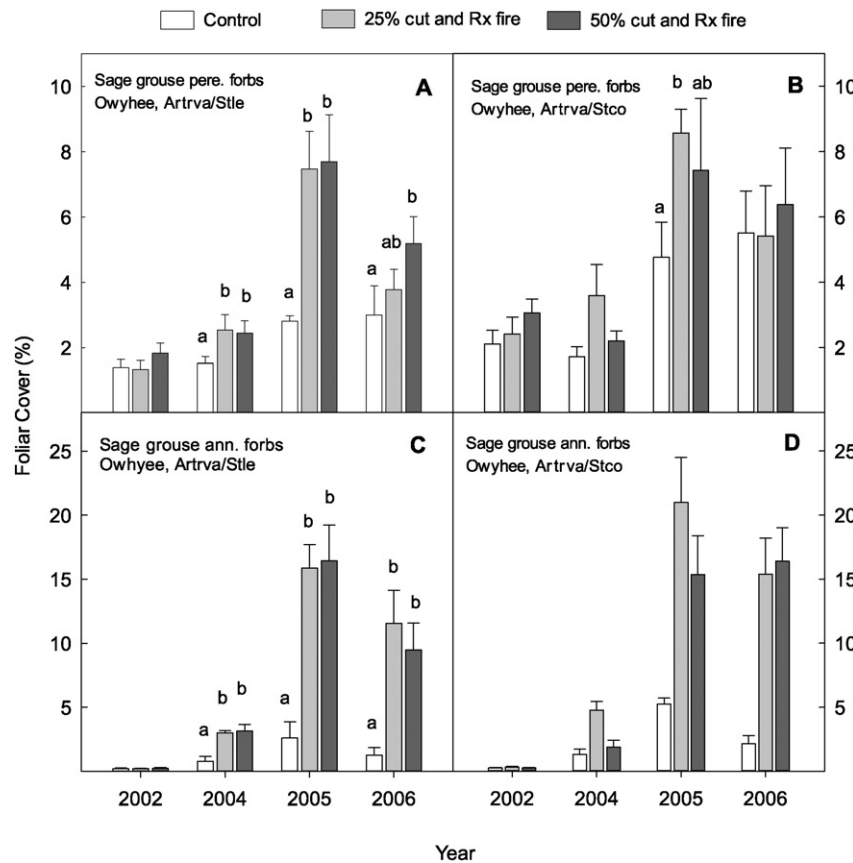


Figure 4. Canopy cover of sage grouse – relevant perennial forbs for the (A) mountain big sagebrush/Letterman's needlegrass association (Artrva/Acle) and (B) mountain big sagebrush/columbia needlegrass association [Artrva/Acne]; canopy cover of sage grouse – relevant annual forbs for the (C) Artrva/Acle association, and (D) Artrva/Acne association, Owyhee study sites, Idaho, 2002–2006, following prescribed fire (Rx fire) treatments in phase 3 western juniper woodlands. Data are in means + one standard error. Means sharing a common lowercase letter are not significantly different ($P > 0.05$). The pretreatment year was 2002. Sites were burned 10/2003).

conducted in Wyoming big sagebrush (Beck et al. 2009; Rhodes et al. 2010; Bates et al. 2011b; Davies et al., 2011a, 2011b) and mountain big sagebrush (Fischer et al. 1996; Nelle et al. 2000). Elsewhere, perennial forbs increased following burning and mechanical treatments in sagebrush-steppe (Wambolt and Payne 1986; Wroblewski and Kauffman 2003; Dahlgren et al., 2006).

Sage grouse perennial forb cover was generally similar among prescribed fire, clear-cutting, and fuel reduction treatments, indicating that response was independent of conifer removal method (see Table 3). However, the mastication treatment in the JFSWYO study clearly suppressed perennial forb response compared with prescribed fire and clear-cutting. Potential reasons for the lack of perennial forb recovery in the mastication treatment could be damage from vehicle traffic or accumulation of shredded conifer debris smothering forbs. Smothering by felled juniper can eliminate or reduce cover and density of some bunchgrass species (Bates et al. 2007). Mastication of piñon-juniper trees may not, in all cases, prove detrimental to forb recovery. Ross et al. (2012) and Bybee et al. (2016) measured significant increases in perennial forb cover following mastication of piñon-juniper in Utah.

Prescribed fire treatments increased sage grouse annual forb cover compared with controls and other treatments on most of the studies (see Table 3). Exceptions were the NGBER and Hart Mt. studies. The lack of annual forb response at Hart Mt. was likely a result of fires being of only light to moderate severity, leaving sagebrush skeletons and causing little damage to perennial herbaceous vegetation (Davies et al. 2012). Herbaceous recovery at the NGBER study has been mainly dominated by perennial species with limited annual response.

Annual forbs (sage grouse and total) were almost entirely composed of native species on the western juniper studies (Hart Mt., High Desert, NGBER, Owyhee, Steens Mt., JFSMTN). On the fire treatments at the

JFSWYO sites, however, annual forb response was dominated by exotics (e.g., curvseed butterwort, desert madwort, pale madwort, redstem stork's bill). In other Wyoming big sagebrush communities, annual forbs have mainly consisted of exotics following fire and brush beating (Rhodes et al. 2010; Bates et al. 2011b; Davies et al., 2011a, 2011b). Diet studies do not indicate that these exotics are consumed by sage grouse (Klebenow and Gray 1968; Peterson 1970; Wallestad et al. 1975; Barnett and Crawford 1994; Drut et al., 1994). However, diet studies also suggest that forb consumption varies across sites and sage grouse are selective in their foraging, consuming exclusively leaves of some forbs, buds and flowers in others, and all parts of other species (Barnett and Crawford 1994). Additional study is necessary to determine if sage grouse might consume some of these exotics. Sage grouse consume native annual mustards (Peterson 1970); therefore, there is the potential that grouse may use exotic madworts.

Woodland Phase

The comparisons of conifer treatments across woodland phase, although limited, indicate that treating woodlands in phases 1 and 2 might result in better recovery of perennial and annual forbs, including those used by sage grouse. The Steens Mt. and JFSWYO studies measured greater sage grouse perennial forb (both studies) and annual forb (Steens Mt.) cover following treatment in phase 1 and 2 than phase 3 woodlands. As woodlands progressively dominate areas, herbaceous understories are often depleted (Miller et al. 2005; Roundy et al. 2014). This potentially makes it more likely that early woodland phases that have sufficient herbaceous understories will respond more favorably to conifer treatments than phase 3 woodlands (Maestas et al. 2015).

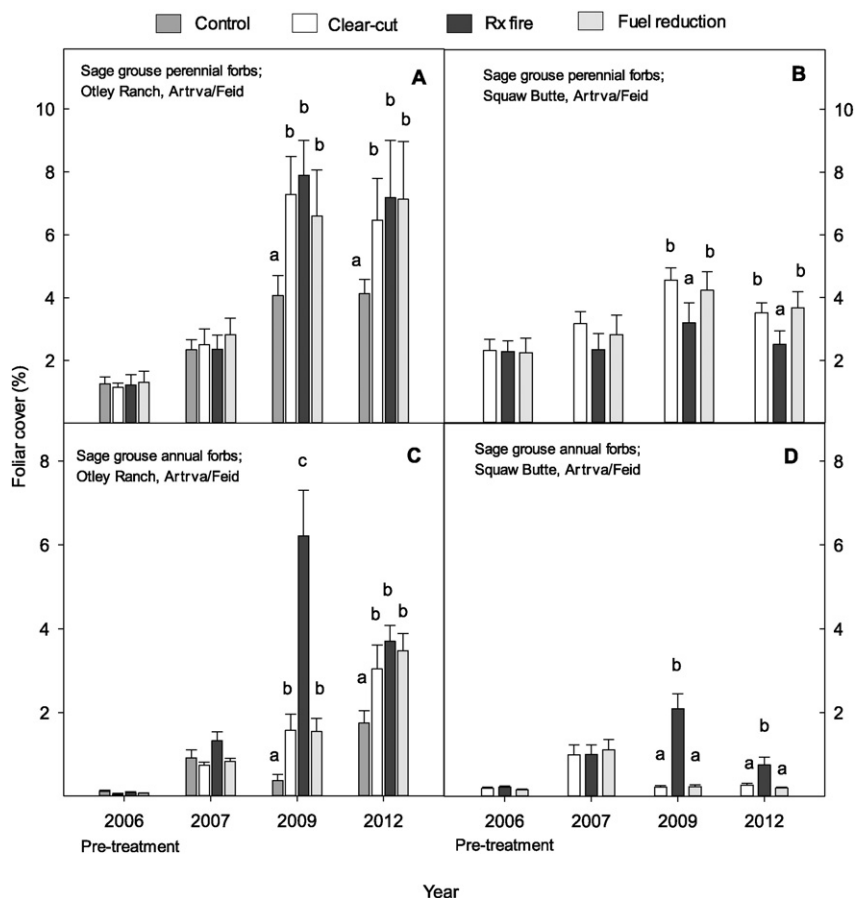


Figure 5. Canopy cover of sage grouse—relevant perennial forbs for the (A) Otley Ranch site (mountain big sagebrush/Idaho fescue association [Artrva/Feid]) and (B) Squaw Butte site (Artrva/Feid). Canopy cover of sage grouse—relevant annual forbs for the (C) Otley Ranch site and (D) Squaw Butte site, High Desert study, Oregon, 2006–2012, following prescribed fire (Rx fire) and fuel reduction treatments in phase 2 and 3 western juniper woodlands. Data are in means + one standard error. Means sharing a common lowercase letter are not significantly different ($P > 0.05$). The pretreatment year was 2006.

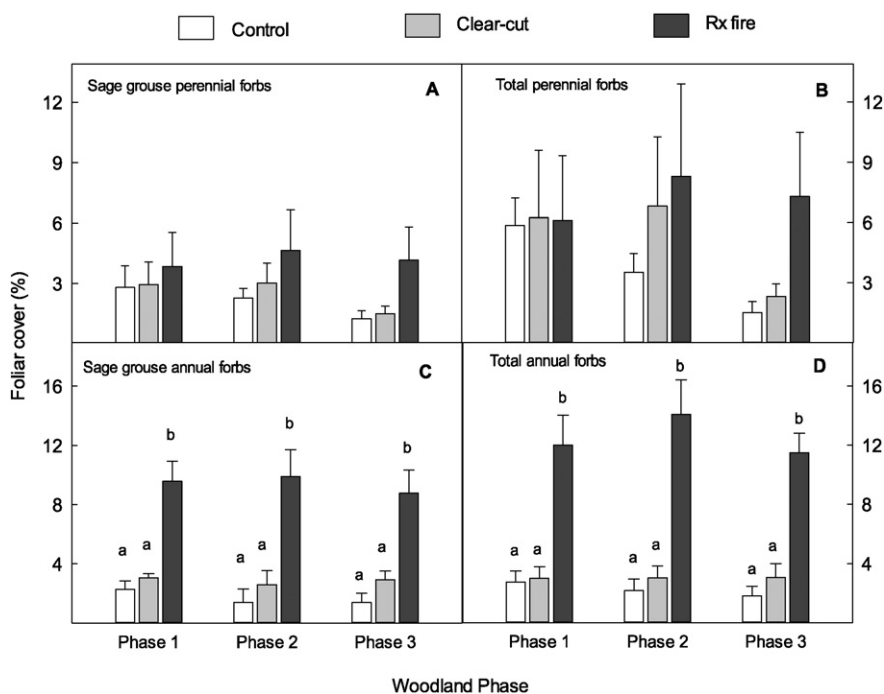


Figure 6. Canopy cover of (A) sage grouse—relevant perennial forbs, (B) total perennial forbs, (C) sage grouse—relevant annual forbs, and (D) total annual forbs, JFSMTN study, Oregon/California, 2006–2014, following prescribed fire (Rx fire) and clear-cutting treatments in phase 1, 2, and 3 western juniper woodlands. Data are in means + one standard error. Means sharing a common lowercase letter are not significantly different ($P > 0.05$).

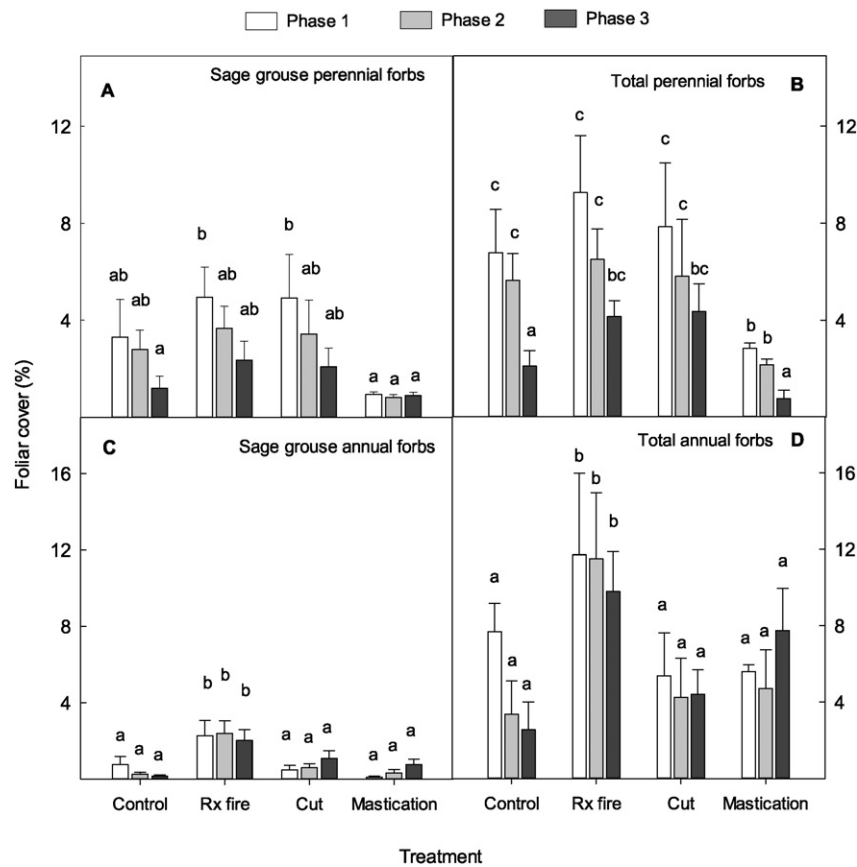


Figure 7. Canopy cover of (A) sage grouse – relevant perennial forbs, (B) total perennial forbs, (C) sage grouse – relevant annual forbs, and (D) total annual forbs, JFSWYO study, Utah/Nevada, 2006–2014, following prescribed fire (Rx fire) and clear-cutting treatments in phase 1, 2, and 3 piñon-juniper woodlands. Data are in means + one standard error. Means sharing a common lowercase letter are not significantly different ($P > 0.05$).

However, the lack of a phase influence on sage grouse perennial forb response in several studies could result from treatment of areas of low potential, at least for perennial forbs. Two of the three sites in the JFSMTN study had low perennial forb cover (about four times less) relative to forb cover in other mountain big sagebrush studies (Hart Mt., Owyhee, High Desert, Steens Mt.; Davies and Bates, 2010a, 2010b). Cover and yields of perennial and annual forbs are influenced by site characteristics in mountain and Wyoming big sagebrush plant communities (Davies et al., 2006; 2007a, 2007b; Davies and Bates, 2010a, 2010b; Bates et al. 2014). In Wyoming big sagebrush plant communities, perennial forb abundance increased as sites became more mesic (Davies et al., 2007a, 2007b).

Management Implications

Prescribed fire, mechanical, and fuel reduction treatment of piñon-juniper woodlands resulted in variable cover responses of perennial

and annual forbs eaten by sage grouse. An assumption has been that woodland control results in increased cover, density, and yield of all herbaceous life-forms (Miller et al. 2005). This is not the case, at least for perennial and annual forbs. For perennial forbs, including forbs used by sage grouse, site potential appears to be a major determinant for gains in cover following conifer control. Additionally, the response of perennial forbs was similar regardless of conifer treatment when comparing prescribed fire, clear-cutting, and fuel reduction. Annual forbs favored by sage grouse benefitted most from prescribed fire treatments with smaller increases following mechanical and fuel reduction treatments. Although annual forbs tended to peak 2 to 5 years after treatment, in several studies elevated annual forb cover persisted for up to 10 years. Dahlgren et al. (2015) indicated that small-acreage sagebrush treatments resulted in increased sage grouse populations, possibly because of greater forb availability. The use of patchy fires or mosaic burns to control conifers might provide managers an alternative to increase forbs important to sage grouse during prenesting and brood-rearing periods, as well as create a more diverse habitat mixture for other species (Petersen and Best, 1987). However, application of patchy fires, as well as landscape-level prescribed fires, require careful consideration and the assistance of sage grouse biologists, as burning in inappropriate habitat or when patches become too large are detrimental to sage grouse and other sagebrush obligate and facultative species (Connelly et al. 2000; Dahlgren et al. 2015).

From a sage grouse management standpoint, mechanical and low disturbance fuel reduction conifer treatments, especially in phase 1 and 2 woodlands, offer the advantage of not only producing a similar perennial forb response compared with fire but also maintaining sagebrush community characteristics that provide optimal sage grouse habitat. These two types of woodland treatments require follow-up control

Table 3

Summary of cover response of sage grouse – relevant perennial and annual forbs to prescribed fire and cutting treatments in conifer woodlands of Oregon, California, Nevada, and Utah.

Conifer treatment ¹	Sage grouse – relevant perennial forbs		Sage grouse – relevant annual forbs	
	Fire	Cutting	Fire	Cutting
Site forb response				
Increase	4	2	8	1
No change	5	2	1	3

¹ Conifer treatments are for prescribed fire and chainsaw cutting. Fuel reduction and mastication treatments are not included.

because conifer seedlings and seed persist, allowing conifers to rapidly restock and eventually reoccupy sites (Tausch and Tueller 1977; Skousen et al. 1989; Bates et al. 2005, 2006; O'Conner et al., 2013). Though forb abundance may not be enhanced consistently, these conifer treatments remain good preventative measures that, at minimum, maintain forbs on the landscape. Additionally, conifer treatments intended to benefit sage grouse should target appropriate seasonal habitats (e.g., brood-rearing) where woodlands may be limiting forb availability and site potential is high.

Supplementary data to this article can be found online at <http://dx.doi.org/10.1016/j.rama.2016.04.004>.

Acknowledgements

We thank the numerous (75+) summer crew members for assistance with data collection and entry over the years; private landowners granting access to work on their properties; and Bureau of Land Management field offices in Oregon, California, Nevada, and Utah for projects located on public lands. Many thanks to Eastern Oregon Agricultural Research Center (EOARC) range technicians for assistance in conducting cutting, fuel reduction, and prescribed fire treatments at the Northern Great Basin Experimental Range and sites on Steen's Mountain, Oregon and South Mountain, Idaho. Thank you to the Joint Fire Science Sage-Steppe Project for allowing use of their forb data. We thank Dr. Chad Boyd, Dr. David M. Bates, Jeremy Maestas, and anonymous reviewers for their comments on previous drafts of the manuscript.

References

- 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.
- Baker, W.L., 2006. Fire and restoration of sagebrush ecosystems. *Wildlife Society Bulletin* 34, 177–185.
- Barnett, J.K., Crawford, J.A., 1994. Pre-laying nutrition of sage grouse hens in Oregon. *Journal of Range Management* 47, 114–118.
- Bates, J.D., Miller, R.F., Svejcar, T., 2005. Long-term successional trends following western juniper cutting. *Rangeland Ecology & Management* 58, 533–541.
- Bates, J.D., Miller, R., Davies, K.W., 2006. Restoration of quaking aspen woodlands invaded by western juniper. *Rangeland Ecology & Management* 59, 88–97.
- 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.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., Svejcar, T.J., 2009. Herbaceous succession after burning cut western juniper trees. *Western North American Naturalist* 69, 9–25.
- 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, UT, May 20–24, 2010. *Natural Resources and Environmental Issues* 17(15), p. 17.
- 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.
- Baughman, C., Forbis, T.A., Provencher, L., 2010. Response of two sagebrush sites to low-disturbance, mechanical removal of piñon and juniper. *Invasive Plant Science and Management* 3, 122–129.
- 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.
- Bybee, J., Roundy, B.A., Young, K.R., Hulet, A., Roundy, D.B., Crook, L., Aanderud, Z., Egget, D.L., Cline, N.L., 2016. Vegetation response to piñon and juniper tree shredding. *Rangeland Ecology & Management* 69, 224–234.
- Casazza, M.L., Coates, P.S., Overton, C.T., 2011. Linking habitat selection to brood success in greater sage-grouse. In: Sandercock, M.K., Martin, K., Segelbacher, G. (Eds.), *Ecology, conservation, and management of grouse, studies in avian biology*, book 39. University of California Press, pp. 151–167.
- Connelly, J.W., Schroeder, M.A., Sands, A.R., Braun, C.E., 2000. Guidelines to manage sage grouse populations and their habitats. *Wildlife Society Bulletin* 28, 967–985.
- Dahlgren, D.K., Chi, R., Messmer, T.A., 2006. Greater sage-grouse response to sagebrush management in Utah. *Wildlife Society Bulletin* 34, 975–985.
- Dahlgren, D.K., Larsen, R.T., Danvir, R., Wilson, G., Thacker, E.T., Black, T.A., Naugle, D.E., Connelly, J.W., Messmer, T.A., 2015. Greater sage-grouse and range management: insights from a 25-year case study in Utah and Wyoming. *Rangeland Ecology & Management* 68, 375–382.
- Davies, K.W., Bates, J.D., Miller, R.F., 2006. Vegetation characteristics across part of the Wyoming big sagebrush alliance. *Rangeland Ecology & Management* 59, 567–575.
- Davies, K.W., Bates, J.D., Miller, R.F., 2007a. Short-term effects of burning Wyoming big sagebrush steppe in southeast Oregon. *Rangeland Ecology & Management* 60, 515–522.
- Davies, K.W., Bates, J.D., Miller, R.F., 2007b. Environmental and vegetation relationships of the *Artemisia tridentata* ssp. *wyomingensis* alliance. *Journal of Arid Environments* 70, 478–494.
- Davies, K.W., Bates, J.D., 2010a. Vegetation characteristics of mountain and Wyoming big sagebrush plant communities in the northern Great Basin. *Rangeland Ecology & Management* 63, 461–466.
- Davies, K.W., Bates, J.D., 2010b. Native perennial forb variation between mountain big sagebrush and Wyoming big sagebrush plant communities. *Environmental Management* 46, 452–458.
- Davies, K.W., Bates, J.D., Nafus, A.M., 2011a. Are there benefits to mowing Wyoming big sagebrush plant communities; an evaluation in southeast Oregon. *Environmental Management* 48, 539–546.
- Davies, K.W., Bates, J.D., Nafus, A.M., 2012. Comparing burning and mowing treatments in mountain sagebrush steppe. *Environmental Management* 50, 451–461 (ARIS# 274394).
- Davies, K.W., Boyd, C.S., Beck, J.L., Bates, J.D., Svejcar, T.L., Gregg, M.A., 2011b. Saving the sagebrush sea: an ecosystem conservation plan for big sagebrush plant communities. *Biological Conservation* 144, 2573–2584.
- Drut, M.S., Pyle, W.H., Crawford, J.A., 1994. Technical note: Diets and food selection of sage grouse chicks in Oregon. *Journal of Range Management* 47, 90–93.
- 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.
- Gregg, M.A., Crawford, J.A., Barnett, J.K., 2008. Temporal variation in diet and nutrition of pre-incubating greater sage-grouse. *Rangeland Ecology & Management* 61, 535–542.
- Gregg, M.A., Crawford, J.A., 2009. Survival of greater sage-grouse chicks and broods in the Northern Great Basin. *Journal of Wildlife Management* 73, 904–913.
- Harniss, R.O., Murray, R.B., 1973. 30 years of vegetational change following burning of sagebrush-grass range. *Journal of Range Management* 26, 322–325.
- Herrick, J.E., Van Zee, J.W., Havstad, K.M., Burkett, L.M., Whitford, W.G., 2009. *Monitoring manual for grassland, shrubland, and savanna ecosystems*. University of Arizona Press, Tucson, AZ, USA 36 pp.
- Klebenow, D.A., Gray, G.M., 1968. Food habits of juvenile sage grouse. *Journal of Range Management* 21, 80–83.
- Knick, S.T., Hanser, S.E., Preston, K.L., 2013a. Modeling ecological minimum requirements for distribution of greater sage-grouse leks: implications for population connectivity across their western range, USA. *Ecology and Evolution* 3, 1–13.
- Knick, S.T., Hanser, S.E., Preston, K.L., 2013b. Modeling ecological minimum requirements for distribution of greater sage-grouse leks: implications for population connectivity across their western range, U.S.A. *Ecology and Evolution* 3, 1539–1551.
- Koniak, S., 1985. Succession in piñon-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.
- Littell, R.C., Milliken, G.A., Stroup, W.W., Wolfinger, R.D., 1996. *SAS system for mixed models*. SAS Institute, Cary, NC, USA.
- Maestas, J.D., Roundy, B.A., Bates, J.D., 2015. Conifer removal in the sagebrush steppe: the why, when, where, and how. *Great Basin Fact Sheet Series*, no. 4, Sage-Grouse Initiative Available at: <http://www.sagegrouseinitiative.com/category/science-to-solutions/great-basin-factsheet-series/>. Accessed 10 Oct 2015.
- 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., 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. *USDA Forest Service Research Paper RMRS-RP-69*. Rocky Mountain Research Station Research, Fort Collins, CO, USA.
- Miller, R.F., Bates, J.D., Svejcar, T.J., Pierson, F.B., Eddleman, L.E., 2005. Biology, ecology, and management of western juniper. Corvallis, OR, USA: Oregon State University Agricultural Experiment Station Technical Bulletin 152 Available at: <http://extension.oregonstate.edu/catalog/html/tb152/>.
- 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., Chambers, J.C., Pyke, D., Pierson, F.B., Williams, C.J., 2013. A review of fire effects on vegetation and soils in the Great Basin region: response and ecological site characteristics. *USDA Forest Service, Rocky Mountain Research Station RMRS-GTR-308*, Fort Collins, CO, USA.
- Miller, R.F., Ratford, J., Roundy, B.A., Tausch, R.J., Hulet, A., Chambers, J.C., 2014. Response of conifer-enriched shrublands in the Great Basin to prescribed fire and mechanical treatments. *Rangeland Ecology & Management* 67, 468–481.
- NRCS, 2006. *Soil Survey of Harney County Area, Oregon*. USDA Natural Resource Conservation Service, Washington, District of Columbia, USA.
- NRCS, 2010. *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 10 Oct 2015.
- NRCS [Natural Resources Conservation Service], 2015. *Outcomes in Conservation: Sage Grouse Initiative*. Available at: http://www.sagegrouseinitiative.com/wp-content/uploads/2015/02/NRCS_SGI_Report.pdf.
- Nelle, P.J., Reese, K.P., Connelly, J.W., 2000. Long-term effects of fire on sage-grouse habitat. *Journal of Range Management* 53, 586–591.
- O'Conner, C.A., Miller, R.F., Bates, J.D., 2013. Vegetation response to western juniper slash treatments. *Environmental Management* 52, 553–566.

- Omernik, J.M., 1987. Ecoregions of the conterminous United States. *Annals of the Association of American Geographers* 77, 118–125.
- Peterson, J.G., 1970. The food habits and summer distribution of juvenile sage grouse in central Montana. *Journal of Wildlife Management* 34, 147–155.
- Petersen, K.L., Best, L.B., 1987. Effects of prescribed burning on nongame birds in a sagebrush community. *Wildlife Society Bulletin* 15, 317–329.
- 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., Davies, K.W., Sharp, R.N., 2010. Fire effects on cover and dietary resources of sage-grouse habitat. *Journal of Wildlife Management* 74, 755–764.
- 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.
- Ross, M.R., Castle, S.C., Barger, N.N., 2012. Effects of fuels reductions on plant communities and soils in a Piñon-juniper woodland. *Journal of Arid Environments* 79, 84–92.
- 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.
- Sage Grouse Initiative, 2014. Conifer removal restores sage grouse habitat. Science to Solutions Series Number 2 Available at: <http://www.sagegrouseinitiative.com/>.
- Shapiro, S.S., Wilk, M.B., 1965. An analysis of variance test for normality (complete samples). *Biometrika* 52, 591–611.
- 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.
- Suring, L.H., Rowland, M.M., Wisdom, M.J., Schueck, L., Meinke, C.W., 2005. Vegetation communities. In: Wisdom, M.J., Rowland, M.M., Suring, L.H. (Eds.), *Habitat threats in the sagebrush ecosystem*. Alliance Communications Group, Lawrence, KS, USA, pp. 94–113.
- Tausch, R.J., Tueller, P.T., 1977. Plant succession following chaining of pinyon–juniper woodlands in eastern Nevada. *Journal of Range Management* 30, 44–49.
- Tidwell, D.P., 1987. Multi-resource management of pinon-juniper woodlands: Times have changed, but do we know? In: Everett, R.L. (Ed.), *Proceedings Pinyon-Juniper Conference Intermountain Research Station*. USDA, Forest Service, Ogden, UT, USA, pp. 5–8.
- Vaitkus, M., Eddleman, L.E., 1987. Composition and productivity of a western juniper understory and its response to canopy removal. In: Everett, R.L. (Ed.), *Proceedings: pinyon-juniper conference*. USDA Forest Service, General Technical Report INT-215, Intermountain Research Station, Ogden, UT, USA, pp. 456–460.
- Wallestad, R., Peterson, J.G., Eng, R.L., 1975. Foods of adult sage grouse in central Montana. *Journal of Wildlife Management* 39, 628–630.
- Wambolt, C.L., Payne, G.F., 1986. An 18-year comparison of control methods for Wyoming big sagebrush in southwestern Montana. *Journal of Range Management* 39, 314–319.
- Weisberg, P.J., Emanuel, L., Pillai, R.B., 2007. Spatial patterns of pinyon–juniper expansion in central Nevada. *Rangeland Ecology & Management* 60, 115–124.
- Wroblewski, 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. Postfire recovery of two shrubs in the interiors of large burns in the Intermountain West. *Western North American Naturalist* 69, 195–205.