Research Article

Native Bunchgrass Response to Prescribed Fire in Ungrazed Mountain Big Sagebrush Ecosystems

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ABSTRACT

Fire was historically a dominant ecological process throughout mountain big sagebrush (*Artemisia tridentata* Nutt. ssp. *vaseyana* [Rydb.] Beetle) ecosystems of western North America, and the native biota have developed many adaptations to persist in a regime typified by frequent fires. Following spring and fall prescribed fires conducted in sites of different ecological conditions at the Lava Beds National Monument, California, USA, we examined the reproductive, density, and cover responses of four native bunchgrasses: bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] A. Löve), Thurber's needlegrass (*Achnatherum thurberianum* [Piper] Barkworth), squirreltail (*Elymus elymoides* [Raf.] Swezey), and Sandberg bluegrass (*Poa secunda* J. Presl). High rates of survival and fire-enhanced flowering were measured following fires. Thurber's needlegrass density decreased following spring burns in sites dominated by cheatgrass (*Bromus tectorum* L.) (from 3.3 plants m^{-2} to 0.8 plants m^{-2}; $P < 0.05$). Density of bluebunch wheatgrass decreased following spring fires (from 3.7 plants m^{-2} to 1.9 plants m^{-2}; $P = 0.02$) and cover was reduced in both spring and fall burn treatments ($P = 0.04$) in native dominated sites. Fire-enhanced flowering (increases in reproductive efforts) occurred in bluebunch wheatgrass in cheatgrass dominated sites (244 % increase in reproductive culms following fire), native dominated sites (350 % increase), and woody encroachment sites (500 % increase) sites following fall fires. These results show that these native bunchgrasses positively respond to prescribed fire through increases in reproductive efforts and high rates of survival following fires. This suggests that fire can be an important tool for the restoration and conservation of these fire adapted bunchgrasses.

Keywords: *Artemisia tridentata*, *Bromus tectorum*, bunchgrass, cheatgrass, fire return interval, mountain big sagebrush, prescribed fire, *Pseudoroegneria spicata*, rangeland restoration

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INTRODUCTION

Dramatic changes in vegetation structure and composition have occurred in the Great Basin of North America due to human activities including fire suppression, livestock grazing, increased ignitions by Native Americans, and the introduction of non-native plant and animal species. Prior to Euro-American settlement, stand replacing fires were frequent, occurring at intervals of less than 30 years in mountain big sagebrush (*Artemisia tridentata* Nutt. ssp. *vaseyana* [Rydb.] Beetle) ecosystems (Young and Evans 1981, Miller and Rose 1999, Miller *et al.* 2000). The Great Basin has experienced two general shifts in structure related to changes in fire regimes. Low-elevation areas subject to frequent human disturbances became susceptible to increased fire frequency and invasion and dominance by exotic grasses (D'Antonio and Vitousek 1996, Brooks and Pyke 2001). During the 1900s, fire frequency decreased in wetter or higher elevation areas due to fire exclusion and livestock grazing (Miller and Tausch 2001), resulting in expansion of western juniper (*Juniperus occidentalis* Hook.) and a reduction of native bunchgrasses and forbs (Miller and Rose 1999). Prior to Euro-American settlement, expansion of western juniper was believed to have been limited by fire, drought, and competition with grasses (Kilgore 1981). The introduction of domestic grazing animals in these areas decreased the amount of fine fuels necessary for fire spread (Kauffman and Sapsis 1989), and western juniper increased in range under the longer fire-return interval (Miller *et al.* 1994). The current rate and extent of western juniper encroachment onto sites formerly occupied by bunchgrasses and sagebrush has exceeded rates of expansion from the preceding 5000 years (Miller and Wigand 1994). Restoration and maintenance of native plant communities in mountain big sagebrush systems may require a reintroduction of fires that have shaped its development.

Plant communities in the Great Basin developed in response to a natural fire regime, and the biota evolved adaptations to persist within its natural range of fire return (Kauffman *et al.* 1997, Pendergrass *et al.* 1999, Wroblesky and Kauffman 2002). Individual survival as well as increased reproductive effort through fire-enhanced flowering may facilitate recovery of these plant communities following fire (Kauffman 1990). Increased flowering has been observed following fire in grasses of high deserts east of the Oregon Cascades (Sapsis 1990). Uresk *et al.* (1976) reported increased vegetative growth in bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] A. Löve) following wildfire, but no difference in number of reproductive culms.

In this study, we examined the effects of prescribed fire on ungrazed mountain big sagebrush ecosystems in three different ecological conditions (cheatgrass [*Bromus tectorum* L.] dominated, native dominated, and juniper dominated) at Lava Beds National Monument, California, USA. We sought to answer the following research questions: 1) Is there a change in reproductive effort, cover, or density of native bunchgrass species following prescribed fire in ungrazed mountain big sagebrush plant communities? 2) Is there a differential effect of prescribed fire on native bunchgrass species due to the season of burn? 3) Is the response of these species to fire different in sites with a different current plant composition (native, cheatgrass, juniper)? We hypothesized that: 1) reproductive effort would increase in bunchgrass species in the year following prescribed fire, and that bunchgrass densities would not change significantly following fire, but cover would be decreased in the first post-fire year; 2) plants burned in the fall would have fewer reductions in cover and density than those burned in the spring due to lower intensity burns that occurred after the active growing season had passed; and 3) bunchgrasses in sites dominated by native plants with an intact fire return interval would demonstrate a greater reproductive effort and no reduction in cover and density as compared to bunchgrasses in sites where the plant communities have been altered by fire suppression and invasion of exotic plants.

METHODS

Study Area

The study was conducted at Lava Beds National Monument, 77 km southeast of Klamath Falls, Oregon, USA (Figure 1). This area ranges in elevation from 1228 m along the shore of Tule Lake to 1725 m at its highest point (Erhard 1979). The climate is cool and semi-arid; the average annual precipitation is 39 cm (Miller *et al.* 2003), and the average temperature ranges from −1 ºC in January to 20 ºC in July (Erhard 1979). Most naturally ignited fires occur from July to September, when dry thunderstorms often coincide with high temperatures and low fuel moisture contents. Soils are of volcanic origin, and shallow with basaltic outcrops (Erhard 1979). Lava Beds National Monument was chosen for this study due to an existing plant community gradient from cheatgrass dominated in the lowest elevation site, native dominated at mid-elevation where access is difficult, and juniper dominated at the highest elevation near the monument headquarters, where fire has been suppressed. We chose three sites that are classified as mountain big sagebrush-bluebunch wheatgrass-Thurber's needlegrass (*Achnatherum thurberianum* [Piper] Barkworth) habitat type (Erhard 1979), but with variation in plant composition, land use history, soils, and microtopography (Figure 2). Historically, fire return intervals were likely about 50 yr (±20 yr) (Miller *et al*. 2003), and were of moderate to high severity, limiting encroachment of western juniper.

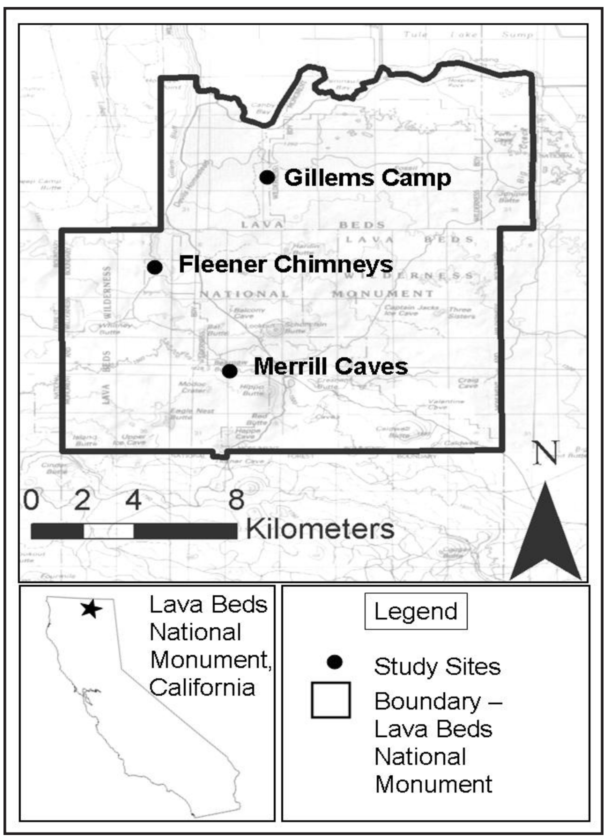

Figure 1. Study was conducted at the Lava Beds National Monument, California, USA, in mountain big sagebrush ecosystems.

At the lowest elevation site (Gillems Camp; elevation: 1234 m to 1244 m), the plant communities were dominated by a continuous cover of cheatgrass, with rubber rabbitbrush (*Ericameria nauseosa* [Pall. ex Pursh] G.L. Nesom & Baird), Thurber's needlegrass, and squirreltail (*Elymus elymoides* [Raf.] Swezey) also common. Because of the close proximity to water, these areas were likely heavily grazed by domestic livestock prior to monument establishment. Soils are classified in the Bakeoven family (Luckow and Ahuja 2001), which are well-drained very cobbly fine sandy loams.

The Fleener Chimneys site (elevation: 1341 m to 1362 m) is presumed to have been grazed less intensively than the Gillems Camp site due to its distance from water and difficulty of terrain (i.e., lava flows that limit domestic ungulate movement from water to this site). Plant communities are dominated by native vegetation including mountain big sagebrush, native bunchgrasses (bluebunch wheatgrass,

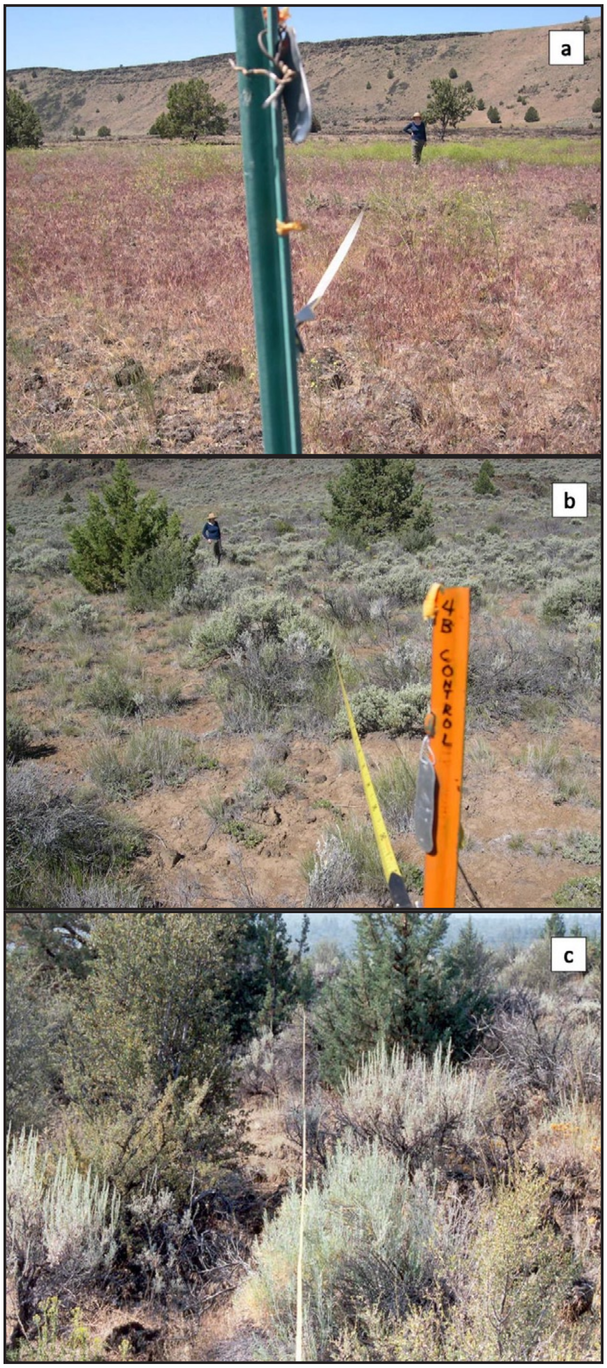

Figure 2. Sampling locations represent areas of different ecological conditions within mountain big sagebrush communities at the Lava Beds National Monument, California, USA: a) Gillems Camp, dominated by invasive cheatgrass with history of livestock grazing; b) Fleener Chimneys, intact site dominated by mountain big sagebrush and native bunchgrass; and c) Merrill Caves, dominated by western juniper with native understory.

Thurber's needlegrass, squirreltail, Idaho fescue [*Festuca idahoensis* Elmer]) and native forbs (spiny phlox [*Phlox hoodii* Richardson], threadleaf phacelia [*Phacelia linearis* {Pursh} Holz.], common yarrow [*Achillea millefolium* L.]). Soils are classified in the Searles association and are gravelly sandy loams (Luckow and Ahuja 2001). Few non-native plants occur on these sites, and there has been minimal encroachment by western juniper.

At the highest elevation site (Merrill Caves; elevation: 1451 m to 1472 m), fire suppression has resulted in the encroachment of western juniper, with a high cover of trees and shrubs (mountain big sagebrush, antelope bitterbrush [*Purshia tridentata* {Pursh} DC], curl-leaf mountain mahogany [*Cercocarpus ledifolius* Nutt.]). Soils are in the Searles association, with frequent rocky outcroppings. Frequent understory species include bluebunch wheatgrass, squirreltail, threadleaf phaecelia, tapertip hawksbeard (*Crepis acuminata* Nutt.), and sulphur-flower buckwheat (*Eriogonum umbellatum* Torr.). There were few cheatgrass individuals, as well as a low incidence of other exotic plants at this site.

Lava flows throughout the National Monument act as natural fuel breaks as well as livestock barriers, and contribute to a diverse land use and fire history. Management personnel at Lava Beds National Monument have demonstrated a commitment to restoration of native plant communities, structure, and ecosystem function. Livestock grazing was removed from all areas of the National Monument by the mid 1970s, and plant communities have responded positively to the release from this disturbance (Erhard 1979, Martin *et al.* 1980, Olsen *et al.* 1980). Native herbivores, notably mule deer (*Odocoileus hemionus* Rafinesque) and pronghorn (*Antilocapra americana* [Ord]) continue to occupy all areas within the monument.

Experimental Design and Bunchgrass Sampling

The experiment was established as a randomized block design. Five experimental blocks were established at each of the three sites. Each block contained three 0.40 ha (1 ac) treatment plots in which either a spring burn, fall burn, or control treatment was applied. Spring burns at Fleener Chimneys and Gillems Camp were conducted on 25 June 2003. Due to weather constraints during 2003, spring burns at Merrill Caves were not conducted. Fall burns at all three sites took place on 12 November 2003. Temperature was higher and relative humidity was lower during the spring burns compared to fall burns, and we saw some differences in resultant fire behavior measures (flame lengths, rate of spread, etc.; Kauffman *et al.* 2006). Both spring and fall fires burned in a mosaic pattern, burning some areas and leaving small patches unburned.

Density of bunchgrass individuals was calculated from microplot measurements along five 20-meter permanent transects within each treatment plot. Each transect contained two 30 × 60 cm microplots (n = 50 for each treatment by site combination) at fixed locations along the transect, in which all bunchgrass individuals were identified to species. Measurements of bunchgrass density were made during the active growing season immediately preceding spring fires (June 2003, pre-fire) and one year following fires (July 2004, post-fire).

Percent cover of bunchgrasses was also quantified in 30 × 60 cm microplots along permanent sampling transects. Pre-fire cover was measured in late June 2003, and post-fire cover was measured in early July 2004, during the active growing season. Change following fire was analyzed at the microplot level and averaged for each transect.

We quantified reproductive effort of the most abundant native bunchgrasses (bluebunch wheatgrass, squirreltail, and Thurber's needlegrass) following fall fires. In each plot, the number of flowering culms of at least 15 individuals of each species was counted as they were encountered along a 20 × 1 meter belt transect. Measurements were taken during peak flowering of plants (late in the growing season). Measurements were taken in late June 2003 (pre-fire) and early July 2004 (post fire).

Statistical Analysis

Fixed effects Analysis of Variance (ANOVA) models were used to determine whether there was an effect of fire treatment on bunchgrass cover, density, and reproductive effort after controlling for the site and the blocked design. The interaction of site and treatment was evaluated in the model to assess whether there was a different effect of the fire treatment depending on the site. Because the spring fire treatment was not applied at the Merrill Caves site, the site × treatment combination was removed from the analysis and two balanced two-way ANOVAs were used. One model included all three sites and two treatments (control, fall) as well as the site by treatment interaction. A second model included the Fleener and Gillems sites and all fire and control treatments (control, fall, spring), as well as the site by treatment interaction. A multiple comparison test (Tukey) was used if the F-test for treatment effect was significant at the $P < 0.05$ significance level. All statistical analyses were performed using SPSS 10.0 for Windows (SPSS, IBM Corporation, Somers, New York, USA).

RESULTS

Gillems Camp

At the low-elevation, cheatgrass dominated site, shortened fire return intervals, increased disturbance, and a continuous fuel load has resulted in a landscape dominated by non-native annual grass (33% to 41% cheatgrass cover before fire) (Ellsworth 2006). The continuous fuel load provided for high fuel consumption (spring fires, 89% consumption from 6.89 Mg ha^{-1} to 0.74 Mg ha^{-1}; fall, 81% combustion from 6.55 Mg ha^{-1} to 1.24 Mg ha^{-1}) (Kauffman *et al.* 2006). Although the prescribed fires were of high intensity with high levels of fuel consumption (Table 1), density of squirreltail, Sandberg bluegrass, and bluebunch wheatgrass did not decline. Spring fires resulted in a decrease in density of Thurber's needlegrass from 3.3 to 0.8 plants per m^2 (site × treatment effect: $P < 0.05$), but there was no change following fall fires. There was no significant increase in flowering of squirreltail following fires. In contrast, there was a significant increase in flowering of Thurber's needlegrass following fall fires compared to unburned controls ($P < 0.01$; Figure 3). Fire-enhanced flowering was observed in bluebunch wheatgrass following fall burns (Figure 4) and this effect was most pronounced at the Gillems Camp site. Flowering culms increased from 9 to 31 per plant in fall fire plots, compared to an increase from 9 to 18 culms per plant in unburned controls (treatment effect: $P < 0.01$; site × treatment effect: $P < 0.01$). There was no significant change in cover of native bunchgrass species following prescribed fires or in unburned controls (Figure 5).

Fleener Chimneys

At the native dominated site, cheatgrass cover was minimal (0.5% to 2% cover before fire), and there was an intact native bunchgrass and shrub component (16% average shrub cover) with interspersed bare ground prior to burns. Fires were patchy and resulted in a mosaic burn pattern (Table 1). Fall fires were much lower in intensity and severity than spring fires, resulting in less consumption of fuel and a patchier burn response. Fuel loads in spring fires were reduced from 9.98 Mg ha^{-1} to 2.16 Mg ha^{-1}; fuels in fall burns were reduced from 8.98 Mg ha^{-1} to 5.96 Mg ha^{-1}. Density of bluebunch wheatgrass was reduced following spring fires (from 3.7 plants per m^2 to 1.9 plants per m^2; $P = 0.02$) and cover (Figure 5) was reduced in both spring (7% decrease) and fall (5% decrease) burn treatments ($P = 0.04$). Fire treatments had no significant effects on cover or density of Thurber's needlegrass, squirreltail, or Sandberg bluegrass in the first post-fire year.

Table 1. Weather, fire behavior, and fuel consumption was measured during spring (June 2003) and fall (November 2003) prescribed fires at Lava Beds National Monument, California, USA (taken from Kauffman *et al.* 2006).

	Gillems Camp		**Fleener Chimneys**		**Merrill Caves**
	Spring	**Fall**	**Spring**	**Fall**	**Fall**
Weather (min-max)					
Temperature (°C)	17-28	7-12	14-24	6-11	8-16
Relative humidity (%)	28-53	41-55	30-54	53-60	30-68
Wind speed (m s^{-1})	1-2	0-3	1-4	0-2	0-3
Fine fuel moisture (%)	6-10	8-9	5-10	10-11	7-12
Fire behavior (min-max)					
Rate of spread (m s^{-1})	0.04-0.07	0.01-0.46	0.01-0.05	0.04-0.41	0.00-0.03
Flame length (m)	0.3-3.0	0.1-3.7	0.2-1.5	0.2-1.8	0.3-4.6
Fuel consumption (mean ± 1 SE)					
Fine surface fuels (Mg ha^{-1})	2.00 ± 0.36	2.63 ± 0.29	0.35 ± 0.18	1.06 ± 1.21	1.36 ± 0.87
Total fuels (Mg ha^{-1})	6.15 ± 1.27	5.31 ± 1.51	5.50 ± 2.31	3.02 ± 1.48	12.11 ± 6.18

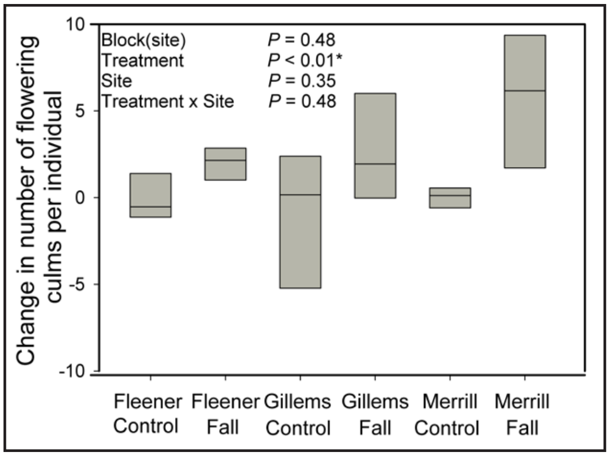

Figure 3. Reproductive effort (number of flowering culms per plant) of Thurber's needlegrass was measured following fall prescribed fires and in unburned control plots in mountain big sagebrush systems at the Lava Beds National Monument, California, USA. Upper bounds of boxes indicate the seventy-fifth percentile, and lower bounds indicate twenty-fifth percentile. Line within each box indicates the median. *P*-values are results of fixed effects ANOVA model. Asterisks denote statistical significance at α = 0.05 for model terms.

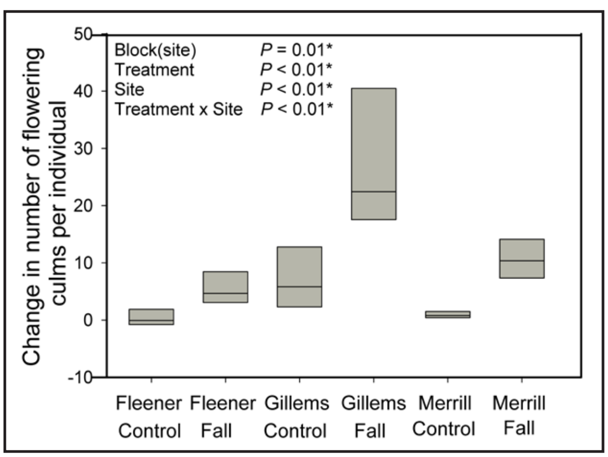

Figure 4. Reproductive effort (number of flowering culms per plant) of bluebunch wheatgrass was measured following fall prescribed fires and in unburned control plots in mountain big sagebrush systems at the Lava Beds National Monument, California, USA. Upper bounds of boxes indicate the seventy-fifth percentile, and lower bounds indicate the twenty-fifth percentile. Line within each box indicates the median. *P*-values are results of fixed effects ANOVA model. Asterisks denote statistical significance at α = 0.05 for model terms.

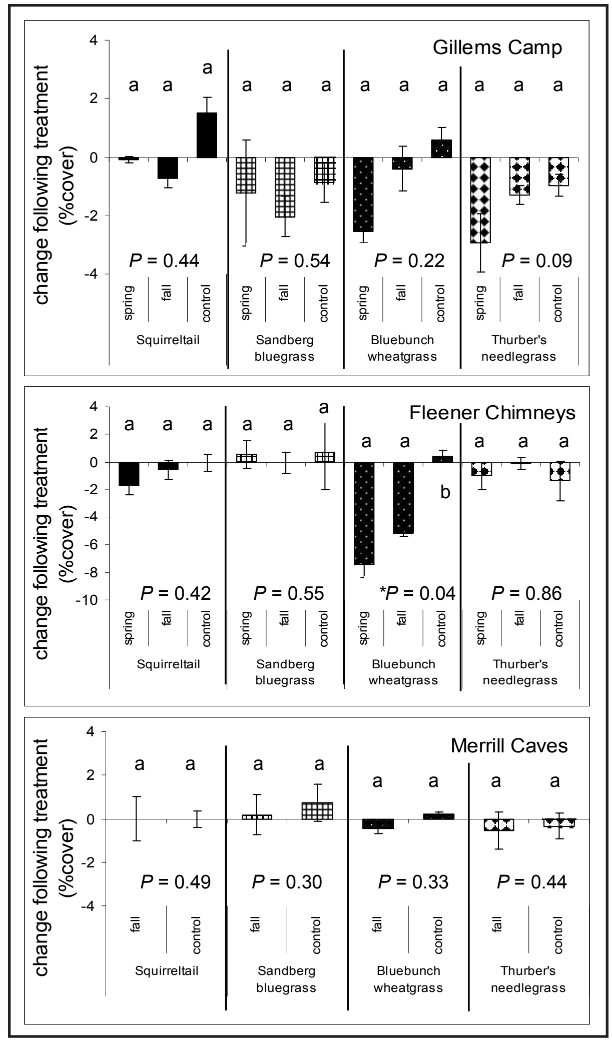

Figure 5. Change in cover of native bunchgrass species following spring (June 2003) and fall (November 2003) prescribed fire treatments and controls at Lava Beds National Monument, California, USA. Data were collected prior to spring fires (2003) and in July 2004. Bars are mean values for differences in cover and error bars are one standard error. *P*-values are results of fixed effects ANOVA model. Asterisks denote statistical significance at α = 0.05.

Fire-enhanced flowering was apparent in bluebunch wheatgrass and Thurber's needlegrass plants the year following fall burns. Reproductive culms increased from 2 per individual before fire to 9 per individual in the first post-fire year (treatment effect: $P < 0.01$; Figure 4) in bluebunch wheatgrass and from 0.02 to 4 flowering culms per Thurber's needlegrass individual following fall burns (treatment effect: $P <$

0.01; Figure 3). There was no evidence of fire-enhanced flowering in squirreltail.

Merrill Caves

At the site characterized by western juniper dominance, high fire consumption rates were measured (a fuels reduction of 21.62 Mg ha^{-1} to 9.51 Mg ha^{-1} in fall burn plots). Understory fuels burned in a mosaic pattern, with some unburned islands remaining following the prescribed fires. Bunchgrass density and cover (Figure 5) did not significantly change following fall fires for any species studied. Fire-enhanced flowering was observed following fall fires in bluebunch wheatgrass and Thurber's needlegrass (Figures 3 and 4). Fall fires resulted in significant increases in flowering for bluebunch wheatgrass from 2 flowering culms per individual before fire and 12 flowering culms the year following fire (treatment effect: $P < 0.01$). Increases in reproductive effort following fall fire was also measured in Thurber's needlegrass (from 1 flowering culm to 7 flowering culms; $P < 0.01$). There was no evidence of fire-enhanced flowering in squirreltail at this site.

DISCUSSION

Our results suggest that native bunchgrass species in ungrazed mountain big sagebrush ecosystems at Lava Beds National Monument are well adapted to surviving fire and reproducing in the post-fire environment. Fire did not result in the significant decrease in density or cover of most bunchgrass species. Where significant reductions in density or cover were measured, there were also increases in post-fire flowering for the affected species, suggesting a capacity for resilience of these species following fire.

Fire in the sagebrush ecosystem functions structurally to decrease woody vegetation and shift the plant community towards an herbaceous, grass-dominated state (D'Antonio and Vitousek 1992). In the absence of shrub and juniper cover, grasses and forbs are able to utilize available nutrient resources and colonize microsites previously occupied by woody species. In other sagebrush ecosystems, fire has been shown to stimulate vegetative growth of bunchgrass species (Sapsis 1990), as well as enhance sexual reproduction of bunchgrasses (Kauffman and Sapsis 1989) and broad-leaved herbs (Wroblesky and Kauffman 2002).

While the abundance of native plants at the Gillems Camp site had increased since measurements by Erhard (1979), there was still a dominance of invasive annuals such as cheatgrass and tumble mustard (*Sisymbrium altissimum* L.). Nevertheless, there was a low mortality of the native bunchgrasses and significant post-fire flowering. The removal of sheep and cattle grazing within the national monument in 1974 initiated a trend toward reestablishment of native plants in the monument, decreasing the dominance of cheatgrass that was evident in the late 1970s (Erhard 1979). Although the reintroduction of the natural fire regime is a logical approach to the restoration of sagebrush ecosystems that have been degraded by anthropogenic disturbance, it is difficult to predict the response of the native flora to fire where there is a strong presence of highly competitive annuals. This study suggests that the native grasses should be able to persist following fire in mountain big sagebrush communities at Lava Beds National Monument, even in the more degraded areas.

In sites where natives dominate, we hypothesized that native plants would respond positively to prescribed fire. Prior to fire, the Fleener Chimneys site was dominated by sagebrush, perennial bunchgrasses, and native forbs. The increase in reproductive effort and high survival of all studied bunchgrass species at this site suggests that they are well adapted to fire survival under these environmental conditions and that prescribed fire would have few detrimental effects. Although our results show some significant changes in cover and density for studied species, this may largely be a transient immediate post-fire effect, and warrants further monitoring. Other studies have shown that in relatively intact native bunchgrass communities, fire resulted in an immediate reduction in density, followed by an increase in subsequent years, largely due to seedling success in a post-burn environment (Sapsis 1990). Sapsis (1990) also found that increased seedling establishment of bluebunch wheatgrass and Idaho fescue following prescribed burns was characteristic of native bunchgrass communities at John Day Fossil Beds National Monument, Oregon, USA.

Higher intensity spring fires resulted in greater decreases in cover and density than lower intensity fall burns. The weather during spring burns was warmer and drier, resulting in lower fine fuel moistures, but patchy vegetation structure prevented the fire from spreading quickly (Table 1; Kauffman *et al*. 2006). With the reintroduction of fire, we found that reproductive efforts in the native bunchgrasses increased more in the burned plots than in the unburned controls. This may be a response to greater resource availability (water, nutrients, light availability) in the post-fire environment. Cover and density of native bunchgrasses were fairly constant before and after burns, indicating that these native plants will persist if the natural disturbance interval is maintained.

Native plants in sagebrush ecosystems have been shown to respond positively to fire in previous studies in which plants had been released from domestic grazing pressure. In mountain big sagebrush communities of Lava Beds National Monument following removal of domestic cattle, Champlin (1983) observed significant increases in basal area of bluebunch wheatgrass and Sandberg bluegrass two years after burning. Conversely, he found decreases in basal area of Thurber's needlegrass immediately following fire. In an area where domestic grazing had been eliminated 15 years previously, Sapsis (1990) found that both fall and spring burning reduced the frequency of invasive annual grasses in basin big sagebrush (*Artemisia tridentata* Nutt. ssp. *tridentata*)-bluebunch wheatgrass communities at John Day Fossil Beds National Monument, and increased reproductive effort of perennial grasses following fall burns. Wright and Klemmedson (1965) found that early summer burns damaged squirreltail and Thurber's needlegrass, but that only Thurber's needlegrass was harmed by late summer burning. Sandberg bluegrass was not affected by either season of burn. In Wyoming big sagebrush (*Artemisia tridentata* Nutt. ssp. *wyomingensis* Beetle & Young) communities in eastern Oregon, Davies and Bates (2008) found that the cover and density of Thurber's needlegrass was no different than in adjacent unburned areas two years following fire.

The results of this study and others (Sapsis 1990, Wroblesky and Kauffman 2002) suggest that in ungrazed systems of various conditions that are managed for restoration of native ecosystem diversity, native grass species can survive fire and even benefit from conditions present in post-fire environments. Lower intensity fall fires provided more positive post-fire effects than spring fires, suggesting that it is more advantageous to apply prescribed fires when the active growing season has passed and fires are easier for managers to control. While a need for longer term monitoring following prescribed fire is imperative, initial post-fire response suggests that fire-adapted species will respond positively to prescribed fire when applied within the natural range of variability.

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