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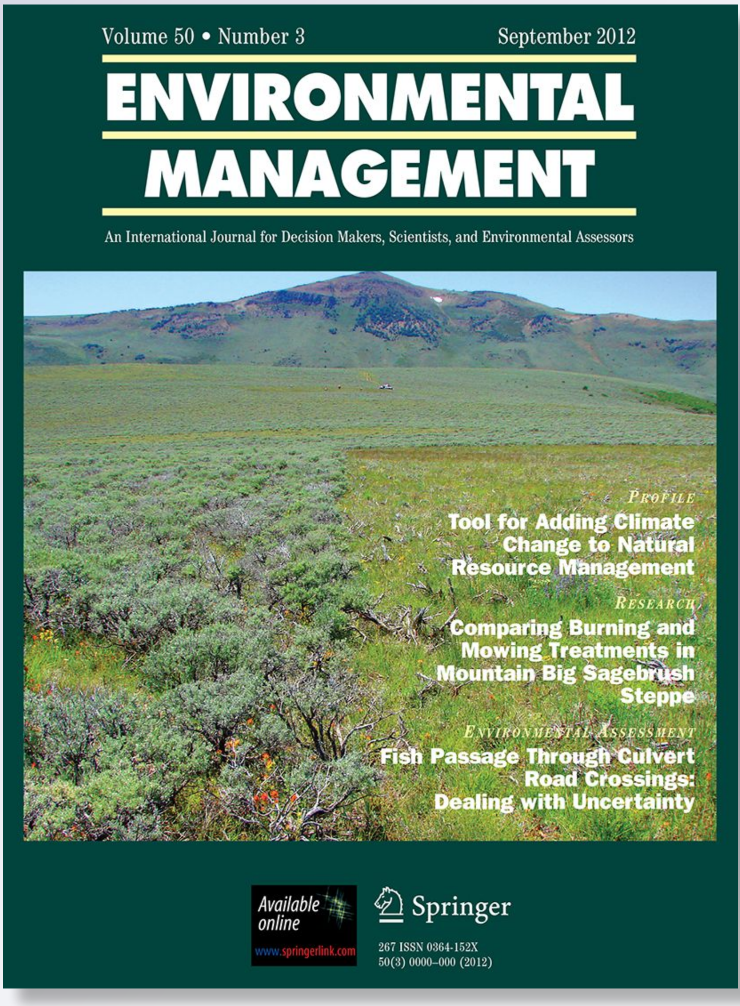

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Comparing Burned and Mowed Treatments in Mountain Big Sagebrush Steppe

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Abstract Fires in mountain big sagebrush [*Artemisia tridentata* spp. *vaseyana* (Rydb.) Beetle] plant communities historically shifted dominance from woody to herbaceous vegetation. However, fire return intervals have lengthened with European settlement, and sagebrush dominance has increased at the expense of herbaceous vegetation in some plant communities. Management actions may be needed to decrease sagebrush in dense sagebrush stands to increase herbaceous vegetation. Prescribed fire is often used to remove sagebrush; however, mechanical treatments, such as mowing, are increasingly used because they are more controllable and do not pose an inherent risk of escape compared with fire. However, information on the effects of burned and mowed treatments on herbaceous vegetation and whether fire and mowed applications elicit similar vegetation responses are limited. We evaluated the effects of prescribed burning and mowing for 3 years after treatment in mountain big sagebrush plant communities. The burned and mowed treatments generally increased herbaceous cover, density, and production compared with untreated controls ($P < 0.05$). However, neither treatment induced a response in native perennial forb cover, density, or biomass ($P > 0.05$). In contrast, annual forb (predominately natives) cover, density, and biomass increased with mowing and burning ($P < 0.05$). Vegetation generally responded similarly in burned and mowed treatments; however, the burned treatment had less sagebrush, greater herbaceous vegetation production, and more bare ground than the mowed treatment ($P < 0.05$). These differences should be considered when selecting treatments to decrease sagebrush.

Keywords *Artemisia tridentata* · Brush management · Disturbance · Prescribed burning · Wildlife habitat

Introduction

Infrequent fires in big sagebrush (*Artemisia tridentata* Nutt.) plant communities historically have shifted dominance from woody vegetation to perennial herbaceous vegetation (Wright and Bailey 1982; Miller and Rose 1999). These infrequent fires in sagebrush-dominated landscapes probably created a mosaic of different vegetative states that provided habitat for a variety of wildlife species (Noson and others 2006; Holmes 2007; Reinkensmeyer and others 2007). With European settlement, fire return intervals have commonly been lengthened in mountain big sagebrush [*Artemisia. tridentata* spp. *vaseyana* (Rydb.) Beetle] plant communities (Miller and Rose 1999; Miller and Heyerdahl 2008). The longer fire return intervals have led to increased dominance by mountain big sagebrush and depleted perennial herbaceous understories (West 1983; Miller and Rose 1999). Thus, to increase understory vegetation production in dense sagebrush stands, management actions may be needed to decrease sagebrush dominance (Connelly and others 2000; Olson and Whitson 2002; Crawford and others 2004).

Treatments to decrease sagebrush are often applied because a decrease in sagebrush dominance is expected to increase native perennial herbaceous vegetation (Hedrick and others 1966; Sneva 1972; McDaniel and others 1991; Davies and others 2007). These treatments were historically

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applied to increase forage production for livestock (Vale 1974; Beck and Mitchell 2000). Sagebrush-reduction treatments are now often applied with the goal of increasing the production and abundance of perennial forbs, which are highly nutritious and often consumed by wildlife species (Connelly and others 2000; Wrobleski and Kauffman 2003; Crawford and others 2004). However, perennial forb response has frequently been grouped with annual forb response in posttreatment measurements, or the characteristics measured have limited inference to production and abundance. For example, Mueggler and Blaisdell (1958) and Dahlgren and others (2006) documented an increase in forbs after mountain big sagebrush dominance was decreased, but annual and perennial forbs were grouped together for analyses. Wrobleski and Kauffman (2003) reported an increase in perennial forb reproduction effort after prescribed burning of Wyoming big sagebrush (*A. tridentata* ssp. *wyomingensis* Beetle and Young) plant communities, but they did not determine if an increase in perennial forb abundance or production occurred. Greater survival of seeded and transplanted native perennial forbs in burned compared with unburned Wyoming big sagebrush plant communities was reported by Wirth and Pyke (2003), but they did not determine if perennial forbs would increase naturally after fire. In contrast, Davies and others (2012) found no evidence that perennial forbs increased when mountain big sagebrush was mowed. Nevertheless, it remains unclear if decreasing mountain big sagebrush dominance, especially with fire, will increase perennial forb abundance and production.

In addition, disturbances that decrease or remove big sagebrush do not always increase native perennial vegetation (Peek and others 1979; Wambolt and others 2001; Beck and others 2009; Davies and others 2011; Hess and Beck 2012) and may promote an increase in exotic annuals (Stewart and Hull 1949; Davies and others 2009b). For example, Wambolt and others (2001) did not find a difference in perennial grass and forb canopy cover between burned and unburned mountain big sagebrush sites and suggested that decreasing sagebrush cover may not increase herbaceous production. Furthermore, Davies and others (2009b) showed that mimicking historical disturbance regimes (periodic fire and no livestock grazing) that removed sagebrush in Wyoming big sagebrush plant communities promoted exotic annual grass invasion. However, mountain big sagebrush communities are more diverse and productive than Wyoming big sagebrush communities and may respond differently to disturbances (Davies and Bates 2010a, b). Although the probability of exotic annual grass invasion after disturbance is greater in Wyoming big sagebrush communities (Chambers and others 2007), exotic annual grasses have been reported to increase after disturbance in some mountain big sagebrush communities (Bates and others 2005). Thus, there is a need to determine if herbaceous vegetation increases with treatments that decrease sagebrush dominance and how response varies among different plant functional groups, especially native perennial vegetation and exotic annual grasses, in mountain big sagebrush plant communities.

Prescribed fires have commonly been used in mountain big sagebrush plant communities to shift dominance from sagebrush to herbaceous vegetation (Harniss and Murray 1973; Wambolt and others 2001). Mechanical treatments, such as mowing, have also been used to decrease sagebrush dominance because these treatments allow more control of the size and shape of the treatment compared with fire (Mueggler and Blaisdell 1958; Urness 1979). The potential for mortality of perennial herbaceous species may also be less with mowing than prescribed burning because the severity of the disturbance is more controllable. Mowing and other mechanical treatments may also be preferred in wildland–urban interfaces because prescribed burning poses inherent risks to life and property from escaped fire and air quality concerns (Collins and others 2010). Although burning and mowing have both been used to decrease sagebrush dominance, information is lacking that would allow comparisons of vegetation responses between these two treatments in mountain big sagebrush communities.

The objectives of this study were to determine if perennial herbaceous vegetation increased when sagebrush dominance was decreased and if mowing produced the same vegetation response as prescribed fire. To accomplish these objectives, we evaluated plant community response to mowing and prescribed fall burning. We hypothesized that (1) perennial forbs and grasses would increase with decreased sagebrush dominance; and that (2) herbaceous vegetation response would be greater in burned compared with mowed treatments because burning would remove more sagebrush than mowing.

Methods

Study Area

The study was conducted on the Hart Mountain National Antelope Refuge (42°21′16″N 119°22′54″W) in southeastern Oregon. Study sites were located on the eastern side of Hart Mountain adjacent to the Skyline Drive or Barnhardi Road depending on site. Both roads experience little traffic as they are only seasonally (<2 months) open to the public and are not maintained. Elevation at the study sites are from 2,013 to 2,166 m above sea level. Slopes vary from 0° to 7° with aspects ranging from south to north. Long-term average annual precipitation was between 400 and 510 mm (Natural Resource Conservation Service 1998). Annual precipitation in southeastern Oregon was 80, 66, 87, and 101 % of the 69-year long-term average in 2007, 2008, 2009, and 2010, respectively (Eastern Oregon Agricultural Research Center 2010). Climate is typical of the northern Great Basin: hot, dry summers and cool, wet winters. Livestock have been excluded from Hart Mountain National Antelope Refuge since the mid-1990s. Mountain big sagebrush was the dominant shrub on all study sites. Common perennial grasses included Idaho fescue (*Festuca idahoensis* Elmer), bluebunch wheatgrass [*Pseduoroegneria spicata* (Pursh) A. Löve], Columbia needlegrass [*Achnatherum nelsonii* (Scribn.) Barkworth], prairie junegrass [*Koeleria macrantha* (Ledeb.) Schult.], and bottlebrush squirreltail [*Elymus elymoides* (Raf.) Swezey]. Common perennial forbs included common yarrow (*Achillea millefolium* L.), milkvetches (*Astragalus* L.), paintbrushes (*Castilleja* Mutis ex L. f.), fleabanes (*Erigeron* L.), biscuitroots (*Lomatium* Raf.), and lupines (*Lupinus* L.).

Experimental Design

A randomized complete block design was used to evaluate vegetation responses to burned and mowed treatments in mountain big sagebrush plant communities. Six sites (blocks) with varying slope, aspect, elevation, soil, and vegetation were selected for this study. Before treatment, plots within a block were determined to have uniform site and vegetation characteristics. Sagebrush cover ranged from 26 to 34 % among plots but did not vary between treatments before treatment ($P > 0.05$). Perennial grass densities averaged 25 ± 3, 24 ± 2, and 22 ± 3 individuals m^{-2} in the mowed, burned, and control plots before treatment, but they did not differ significantly among treatments ($P > 0.05$). Other plant functional group densities and cover values also did not differ among treatments before treatment ($P > 0.05$). Sampling methods and design are reported later in the text. Treatments were randomly assigned to three 60×90-m areas at each block. Treatments were an untreated control, mowed, and burned (prescribed fall burning). Mowed treatments were implemented in September 2007 by mowing with a John Deere 1418 rotary cutter set to mow at a 20 cm height (Deere and Company, Moline, IL). Burned treatments were applied as prescribed fall burns ignited with drip-torches as strip-head fires between mid-October and early November 2007. Fine fuel loads varied between 327 and 977 kg ha^{-1}, and sagebrush cover averaged 30 %. Air temperatures varied between 6 and 11 °C; wind speed ranged from 2 to 10 km h^{-1}; and relative humidity was 33–43 % during the prescribed burns.

Sampling

One 50×80-m plot was used to sample each treatment at each site in early July before treatment (2007) and for 3 years after treatment (2008 through 2010). Vegetation was measured along four parallel 50-m transects spaced at 20-m intervals. Shrub canopy cover by species was measured using the line intercept method (Canfield 1941) on each of the 50-m transects. Canopy gaps <15 cm were included in the shrub canopy cover measurements. Shrub density was determined by species by counting all of the shrubs rooted inside four 2×50-m belt transects centered on each 50-m transect. Herbaceous canopy cover was estimated by species inside 40×50-cm quadrats (0.2 m^2) located at 3-m intervals along each 50-m transect (starting at 3 m and ending at 45 m) resulting in 15 quadrats/transect and 60 quadrats/plot. Bare ground and litter were also estimated inside each 0.2-m^2 quadrat. Herbaceous vegetation density was determined by species by counting individuals inside each 0.2-m^2 quadrat. Plants were counted if more than half of their basal crown was inside the 0.2-m^2 quadrat. Density of species that spread vegetatively was estimated by considering stems separated by >10 cm as individuals. Herbaceous biomass production (aboveground) was determined by clipping by plant functional group in 15 randomly located 1-m^2 quadrats/plot. Clipped herbaceous biomass was oven-dried at 50 °C until reaching a consistent weight, and then the current year's growth was separated from the previous years' growth and weighed to determine biomass production. Standing crop biomass was determined by summing current and previous years' growth.

Statistical Analyses

Vegetation data collected from the individual transects were summarized for the entire plot for analyses ($n = 6$). Repeated-measures analysis of variance (ANOVA) using the mixed models procedure (Proc Mix) in SAS v.9.1 (SAS, Cary, NC) was used to determine the influence of treatments on response variables. Fixed variables were treatment and time since treatment (year) and their interactions. Random variables were sites and site by treatment interactions. Covariance structures used in the repeated measures ANOVAs were selected using Akaike's Information Criterion (Littell and others 1996). When there was an interaction between year and treatment, treatment effects were also evaluated in each year of the study using ANOVAs. Fisher's protected least significant difference test was used to test for differences between treatment means. Data were tested for normality using the univariate procedure in SAS v.9.1 (Littell and others 1996). Data that violated assumptions of normality were log-transformed. All figures present original data (i.e., nontransformed). Response variable means were reported with SEs. Differences between means were considered significant at $P \leq 0.05$. For analyses, herbaceous cover, density, and biomass production were grouped into five functional groups: Sandberg bluegrass (*P. secunda* J. Presl), perennial grasses, exotic annual grasses, perennial forbs, and annual forbs. Sandberg bluegrass was treated as a separate functional group from the other perennial grasses because of its earlier phenological development.

Results

Cover

Perennial grass, Sandberg bluegrass, annual forb, total herbaceous, and litter cover all varied by interaction between treatment and year (Fig. 1; $P < 0.05$), whereas sagebrush, perennial forb, and exotic annual grass did not ($P > 0.05$). Perennial grass cover did not differ between the control and either the mowed or burned treatment in 2008 ($P > 0.05$); however, the mowed treatment had greater cover than the burned treatment (Fig. 1a; $P = 0.04$). In 2009 and 2010, the mowed and burned treatments had greater perennial grass cover than the control ($P < 0.05$) but did not differ from each other ($P > 0.05$). Perennial grass cover was 1.5- and 1.6-fold greater in the mowed and burned treatments, respectively, compared with the control in 2010. Sagebrush cover varied among the treatments in all three posttreatment years (Fig. 1b; $P < 0.01$) with the greatest cover in the control and the least cover in the burned treatment ($P < 0.01$). Average sagebrush cover was <0.1, 3–4, and 29–35 % in the burned, mowed, and control treatments, respectively. Sandberg bluegrass cover did not differ among treatments in 2008 and 2009 (Fig. 1c; $P > 0.05$). In 2010, the mowed and burned treatments had 1.7- to 1.9-fold greater Sandberg bluegrass cover than the control ($P = 0.05$ and $P = 0.02$, respectively). Perennial forb and exotic annual grass cover did not differ among treatments (Fig. 1d, e, respectively; $P < 0.05$). Mowed treatments had greater annual forb cover than the burned and control treatments in 2008 (Fig. 1f; $P = 0.02$ and $P < 0.01$, respectively), whereas the control and burned treatments did not differ in annual forb cover ($P = 0.28$). In 2009 and 2010, the mowed and burned treatments had greater annual forb cover than the control ($P < 0.05$), but did not differ from each other ($P > 0.05$). In 2010, annual forb cover was 2.5- and 3.1-fold greater, respectively, in the mowed and burned treatments compared with the control. Total herbaceous cover did not differ among treatments in 2008 ($P = 0.190$) nor between the mowed and burned treatments in 2009 and 2010 (Fig. 1g; $P = 0.22$ and 0.40, respectively). Total herbaceous cover was 1.2- to 1.3-fold greater in the mowed and burned treatments than the control in 2009 and 2010 ($P < 0.01$). The burned treatment had less litter cover than the mowed and control treatments in 2008 ($P < 0.01$), but litter cover did not vary between the control and mowed treatments (data not presented; $P = 0.21$). In 2009 and 2010, all treatments differed in litter cover ($P < 0.05$). Litter cover was greatest in the control and least in the burned treatment. The burned treatment had greater bare ground than the control and mowed treatment in all 3 years of the study (Fig. 1h; $P < 0.01$). Bare ground did not differ between the mowed treatment and control in any year of the study ($P > 0.05$).

Density

Interactions between treatment and year were not significant for the density of any plant functional group (Fig. 2; $P > 0.05$) except annual forb density ($P < 0.01$). Perennial grass and sagebrush density varied by treatment (Fig. 2a, b, respectively; $P < 0.05$). Perennial grass density was greater in the mowed and burned treatments compared with the control ($P < 0.05$), but it did not vary between the mowed and burned treatments ($P > 0.05$). Perennial grass density was on average 5–8 plants m^{-2} greater in the mowed and burned treatments compared with the control. Sagebrush density varied among all of the treatments in all years ($P < 0.01$). The untreated control had the greatest sagebrush density followed by the mowed treatment and then the burned treatment ($P < 0.01$). Sagebrush density in the mowed treatment was approximately one third the density of the control, whereas sagebrush was mostly absent from the burned treatment. In 2008, annual forb density was greater in the control and mowed treatments compared with the burned treatment (Fig. 2f; $P < 0.01$ and $P = 0.02$, respectively), but it did not vary between the control and mowed treatments ($P = 0.14$). In 2009 and 2010, the mowed and burned treatments had approximately three- to sixfold greater annual forb density than the control ($P < 0.05$). Annual forb density did not vary between the mowed and burned treatments in 2009 and 2010 ($P > 0.05$). Perennial forb, exotic annual grass, and Sandberg bluegrass density did not vary among the treatments (Fig. 2; $P > 0.05$).

Biomass

Perennial grass, total herbaceous, and standing crop biomass varied by the interaction between treatment and year (Fig. 3; $P < 0.01$). Biomass of the other plant functional groups was not influenced by the interaction between treatment and year ($P > 0.05$). Perennial grass, total herbaceous, and standing crop biomass did not vary among treatments in 2008 ($P = 0.65$, $P = 0.49$, and $P = 0.35$, respectively). In 2009 and 2010, perennial grass biomass was two- to threefold greater in the mowed and burned treatments compared with the control ($P < 0.01$), but it did not differ between the mowed and burned treatments

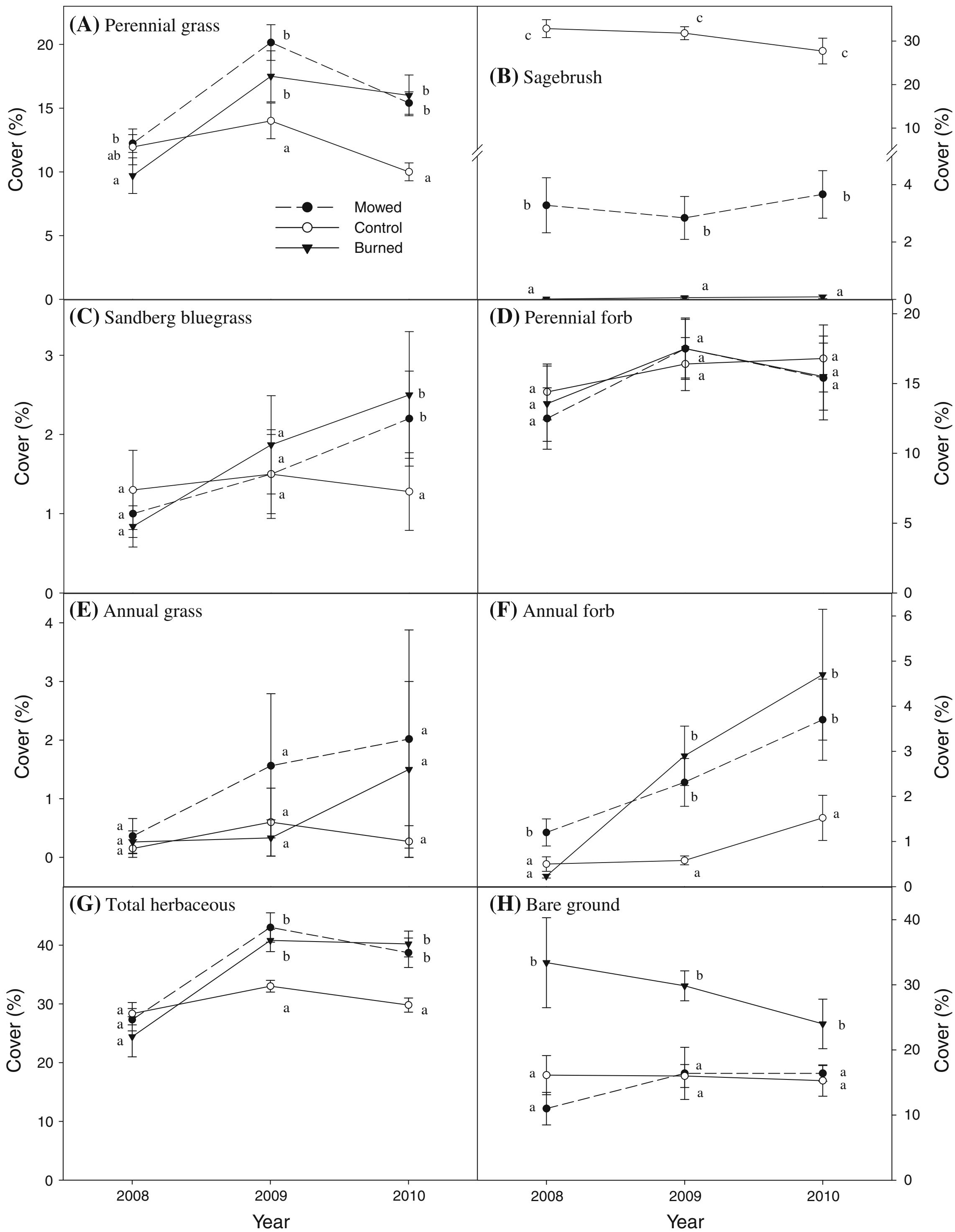

Fig. 1 Vegetation cover values and bare ground (mean ± SE) in the mowed, burned, and untreated (control) treatments in mountain big sagebrush plant communities on Hart Mountain, Oregon, USA, in 2008, 2009, and 2010 ($n = 6$). **a** Perennial grass. **b** Sagebrush. **c** Sandberg bluegrass. **d** Perennial forb. **e** Annual grass. **f** Annual forb. **g** Total herbaceous. **h** Bare ground. Data presented are original, nontransformed data. *Different lower case letters* indicate significant differences between treatments in that year ($P \leq 0.05$)

(Fig. 3a; $P > 0.05$). Annual forb biomass varied among the treatments (Fig. 3e; $P = 0.03$). The mowed and burned treatments had on average 2.5- to 2.7-fold greater annual forb biomass compared with the control ($P = 0.03$ and $P = 0.01$, respectively). Annual forb biomass did not differ between the mowed and burned treatments ($P = 0.72$).

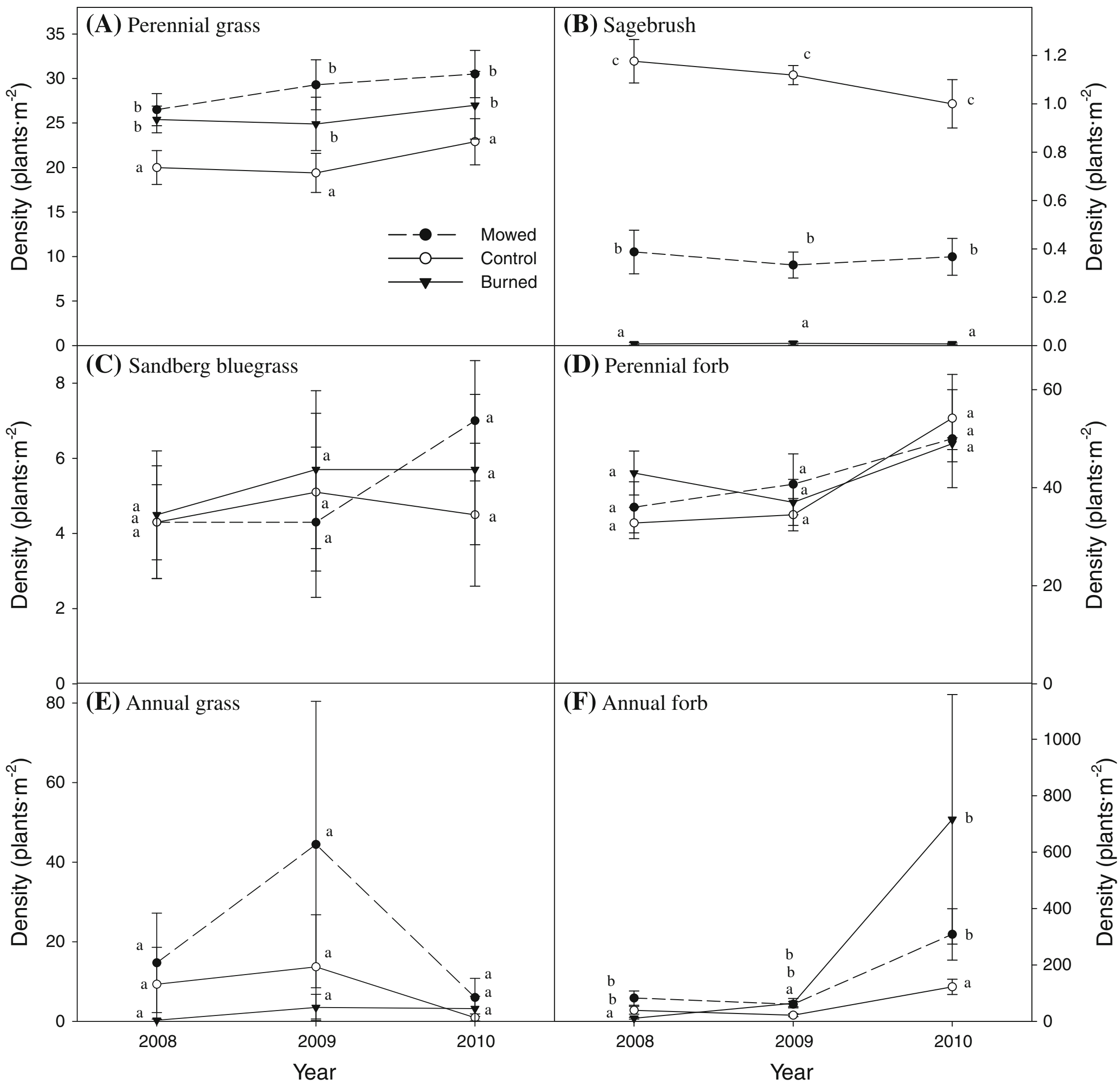

Fig. 2 Vegetation densities (mean ± SE) in the mowed, burned, and untreated (control) treatments in mountain big sagebrush plant communities on Hart Mountain, Oregon, USA in 2008, 2009, and 2010 ($n = 6$). **a** Perennial grass. **b** Sagebrush. **c** Sandberg bluegrass. **d** Perennial forb. **e** Annual grass. **f** Annual forb. Data presented are original, nontransformed data. *Different lower case letters* indicate significant differences between treatments in that year ($P \leq 0.05$)

Total herbaceous biomass was approximately twofold greater in the mowed and burned treatments compared with the control in 2009 ($P < 0.01$), but it did not vary between the mowed and burned treatments (Fig. 3f; $P = 0.32$). In 2010, the mowed and burned treatments still had 1.7- to 2-fold greater total herbaceous biomass than the control, respectively ($P < 0.01$), but the burned treatment produced approximately 200 kg ha^{-1} more total herbaceous biomass than the mowed treatment ($P = 0.05$). Standing crop biomass was greater in mowed and burned treatments compared with the control in 2009 and 2010 (Fig. 3g; $P < 0.01$). Standing crop biomass did not differ between the mowed and burned treatments in 2009 ($P = 0.73$), but it was approximately 190 kg ha^{-1} greater in the burned treatment compared with mowed treatment in 2010 ($P = 0.04$). Sandberg bluegrass, perennial forb, and exotic annual grass biomass did not vary among treatments (Fig. 3; $P = 0.71$, $P = 0.14$, and $P = 0.30$, respectively).

Discussion

Decreasing mountain big sagebrush shifted dominance from woody to herbaceous vegetation. Herbaceous vegetation biomass production was between 400 and 600 kg ha^{-1} greater in the second and third years after treatment in the mowed and burned treatments compared with the untreated control (Fig. 3f), showing that decreasing woody dominance in dense stands of mountain big sagebrush can increase herbaceous vegetation. This

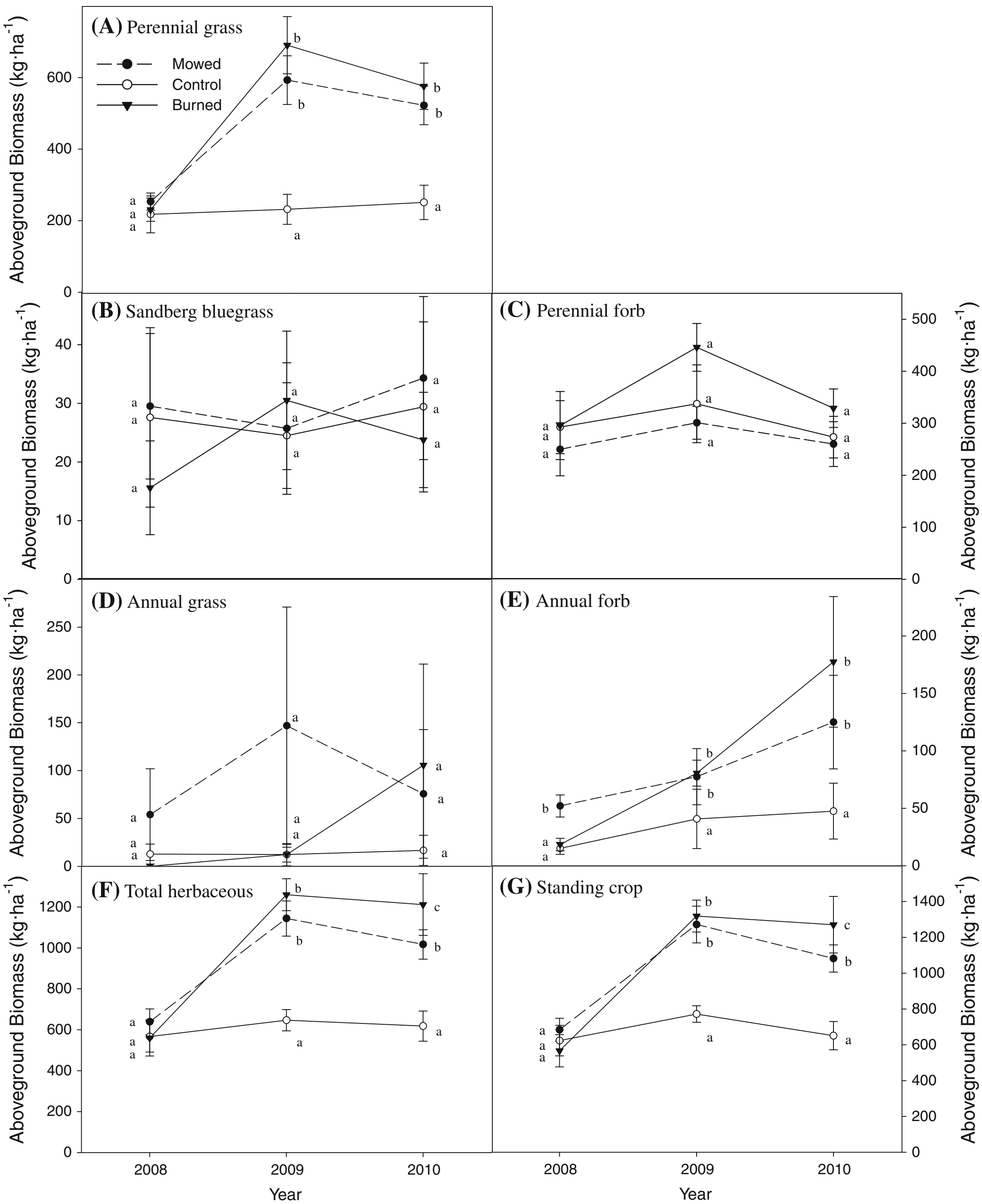

Fig. 3 Vegetation biomass (mean ± SE) in the mowed, burned, and untreated (control) treatments in mountain big sagebrush plant communities on Hart Mountain, Oregon, USA, in 2008, 2009, and 2010 ($n = 6$). **a** Perennial grass. **b** Sandberg bluegrass. **c** Perennial forb. **d** Annual grass. **e** Annual forb. **f** Total herbaceous. **g** Standing crop. Data presented are original, nontransformed data. *Different lower case letters* indicate significant differences between treatments in that year ($P \leq 0.05$)

approximate twofold increase is similar to other reported two- to threefold increases in herbaceous production after treatments that decreased big sagebrush dominance (Harniss and Murray 1973; Wambolt and Payne 1986; Davies and others 2007). The increase in herbaceous vegetation at our study sites was mainly the result of the response of native perennial grasses and annual forbs; however, vegetation response may differ in mountain big sagebrush communities with more depleted herbaceous understories.

Cover of herbaceous plant functional groups was largely unaffected by mowing or burning the first growing season after treatment. Typically, herbaceous cover, especially perennial grasses, decreases the first growing season after fire in sagebrush plant communities and commonly requires two growing seasons to return to preburn levels and greater than two growing seasons to increase (Blaisdell 1953; Conrad and Poulton 1966; Rhodes and others 2010; Uresk and others 1976; West and Hassan 1985). In our study, we measured increases in perennial grass, annual forb, and total herbaceous cover by the second growing season after either burning or mowing. The relatively rapid response after fire may have been a result of the relatively cool and wet conditions when the sites were burned in October and early November. Wildfires in the Intermountain West sagebrush steppe typically occur in the summer (July to September), and prescribed burns are usually applied in early fall (September to October) (Wright and others 1979) under hotter and drier conditions than when fires were applied in our study. These earlier season burns are typically characterized by greater fire severity that often decreases perennial grass density and crown area, which delays recovery the first several years after fire (Uresk and others 1976, 1980; Bates and Svejcar 2009; Bates and others 2011). The mowed treatment probably had limited, if any, negative impact on native perennial grass and other herbaceous functional groups because it was applied after the growing season and at a 20-cm height.

Compared with our results, Dahlgren and others (2006) reported that decreasing mountain big sagebrush dominance with mechanical treatments (Dixie harrow or Lawson aerator) or herbicide application in Utah did not increase grass cover. However, increases in perennial grass are inversely correlated to sagebrush cover after treatment (Rittenhouse and Sneva 1976). In our study, sagebrush cover was decreased by 86 % with mowing and nearly eliminated with burning. The mechanical and herbicide treatments used by Dahlgren and others (2006) decreased sagebrush cover between 34 and 62 % from pretreatment levels of approximately 31–38 %. Therefore, differences in methods used to decrease sagebrush dominance and, subsequently, the level of decrease may explain differences between results from Dahlgren and others (2006) and our study. Compared with our study, other studies with high reductions in sagebrush did not measure an increase in perennial grass cover, abundance, or biomass (Peek and others 1979; Wambolt and others 2001; Beck and others 2009; Davies and others 2011; Hess and Beck 2012). However, also in contrast with our study, these studies were conducted in Wyoming big sagebrush plant communities, and differences in plant communities probably explain the dissimilarity in perennial grass response. Mountain big sagebrush plant communities are more productive and diverse than Wyoming big sagebrush communities; thus, they are expected to respond differently to disturbances (Davies and Bates 2010a, b).

A major goal of sagebrush-reduction treatments is to enhance forb abundance and biomass for wildlife (Wirth and Pyke 2003). However, neither treatment used in our study to decrease sagebrush increased perennial forbs, although annual forbs responded positively to both treatments. Annual forb response was largely the result of native annual forbs. The native forb species—*Collinsia parviflora* Lindl., *Collomia grandiflora* Douglas ex Lindl., *Gayophytum racemosum* Torr. and A. Gray, and *Microsteris gracilis* (Hook.) Greene—dominated the annual forb component at our study sites. For example, 93 % of the total annual forb density across all sites was from these four native species. Our results in the first 3 years after burn contrast with Wirth and Pyke's (2003) prediction that perennial forbs would increase in big sagebrush plant communities with burning. Similar to our results, many other studies have not detected increases in perennial forb cover, productivity, or abundance in big sagebrush plant communities after fire (Beck and others 2009; Davies and others 2007; Harniss and Murray 1973; Nelle and others 2000; Rhodes and others 2010; Wrobleski and Kauffman 2003), although most of these studies were conducted in Wyoming big sagebrush communities with the exceptions of Nelle and others (2000) and Harniss and Murray (1973). Pyle and Crawford (1996) measured greater frequency of Cichorieae species in response to fire; however, other forbs were not enhanced by burning in mountain big sagebrush steppe. After using a Dixie harrow or tebuthiuron treatments to thin sagebrush, total forb cover increased in mountain sagebrush steppe (Dahlgren and others 2006); however, because forbs were not separated into perennial and annual life forms, comparisons with other studies are problematic. Reported increases in forbs after treatments applied to decrease sagebrush were mainly a result of greater annual forb response (Rhodes and others 2010; Bates and others 2011; Davies and others 2012). However, increases in perennial forbs in mountain big sagebrush plant communities have been documented in response to prescribed burning (Bates and others 2011).

Perennial forbs may not have responded to the decrease in sagebrush because of the immediate and large increase in perennial grasses. A robust perennial grass response may have pre-empted the ability of perennial forbs to respond by using any resources made available by the decrease in sagebrush. Perennial forbs may be more likely to increase where perennial grasses have been significantly decreased. An increase in perennial forbs after prescribed burning of woodland-encroached mountain big sagebrush plant communities was attributed to high mortality of perennial grasses (Bates and others 2011). Wirth and Pyke (2003) reported that survival of seeded perennial forbs in burned sagebrush communities was greatest in former sagebrush subcanopy locations compared with interspaces. Sagebrush subcanopy locations were probably advantageous to perennial forb establishment because burning decreases the perennial grasses and increases soil resource concentrations more in the subcanopy than interspace locations (Davies and others 2009a; Boyd and Davies 2010). Alternately, perennial forbs may exhibit a lagged response to treatments. Perennial forbs often do not rapidly increase after disturbance, especially compared with annual forbs (Goergen and Chambers 2009; Boyd and Svejcar 2011). For example, increases in silvery lupine (*Lupinus argenteus* Pursh) density from burning were largely not realized until 3 years after fire due to limited recruitment in the first 2 years after fire (Goergen and Chambers 2009). In addition, recruitment events are rare and episodic for many perennial species native to arid and semiarid regions (Ackerman 1979; Kigel 1995). Long-term evaluation is needed to fully appraise perennial forb responses to burned and mowed treatments.

Data from the untreated plots also suggest that perennial forb abundance and productivity may not be overly suppressed by the presence of sagebrush. Perennial forb production averaged approximately 300 kg ha^{-1} across the untreated plots, which is approximately 100 kg ha^{-1} more than the average reported for relatively intact mountain big sagebrush plant communities in the northern Great Basin (Davies and Bates 2010b). Perennial forb density at the study sites was also approximately 1.5-fold greater than the average reported for intact mountain big sagebrush communities (Davies and Bates 2010a). Thus, sagebrush may not suppress perennial forbs as much as it does perennial grasses. Conversely, perennial grasses may be able to respond more rapidly than perennial forbs to disturbances that decrease sagebrush.

Although exotic annual grass can increase and potentially dominate sagebrush plant communities after disturbances (Stewart and Hull 1949; Davies and others 2009b), we found no evidence that exotic annual grasses would become an issue at our study sites after mowing or prescribed burning. Large increases in perennial grasses may have greatly limited exotic annual grasses in both the mowed and burned treatments. Exotic annual grass establishment and proliferation is limited in plant communities with high perennial grass densities (Davies 2008; James and others 2008). A higher severity fire that caused greater perennial grass mortality may have made the plant community more susceptible to exotic annual grasses. Burning or mowing under conditions similar to the application used in this study and on sites with nearly intact herbaceous understories does not appear to increase the risk of converting the plant community to an exotic annual grass-dominated community.

In general, vegetation responded similarly to mowing and burning. However, there were some noteworthy differences between the treatments. Greater density and cover of sagebrush in the mowed compared with the burned treatment suggest that sagebrush recovery will be accelerated in the mowed treatment. Therefore, mowing may be preferred in areas where less decrease in sagebrush is desired. Similar to our results, Wambolt and Payne (1986) reported that sagebrush recovery was faster in mechanically treated compared with burned Wyoming big sagebrush plant communities. Burning usually eliminates sagebrush from the plant community, whereas smaller sagebrush plants often survive mowing treatments. Sagebrush that survived mowing may foster earlier sagebrush recovery because re-establishment of sagebrush is often limited by proximity to surviving plants, seed availability, and establishment conditions (Johnson and Payne 1968; Young and others 1990; Maier and others 2001; Ziegenhagen and Miller 2009). A major reason that sagebrush recovery is limited by proximity to sagebrush plants is that sagebrush seeds are disseminated primarily by wind with the majority of seeds being dispersed only 9–12 m from parent plants (Mueggler 1956; Johnson and Payne 1968). Earlier recovery of sagebrush would be beneficial for sagebrush obligate and facultative wildlife species. However, if the management objective is to maintain increased herbaceous production, retreatment intervals will probably be shorter in the mowed compared with the burned treatment because dense sagebrush stands that suppress herbaceous production will develop more rapidly.

The burned treatment compared with the mowed treatment produced greater total herbaceous and standing crop biomass, which could be an important distinction for some management objectives. For example, the burned treatment may be advantageous compared with the mowed treatment if the primary objective is to increase herbaceous forage. Greater bare ground and lower litter cover in burned areas compared with mowed areas could have significant implications to erosion potential. More bare ground and less litter cover can increase soil erosion in sagebrush communities (Johnson and others 1980; Pierson and others 2008, 2009). Thus, in some sagebrush communities where accelerated soil erosion is a concern, it may be more advantages to mow than burn.

Conclusion

The burned and mowed treatments both decreased mountain big sagebrush and increased herbaceous vegetation. This response was largely from perennial grasses and annual forbs. The general lack of a perennial forb response to treatments suggests that decreasing mountain big sagebrush may not result in greater perennial forb abundance and biomass production. Thus, managers should recognize that prescribing sagebrush removal or reduction with the objective of increasing perennial forbs may not be successful. However, long-term evaluation is needed to determine if there is a lagged perennial forb response and if the response differs with varying site characteristics and climatic conditions. Additional research is also needed to determine if greater mortality of perennial grasses would increase perennial forbs when brush-reduction treatments are applied to mountain big sagebrush communities. However, greater mortality of perennial grasses may also increase the risk of substantial increases in exotic annual grasses. Exotic annual grasses were not an issue in either the mowed or burned treatments in the first 3 years after treatment. Thus, it appears that mountain big sagebrush communities similar to the ones included in this study can be either burned or mowed under similar environmental conditions without promoting exotic annual grass dominance.

The burned and mowed treatments in mountain big sagebrush plant communities generally elicited a similar response from vegetation. However, there were some distinct differences that should be considered when determining whether to use fire or mowing. Specifically, burning increased herbaceous vegetation production, decreased sagebrush, and increased bare ground more than mowing. These differing responses to treatments must be considered, along with the social and logistical aspects, when evaluating whether to use mowing or burning.

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