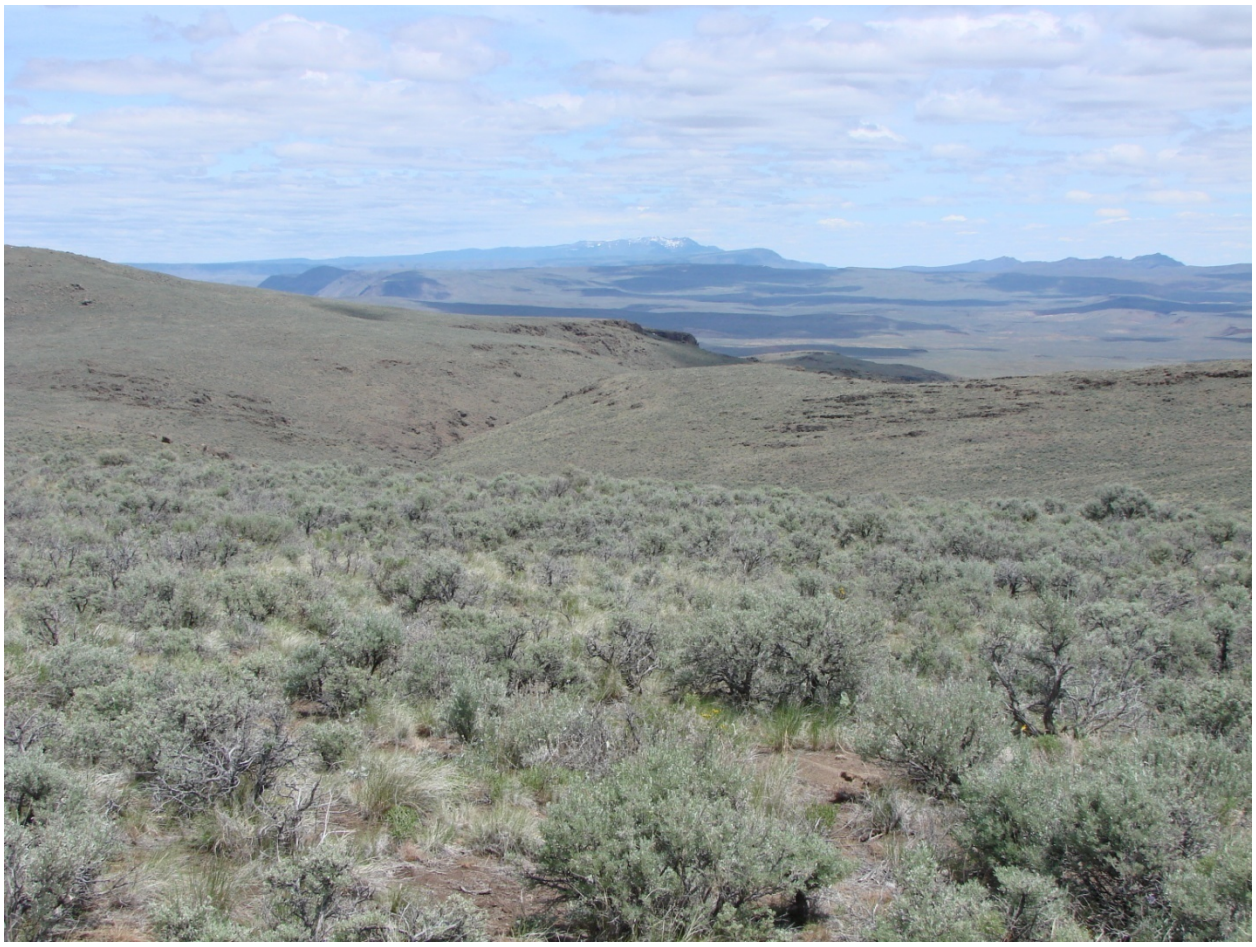
Sagebrush Steppe – Research Progress Report 2007



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Effects of burning Wyoming big sagebrush-bunchgrass communities

Kirk W. Davies, Jonathan D. Bates and Richard F. Miller

Summary

Herbaceous biomass production and cover were increased with fall prescribed burning. Inorganic N concentrations were also increased with burning, while soil water was generally greater in the control than burned plot. Our results suggest that fall prescribed burning can be used in relatively intact, late seral Wyoming big sagebrush communities to increase herbaceous forage and alter wildlife habitat without increasing exotic annual grasses.

Introduction

Wyoming big sagebrush (*Artemisia tridentata* spp. *wyomingensis* [Beetle & A. Young] S.L. Welsh) is the most widely distributed alliance of the big sagebrush (*Artemisia tridentata* Nutt.) complex in the western United States (Küchler 1970; Miller et al. 1994; West and Young 2000). The alliance is considered the least resilient and most susceptible to invasion by exotic weeds (Miller and Eddleman 2000). Large areas of this alliance have been converted to cheatgrass *(Bromus tectorum* L.)-dominated grasslands, particularly in the Intermountain West, because of increased fire frequencies (Whisenant 1990; Miller and Eddleman 2000). The decline of intact Wyoming big sagebrush steppe communities has resulted in uncertainty as to the acceptability of using fire as a management tool to shift dominance from Wyoming big sagebrush to desirable herbaceous vegetation. Of particular concern is the potential for prescribed burning to promote invasion of undesirable exotic annual grasses.

Methods

The study was conducted at the Northern Great Basin Experimental Range (NGBER) in southeastern Oregon. Six randomly selected sites were used. Each site contained an October prescribed burn and an unburned treatment. Soil water content in the 0-15 and 15-30 cm soil depths, total soil N, C, OM in the upper 15 cm of the soil profile, biomass production (aboveground shrub and herbaceous production),total vegetation cover (herbaceous and shrub cover) and perennial herbaceous species density and diversity were measured for the two years following treatment.

Results

Soils

Nitrate and NH^{+}_{4} concentrations in the upper 15 cm of the soil profile were greater in the burned than control treatment ($P = 0.0014$ and 0.0019, respectively; Fig. 1). Soil OM, total soil C, and total soil N were not different between treatments in either year of the study ($P > 0.05$). Soil water content in the 0–15 cm and 15–30 cm depth was generally greater in the control than the burned treatment. Soil water content tended to be greater at both depths in the control compared to the burned treatment during the growing season.

Biomass Production

Aboveground biomass production (shrub and herbaceous) was greater in the control than the burned treatment in 2003 and 2004 (P = 0.0005 and 0.0467, respectively; Fig. 2) although the difference was less in the second postburn year. Herbaceous vegetation production in the burned treatment was greater than in the control treatment in both years of the study (P = 0.0264 and 0.0037, respectively). Tall tussock perennial bunchgrass production was greater in the burned than control treatments in 2003 and 2004 (P = 0.0096 and 0.0153, respectively). Sandberg bluegrass production was less and both annual forb and annual grass production were slightly greater in the burned than control in 2003 ($P < 0.05$), but were not different between treatments in 2004 ($P > 0.05$). Rabbitbrush and perennial forb production did not vary between treatments in either postburning year ($P > 0.05$).

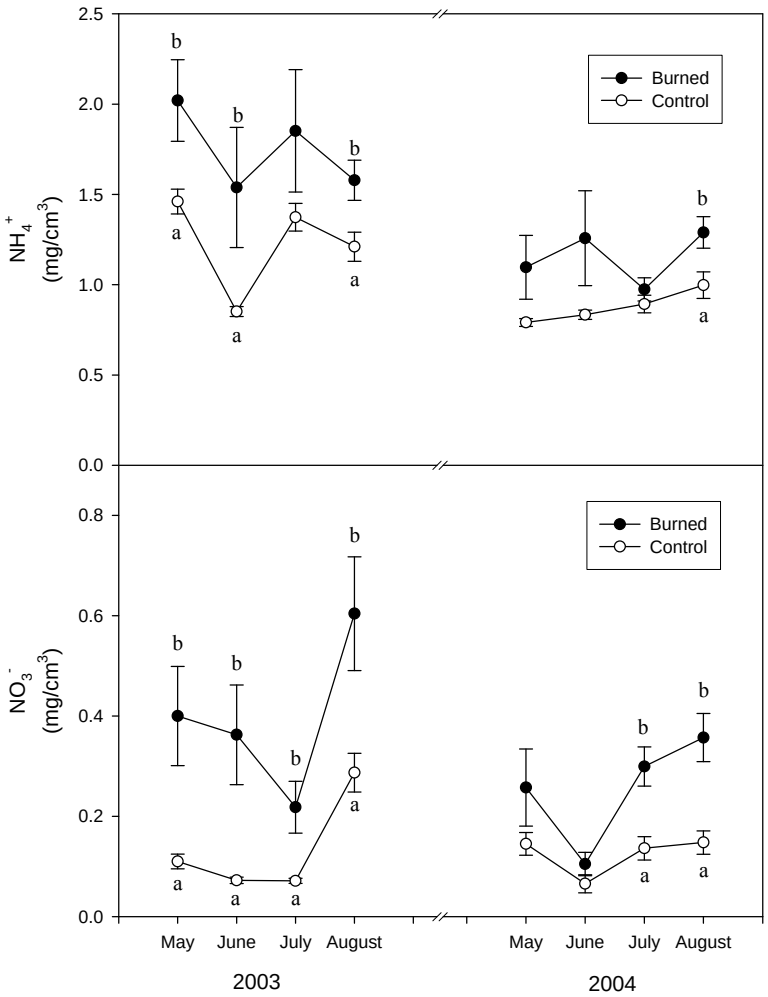

Figure. 1. Soil NO_3^- and NH_4^+ concentrations (mean ± standard error) in the upper 15 cm of the soil profile in burned and control treatments in 2003 and 2004. Different lower case letters indicate differences between treatments on that date ($P < 0.05$).

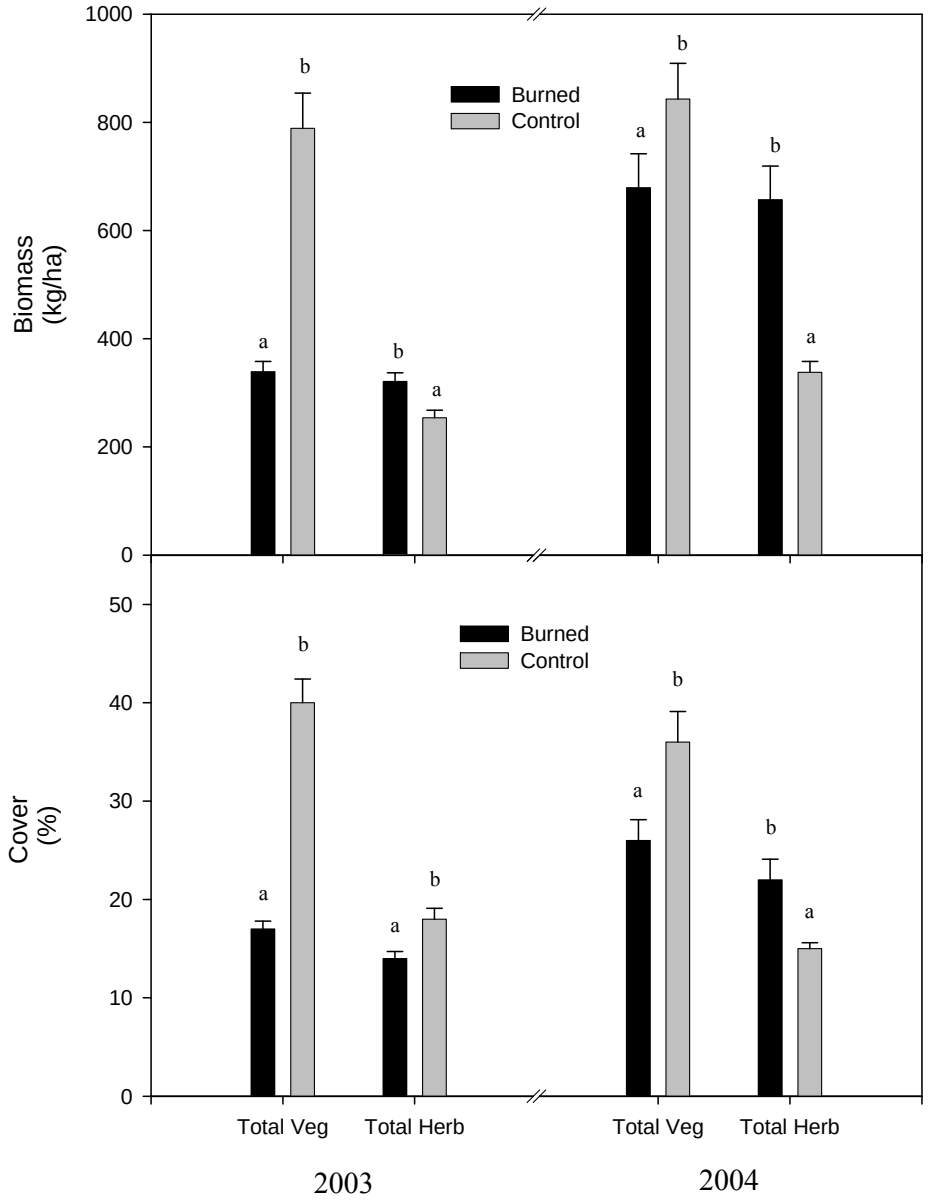

Figure 2. Total vegetation and herbaceous biomass production and cover (mean + standard error) in the burned and control treatments. Total Veg = Total vegetation biomass production. Total Herb = Total herbaceous biomass production. Different lower case letters indicates differences between treatments in that year ($P < 0.05$).

Cover and Diversity

Total vegetation (Fig. 2) and sagebrush cover values were greater in the control than burned treatments in both years of the study ($P < 0.05$). In the first postburn year, total herbaceous, rabbitbrush, and tall tussock perennial grass cover values were greater in the control than the burned treatment ($P < 0.05$). By the second postburn year, herbaceous cover was greater in the burned than control treatments ($P = 0.0326$), and tall tussock perennial grass and rabbitbrush cover did not vary by treatment ($P > 0.05$). Sandberg bluegrass, annual grass, annual forb, and perennial forb cover did not differ between treatments in either year of the study ($P > 0.05$). The Shannon diversity index (Krebs 1998) for the perennial vegetation was not different between the control and the burned treatment in either year of the study ($P > 0.05$).

Discussion

The greater total vegetation aboveground biomass production and cover in the control compared to the burned treatment suggest that burned sites did not attain their potential production. Harniss and Murray (1973) reported that reductions in production of a burned relative to unburned mountain big sagebrush community were evident thirty years after burning. This suggests that the reduction in vegetation production from burning Wyoming big sagebrush communities may be a long-term impact.

In contrast to total vegetation production, herbaceous vegetation production was greater in the burned than control treatment the first year after prescribed burning and more than 2-fold greater the second year, suggesting a greater proportion of resources were available for herbaceous growth. With our fall prescribed burn, we observed limited mortality of perennial herbaceous vegetation. Therefore, herbaceous vegetation could respond rapidly to the release from interference/competition with sagebrush.

Lower soil water content in the burned treatment was probably either due to decreased initial capture of precipitation (especially snow), increased evapotranspiration, or a combination of both (Hutchison, 1965; Sturges, 1977; Obrist et al., 2003). The proportion of resources available to herbaceous vegetation increased with burning, and we measured a primarily perennial response to the increased resources although there was an increase in *Alyssum* species L., an introduced annual plant.

Our results indicate that livestock forage can be increased by prescribed fall burning relatively intact, late seral Wyoming big sagebrush communities. However, the risk of weed invasion greatly increases with increased soil resource availability (Sheley et al. 1999a, 1999b; Davis et al. 2000; Svejcar 2003).

Similar to Humphrey (1984), we found no short-term differences in herbaceous perennial vegetation diversity between the burned and control treatments and attributed it to limited plant mortality from the burn treatment. High vegetation survival of the burn and rapid response by perennials, a limited source of noxious weed propagules, or combinations of these factors may have prevented noxious weed encroachment. Had there been a source of noxious weed propagules near the study site and/or increased herbaceous mortality, noxious weeds may have been more prominent.

Conclusions

Our study is limited to the responses of removing sagebrush with prescribed fall burning on late seral Wyoming big sagebrush communities without a readily available source of noxious weed propagules and limited mortality of perennial herbaceous vegetation. We found that the herbaceous component of late seral Wyoming big sagebrush plant communities can be capable of withstanding disturbance including an occasional prescribed burn. Our results imply that fall prescribed burning can be used in some instances in relatively intact, late seral Wyoming big sagebrush communities to increase herbaceous forage and alter wildlife habitat without increasing exotic annual grasses. However, long-term evaluation is needed to better understand the potential risks and benefits of prescribed burning Wyoming big sagebrush communities. Furthermore, evaluation of prescribed burning Wyoming big sagebrush communities in varying pre- and post-climatic years and across more sites is needed to develop more comprehensive management suggestions. Prescribed burning Wyoming big sagebrush communities should be undertaken with caution because of the threat of exotic annual grasses and the importance of sagebrush to many wildlife species.

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Response of Wyoming big sagebrush communities to wildfire

Jon D. Bates, Kirk W. Davies, and Rob N. Sharp

Introduction

The purpose of this case study has been to evaluate the effects of wildfire to Wyoming big sagebrush (*Artemisia tridentata* spp. *wyomingensis* (Beetle & A. Young) S.L. Welsh) plant associations. The big sagebrush complex is delineated into three alliances: the Wyoming big sagebrush alliance; basin big sagebrush alliance (*Artemisia tridentata* spp. *tridentata* Nutt.); and mountain big sagebrush alliance (*Artemisia tridentata* spp. *vaseyana* (Rydb.) B. Boivin). The Wyoming big sagebrush alliance is considered to have been the most extensive of the big sagebrush in the Intermountain West.

Large areas of the Wyoming big sagebrush alliance are rated in low seral condition or have converted to cheatgrass (*Bromus tectorum* L.) grasslands. The invasion by cheatgrass has resulted in dramatic increases in both size and frequency of wildfires in Idaho's Snake River Plains and Nevada. It is estimated that mean fire return intervals in Wyoming big sagebrush plants communities have been reduced from 50-100 years to < 10 years as a result of cheatgrass (Bromus tectorum L.) invasion. The conversion from native to exotic dominance is a major factor for the loss of wildlife habitat and reduced populations of sagebrush obligate and facultative wildlife species.

Extensive areas in southeastern Oregon, northern Nevada, and southwestern Idaho contain Wyoming big sagebrush communities in mid to late seral ecological stages. These areas are co-dominated by sagebrush and perennial bunchgrasses with limited presence of cheatgrass. Cheatgrass presence, even in limited amounts has the potential to alter these systems after fire disturbance. There is a lack of information on the effects of wildfire in the Wyoming big sagebrush alliance in this region. This information is needed to; (1) evaluate post-burn secondary successional dynamics; and (2) to further development of risk assessments of community susceptibility to cheatgrass or other weed invasion after fire disturbance. In this study, post-wildfire (2002-2007) vegetation responses in two Wyoming big sagebrush associations were assessed in the Sheepshead Mountains in southeastern Oregon.

Methods

Study Area

Wildfire impacts to the Wyoming big sagebrush alliance was monitored in two plant associations in the Sheepshead Mountains in southeast Oregon. Fifteen study sites were set up in spring 2001 (Map 1). Initial vegetation measurements were made in June 2001 as part of a study assessing plant cover potentials in Wyoming big sagebrush associations. Eleven of the plots burned in a wildfire in August 2001. Sagebrush was largely removed across a 16,000 ha area. Few unburned patches remained within the fire perimeter.

Plant Communities

Plant communities monitored in the study included two of the five vegetation Wyoming big sagebrush associations described by Davies et al. (2004); Wyoming big sagebrush/bluebunch wheatgrass and Wyoming big sagebrush/Thurber's needlegrass.

The Wyoming big sagebrush/bluebunch wheatgrass association consisted of seven sites. This association was subdivided into two community types based on forb composition; Wyoming big sagebrush/bluebunch wheatgrass-short forb and Wyoming big sagebrush/bluebunch wheatgrass-tall forb.

The Wyoming big sagebrush/ Thurber's needlegrass association included one site rated in mid seral condition and two sites rated in high seral condition. Wyoming big sagebrush was the dominant shrub in all associations measured. Green rabbitbrush (*Chrysothamnus viscidiflorus*) was present in limited densities on all plots. In the Thurber's needlegrass association, spiny hopsage (*Atriplex spinosa* (Torr. & Frem.) Wats.) and gray horsebrush (*Tetradymia canescens* DC.) were present in low densities. Paired unburned plant associations were located nearby (within 0.5-3 miles) to provide comparison with burned plots.

Vegetation Measurements

Five, 50-meter transects were permanently established on each site. Shrub canopy cover (by species) was determined using the line-intercept method and was separated into live and dead cover. Canopy gaps were included in shrub cover estimates if less than 15 cm. Herbaceous species cover, bare ground, rock, litter, moss, and crust were estimated using 0.2 m^2 frames. Frames were located every 3 meters on transect lines (15 frames per transect/ 75 frames per plot). Plant species richness was estimated by recording all species present within the macro-plot (50 x 80 m).

Data Presentation and Analysis

The report presents pre-burn and post-burn vegetation cover data. Data from paired unburned plots are not presented. Fire impacts are summarized by plant community. Data shown for each burned plot will focus on the major herbaceous functional groups and the dominant perennial grass describing each association. Functional groups include Sandberg's bluegrass (*Poa sandbergii* Vasey), late seral perennial bunchgrasses, cheatgrass, perennial forbs, and annual forbs. Sagebrush cover is reported as live cover only. Individual species responses are briefly mentioned when appropriate. Data was analyzed within each site between years using t-tests to test for significant changes in cover of plant micro-biotic crust, bare ground, and litter.

Results and Discussion

The Sheepshead wildfire eliminated Wyoming big sagebrush on all study plots. Sagebrush seedlings began appearing in several sites in 2004, but at very low densities. Green rabbitbrush re-sprouted the first year after fire but its density is also extremely low across the plots (< 20

plants/ha). Spiny hopsage and gray horsebrush were present in the Wyoming big sagebrush/ Thurber's needlegrass associations, but appear to have been eliminated by the fire. Herbaceous response varied by association.

Wyoming big sagebrush/Thurber's needlegrass association

The Wyoming big sagebrush/Thurber's needlegrass association was the most severely impacted by the wildfire. Bare ground was greater than pretreatment values and unburned sites the first 3 post-fire years (Fig 1A). Total herbaceous cover declined the year after fire but returned or exceeded the pre-burn level from 2003-2005. Micro-biotic crust (primarily moss) and litter were mostly found under sagebrush prior to the fire. The fire eliminated the micro-biotic component and reduced litter cover. Micro-biotic crust began to be detected in 2006 and 2007 but at levels of less than 1% cover. Herbaceous cover in the burn has not exceeded unburned sites.

Although total herbaceous cover recovered by the second year post-fire, there were major compositional changes at the functional group and species levels. Perennial grasses (Sandberg's bluegrass, bluebunch wheatgrass, and Thurber's needlegrass) were significantly reduced in cover (Fig 1B). Sandberg's bluegrass and perennial grasses have been slow to respond, as the fire killed many plants. Cover of perennial forbs, annual forbs, and cheatgrass increased the second year after fire (2003). Perennial and annual forbs increased in cover by the 2nd year post-fire and have been the major herbaceous components. Annual forb cover increased in 2005 and 2006 in response to above average and average precipitation. Cheatgrass has increased slowly. Because of the reduction in the perennial grasses much of the area in this association is open to further colonization by cheatgrass.

Total community cover (sagebrush and herbaceous cover) has been lower in the burn than the unburned areas after fire as a result of the loss of sagebrush (Fig 5). Much of the fluctuation in herbaceous cover across years is a result of perennial and annual forb cover response to the amount of precipitation received on sites. Most of the herbaceous cover in the burn areas was composed of low growing forbs (<5").

Species response to fire was dictated by growth form. The increase in perennial forb cover was mainly comprised of longleaf phlox (*Phlox longifolia* Nutt.) and western and low hawksbeard (*Crepis occidentalis* Nutt. and *Crepis modocensis* Greene). Mat forming perennial forbs were initially eliminated or substantially reduced, including oval-leaved buck-wheat (*Eriogonum ovalfolium* Nutt.), lava aster (*Aster scopulorum* Gray), and Hoods phlox (*Phlox hoodii*). In 2005, these species began reappearing. Annual forbs that increased were fireweed (*Gayophytum* spp.) and desert alyssum (*Alyssum desertorum* Stapf.). Desert alyssum, a non-native, has been the dominant cover type since after fire.

Herbaceous species richness fluctuated since the fire. Until 2005, perennial forb species richness had declined. Perennial forb richness returned to pre-burn levels in 2005, possibly as a result of a combination of mild spring temperatures and higher than average spring precipitation. Overall species richness has been relatively flat across years compared to the bluebunch associations which have measured increases in species richness.

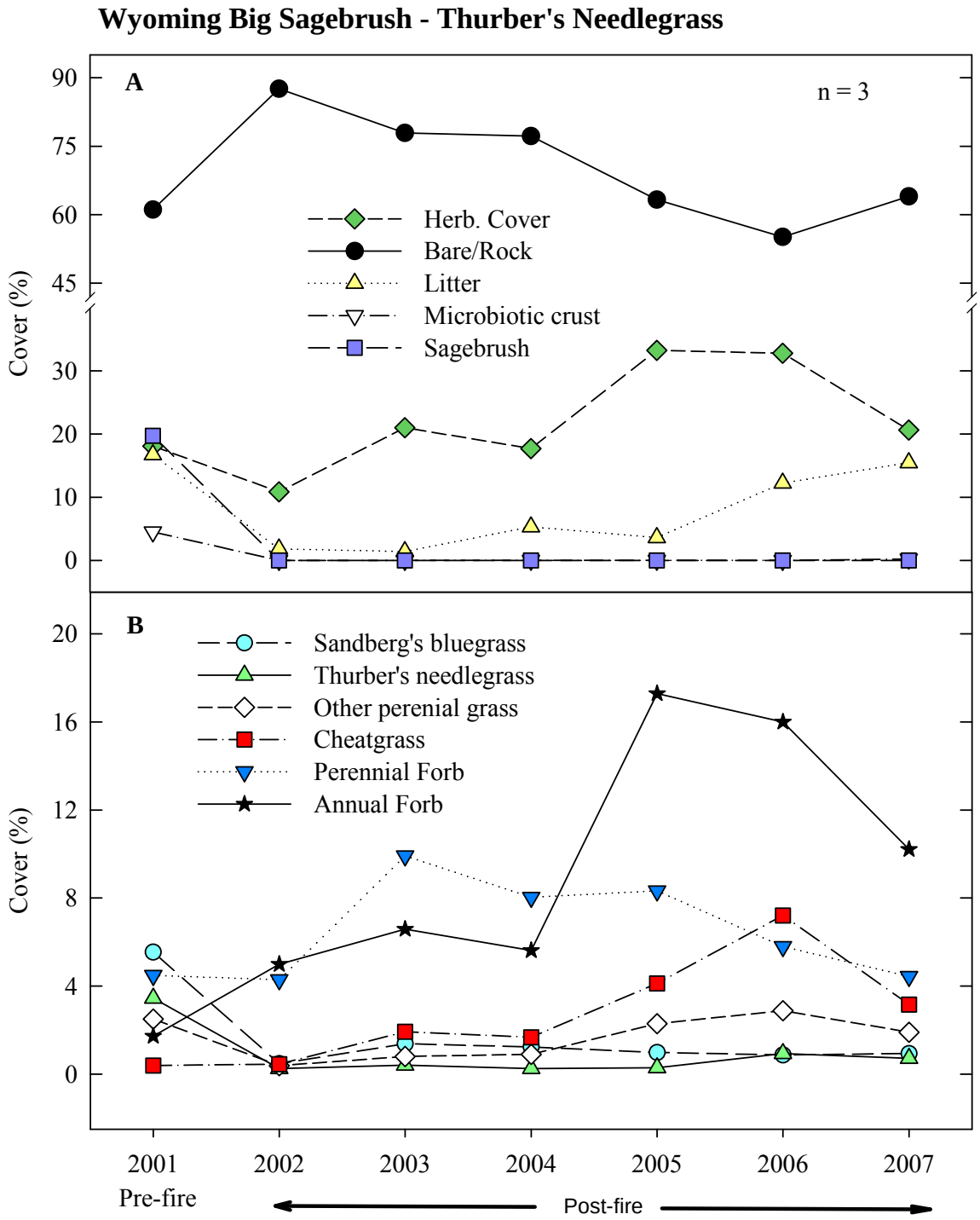

Figure 1. Cover (%) changes in response to the 2001 wildfire in the Wyoming big sagebrush/Thurber's needle-grass association, Sheephead Mountains, Oregon. Data show: A) ground cover and B) species and functional group cover.

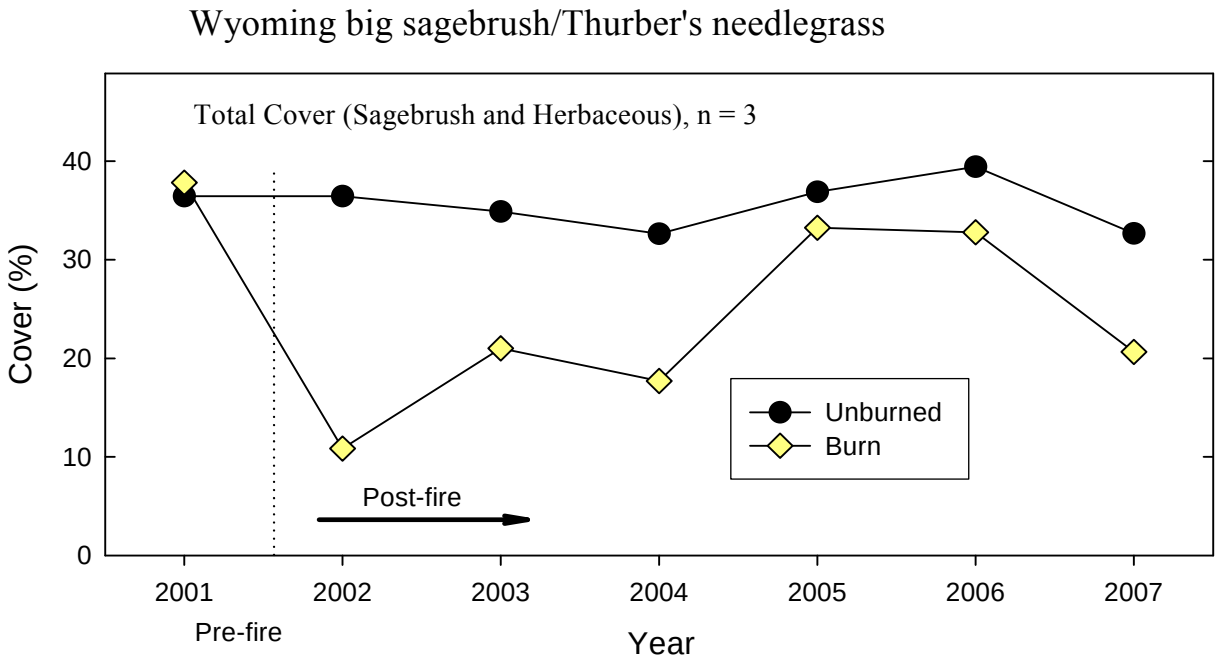

Figure 2. Total vegetation cover (Sagebrush and Herbaceous) in burned and not burned Wyoming big sagebrush/Thurber's needlegrass associations, Sheepshead Mountains, Oregon.

Wyoming big sagebrush/bluebunch wheatgrass association

The response to the fire in the Wyoming big sagebrush/bluebunch wheatgrass association has varied depending on type. Recovery of perennial grasses has more rapid compared to the Wyoming big sagebrush/Thurber's needlegrass association. Bluebunch wheatgrass was less affected by fire and surpassed pre-burn cover levels as early as the 3rd growing season after the wildfire on the tall forb type. Thurber's needlegrass and Cusick's bluegrass (*Poa cusickii* Vasey) were severely reduced by fire in this association. Cheatgrass was either not present or did not increase after the fire. Perennial forb response varied by individual site. Annual forbs in this association responded rapidly and were primarily composed of blue-eyed Mary (*Collinsia parviflora* Lindl.). Recovery of natives has been rapid and lack of cheatgrass indicates that these sites will recover with perennial bunchgrasses and forbs dominating the herbaceous layer.

Wyoming big sagebrush/bluebunch wheatgrass-short forb

Bare ground increased after fire but since 2002 has steadily declined and is now approaching pre-burn levels (Fig 3A). Total herbaceous cover declined the year after fire and remained below pre-burn levels until 2005. Micro-biotic crust (primarily moss) and litter were primarily located beneath sagebrush before the fire. The fire eliminated the micro-biotic component and reduced litter cover by 60%. Litter cover returned to pre-burn levels in 2007.

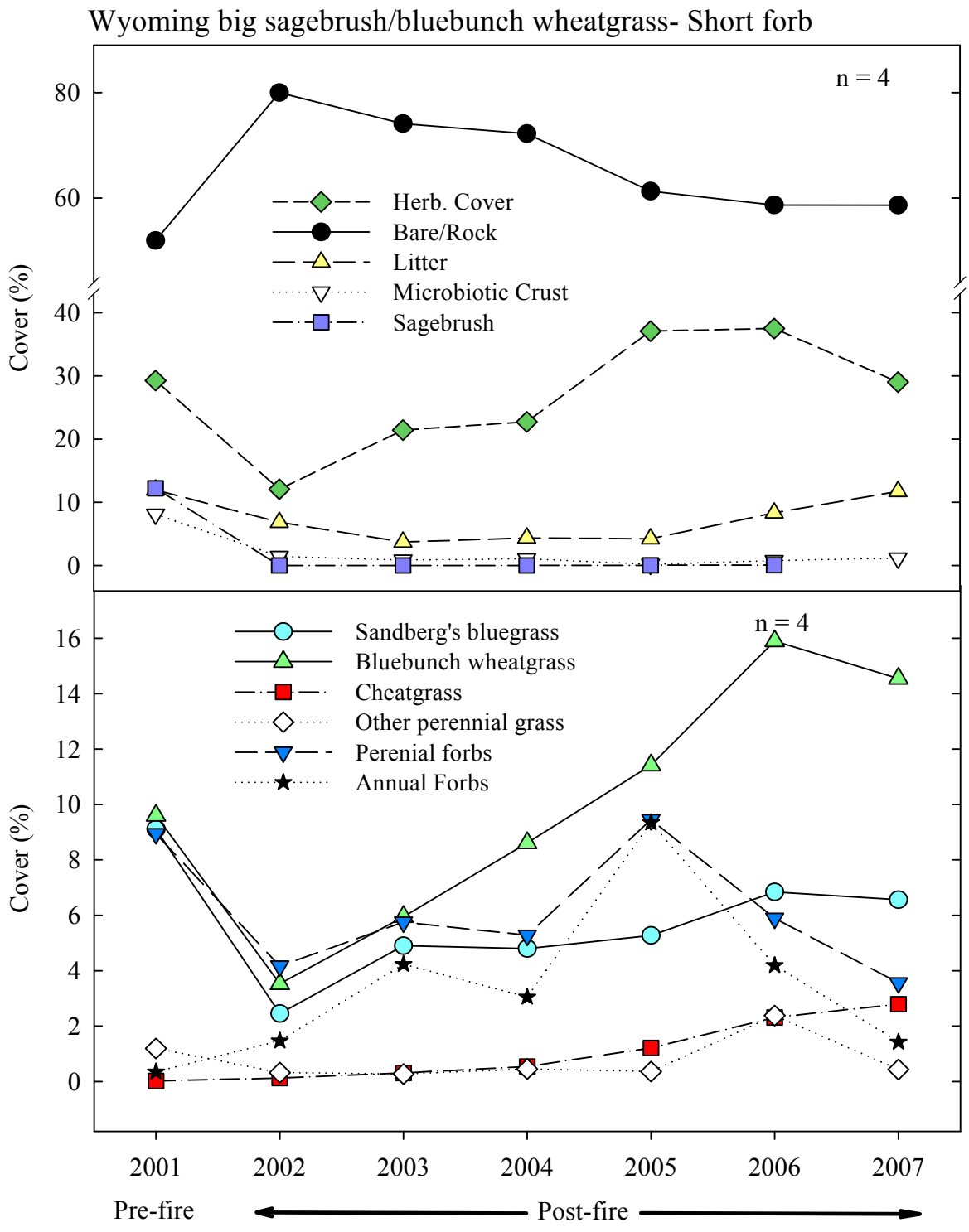

Figure 3. Cover (%) changes in response to the 2001 wildfire in the Wyoming big sagebrush/Bluebunch wheatgrass-short forb type, Sheephead Mountains, Oregon. Data show: A) ground cover and B) species and functional group cover.

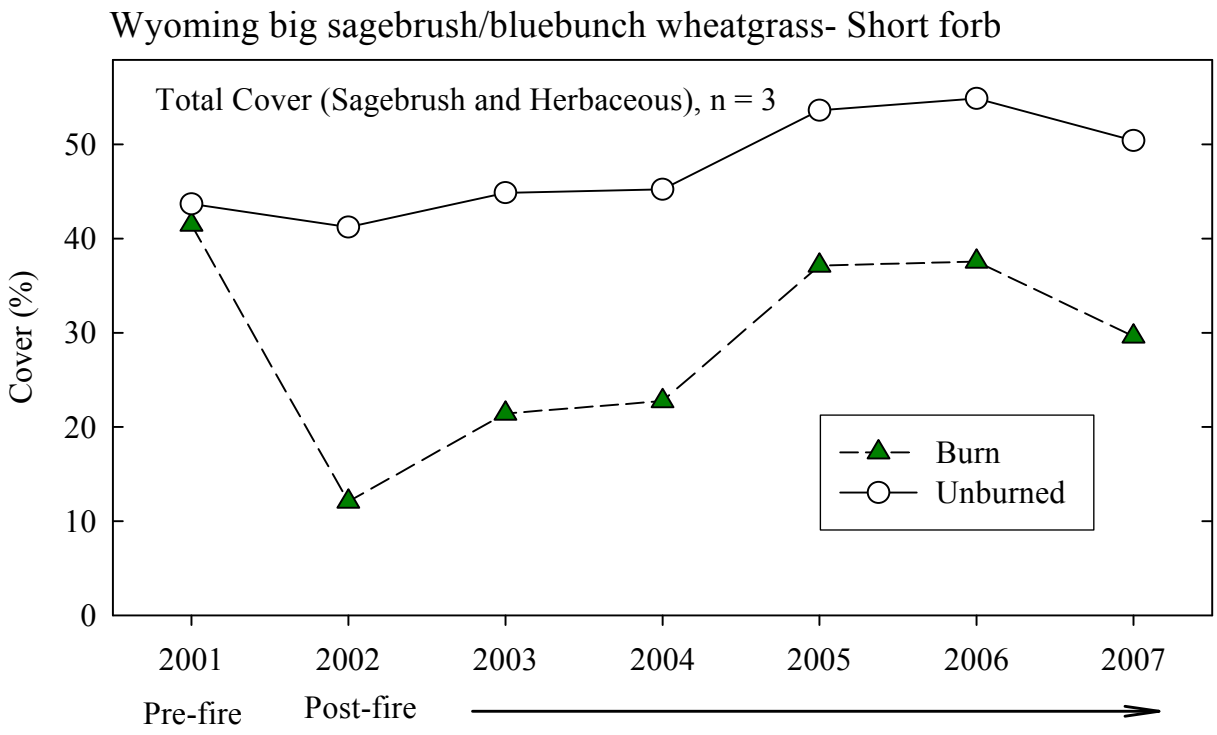

Figure 4. Total vegetation cover (Sagebrush and Herbaceous) in burned and not burned Wyoming big sagebrush/bluebunch wheatgrass- short forb associatios, Sheepshead Mountains, Oregon.

There was a significant decline in cover of Sandberg's bluegrass, bluebunch wheatgrass, and perennial forbs the first year after fire (Fig 3B). Sandberg's bluegrass cover in 2007 was at about 70% of pre-burn levels. Bluebunch wheatgrass took until 2004 to approach pre-burn cover levels and has exceeded pre-burn levels in 2006 and 2007. Perennial forb cover returned to pre-burn levels by 2005. Annual forbs increased significantly the second year after fire (2003), and have continued to be a major component of the understory. Cheatgrass cover has remained below 1-2% since the fire.

Perennial forbs that increased (3 to 4 fold) on all plots were low and western hawksbeard. Prairie lupine (*Lupinus lepidus* Dougl.), long-leaf phlox, and taper-tip hawksbeard (*Crepis acuminata* Nutt.) were also important on one or more of the plots. Annual forbs were mainly composed of blue-eyed Mary which represented between 75-90% of total annual forb cover. Mat-forming perennial forbs were eliminated or substantially reduced in cover and density, including desert yellow fleabane (*Erigeron linearis* Piper), lava aster, and Hood's phlox. These species have slowly been reestablishing on plots. Much of the fluctuation in herbaceous cover across years is a result of perennial and annual forb cover response to the amount of precipitation

received on sites. Perennial and annual forb covered declined in 2006 and 2007 from highs reached in 2005.

Total community cover (sagebrush and herbaceous cover) has been lower in the burn than the unburned areas after fire as a result of the loss of sagebrush and mat-forming forbs (Fig 5). Species richness fluctuated, declining in 2003 and 2004, followed by a small increase in 2005 as mat-forming forbs returned.

Wyoming big sagebrush/bluebunch wheatgrass-tall forb

Bare ground increased after fire, but since 2002 has declined and is now slightly above pre-burn levels (Fig 5A). Herbaceous cover declined the year after fire but returned to pre-burn levels by 2003 (2nd year after fire). In 2005, herbaceous cover increased to above pre-burn values. The fire eliminated the micro-biotic component and reduced litter cover by 60%.

There were several major compositional changes at the functional group and species levels. There was a significant decline in cover of Sandberg's bluegrass (Fig 5B). In 2004 and 2005, Bluebunch wheatgrass cover increased above pre-burn levels in 2004-2007. Other perennial grasses (Idaho fescue, Cusick's bluegrass) were markedly reduced and have not recovered. Perennial forb cover more than doubled since the fire. Perennial forbs that represented much of the increase were taper-tip hawksbeard, western hawksbeard, and prairie lupine. Other forbs that increased were taper-tip onion (*Allium acuminata* Hook.) and fern-leaf lomatium (*Lomatium dissectum* (Nutt.) Math. & Const.). Annual forb cover fluctuated by year but was always greater than pre-burn levels. The past two years (2006 and 2007) were dry and annual forb covered decreased from 2005. Annual forbs were dominated by blue-eyed Mary. Other annuals increasing after the fire were Epilobium, several native cyrptantha's and two non-native mustards (Jim Hill tumble-mustard, pinnate tansey-mustard). The non-native mustards are not highly competitive and should decline over time. Cheatgrass cover (0-0.1%) did not change in response to fire.

Comparing total community cover (sagebrush and herbaceous cover) indicates that cover has been lower in the burn than the unburned areas in most years after fire (Fig 6). Much of the fluctuation in herbaceous cover across years is a result of perennial and annual forb cover response to the amount of precipitation received on sites.

Herbaceous species richness increased overtime in the burn, primarily because of greater numbers of perennial and annual forb species.

Species Response

The initial responses of specific species to the fire have generally agreed with those reported by Wright et al. (1979). As stated, mat-forming forbs and bunchgrasses with densely packed culms (Thurber's needlegrass, Idaho fescue, and Cusick's bluegrass) were the most severely impacted species. Table 1 provides an estimate of herbaceous species response to the effects of the wildfire in the Sheepshead Mountains.

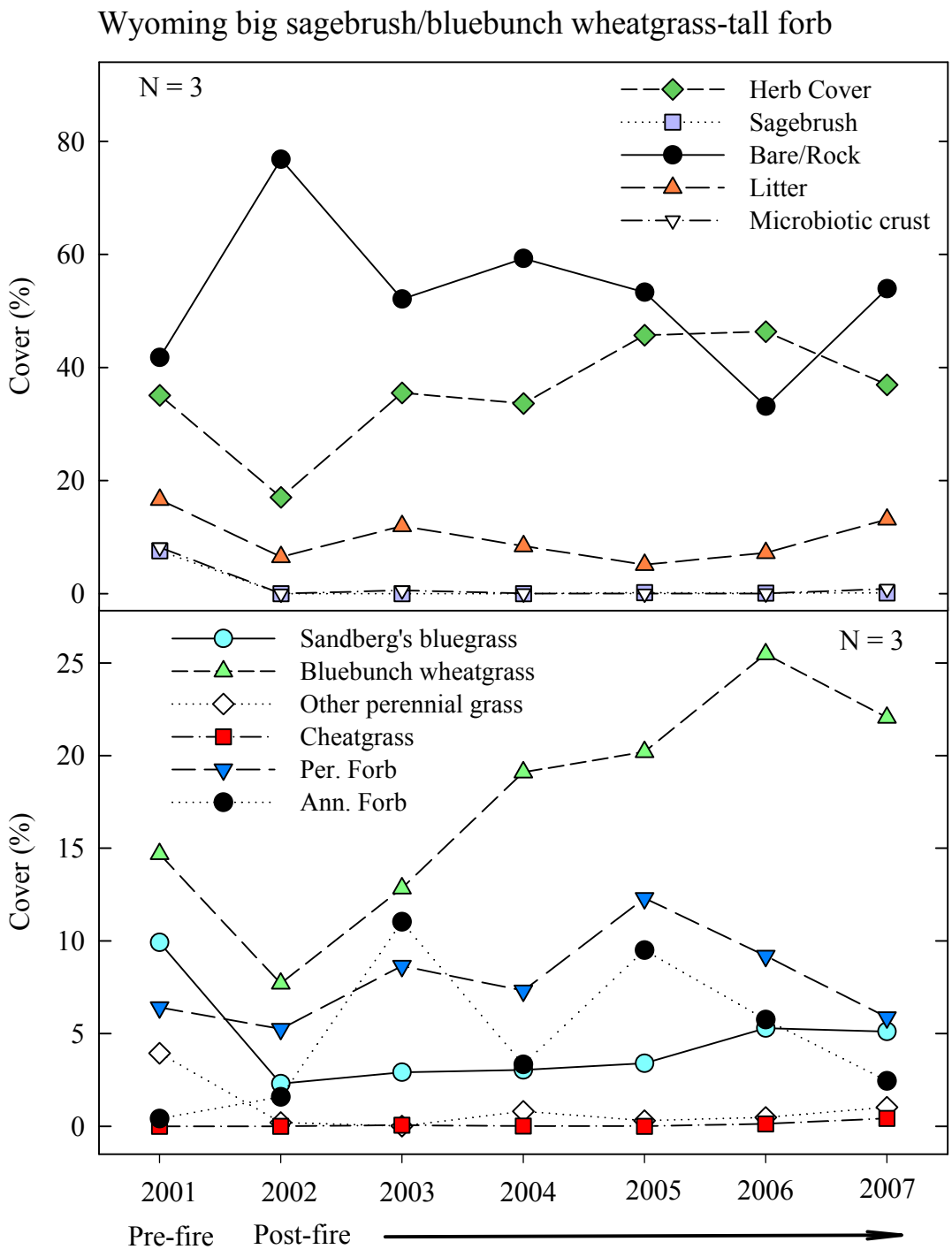

Figure 5. Cover (%) changes in response to the 2001 wildfire in the Wyoming big sagebrush/Bluebunch wheatgrass-tall forb type, Sheepshead Mountains, Oregon.

Data show: A) ground cover and B) species and functional group cover.

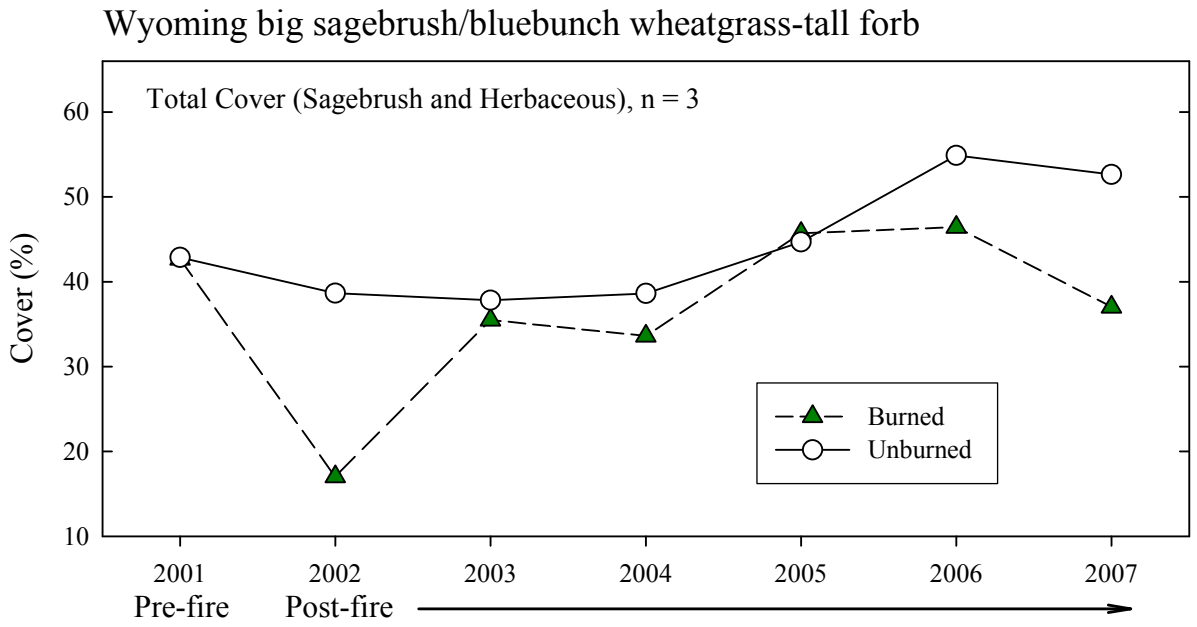

Figure 6. Total vegetation cover (Sagebrush and Herbaceous) in burned and not burned Wyoming big sagebrush/bluebunch wheatgrass-tall forb association, Sheepshead Mountains, Oregon.

Conclusions and Management Implications

A limited number of studies have produced mixed results on the effects of wildfire to the Wyoming big sagebrush alliance. Fire impact on plant communities is dependent on several factors; site potential and characteristics, plant composition, the severity of the wildfire, and pre- and post-fire weather (Wright et al. 1979). In this study, the impact of wildfire and subsequent recovery differed among the Wyoming big sagebrush associations.

Aside from a few scattered seedlings, Wyoming big sagebrush has not reestablished after fire and recovery is likely to be a slow process. Lack of sagebrush recruitment indicates that there was a limited seed pool and/or poor establishment conditions. Results from the mountain big sagebrush alliance indicates that reestablishment by sagebrush are linked to many factors including seed bank, weather, and fire size and intensity.

In remaining areas of the northern Great Basin containing intact Wyoming big sagebrush communities, management of both wild and prescribed fires must be carefully considered. The high mortality of perennial grasses and presence of cheatgrass in the Thurber's needlegrass association suggests there is a substantial risk for annual grass replacement of this association after wildfire. The wildfire did not severely impact the herbaceous layer in the Wyoming big sagebrush/bluebunch wheatgrass association. However, bluebunch wheatgrass and Thurber's needlegrass associations are often arranged in a landscape mosaic. Thus, efforts should be made to limit wildfire disturbance in remaining Wyoming big sagebrush plant associations of the

northern Great Basin. Large wildfires in the alliance would result in further reductions in habitat for sagebrush obligate and facultative wildlife species.

Prescribed fire might remain an option in the alliance at small scales. Forbs are critical in the diet of sage-grouse during pre-laying and brood-rearing periods. We measured increases of several important dietary forbs in this study such as long-leaf phlox and hawksbeard species. If forbs are limiting for sage grouse, patch burning in the fall in mid to high seral Wyoming big sagebrush communities may be a management alternative to increase forb availability in sage-grouse rearing habitat. However, total vegetation cover is substantially reduced and remaining cover may provide little protection from predators for species such as sage-grouse. The Thurber's needlegrass association lost not only the structural cover provided by Wyoming big sagebrush but most of the taller herbaceous cover provided by perennial grasses.

Table 1. Wildfire effects to plant species in Wyoming big sagebrush/Thurber's needlegrass and Wyoming big sagebrush/bluebunch wheatgrass associations, Sheephead Mountains, Oregon. Based on 4 years of post-fire data. Italicized species are non-native weeds.

Severely impacted	Slightly impacted	No impact or enhanced
Grasses	Grasses	Grasses
Thurber's needlegrass	bottlebrush squirreltail	bluebunch wheatgrass
Idaho fescue		six weeks fescue
Cusick's bluegrass		*cheatgrass*
Sandberg's bluegrass		
Perennial Forbs	Perennial Forbs	Perennial Forbs
low pussytoes	daggerpod	speckle pod milkvetch
Hood's phlox	wooly-pod milkvetch	Brunea mariposa lily
obscure milkvetch	morning milkvetch	basalt milkvetch
dwarf yellow fleabane		low hawksbeard
scabland fleabane		taper-tip hawksbeard
desert yellow fleabane		western hawksbeard
oval-leaf eriogonum		big seed lomatium
Hook's daisy		broadsheath lomatium
lava aster		Nevada lomatium
		prairie lupine
		taper-tip onion
		long-leaf phlox
		one-stemmed groundsel
		Bolander's yampah
	Annual forbs	Annual forbs
	white daisy tidytips	little blue-eyed Mary
		cushion cyrptantha
		Torrey's cryptantha
		autumn willow-weed
		groundsmoke spp.
		sinuate gilia
		white-stemmed blazing star
		thread-stem linanthus
		pink microsteris
		thread-leaf phacelia
		desert alyssum
		burr buttercup
		Jim Hill tumble mustard
		pinnate tansy mustard
		yellow salsify

Severely impacted – species cover reduced by more than 80% with no change in cover in years following fire.
Slightly impacted – species cover between 50% -90% of pre burn levels the first 2 years after fire.
No impact or enhanced – Cover not affected or increased above pre-burn levels.

Does re-introducing disturbances in sagebrush steppe promote invasion or resistance to invasion after a recovery period?

K.W. Davies, R.L. Sheley, and J.D. Bates

Summary

Prescribed burning of Wyoming big sagebrush-bunchgrass steppe has generally been avoided to prevent invasion of exotic species. However, in a situation where invasive plants were not already established, burning followed by a 3-year recovery interval prior to exotic annual introduction may have helped increase the resistance of the community to invasion.

Introduction

Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis* (Beetle & A. Young) S.L. Welsh)-bunchgrass communities were historically maintained by periodic wildfires (Wright and Bailey, 1982). However, modern day burning may promote the invasion of these communities by cheatgrass (*Bromus tectorum* L.)(Stewart and Hull, 1949; Young and Allen, 1997). Prescribed burning of Wyoming big sagebrush-bunchgrass steppe has generally been avoided because it is assumed to increase the invasibility of these communities. Invasion by exotic annual grasses, especially cheatgrass, can produce fire return intervals that are too short for reestablishment of big sagebrush and are detrimental to desirable herbaceous vegetation (Stewart and Hull, 1949; Whisenant, 1990). However, removing natural disturbances often reduces community resilience by eliminating the mechanisms that allow the system to adapt to external change (Groffman et al., 2006). We hypothesized that on sites not yet invaded by exotic annual grasses, burning followed by a short recovery interval (three years) would increase invasion resistance in the community.

Methods

The study sites were located on the Northern Great Basin Experimental Range (NGBER) in southeastern Oregon. Six sites in late seral Wyoming big sagebrush-bunchgrass communities with no documented cheatgrass prior to the study were selected. Each site contained an unburned and an October burned treatment. The burned plots were allowed to recover for three growing seasons before cheatgrass was broadcast seeded at 1, 10, 100, 1000, or 10 000 seeds*m^{-2}.

Measurements included cheatgrass cover and density, other herbaceous cover, density and biomass, bare ground cover, and soil water, phosphorus, potassium, and inorganic nitrogen in the upper 20 cm of the soil profile.

Results

Cheatgrass only established when introduced at 10 000 seeds*m^{-2}. In the areas seeded at 10 000 seeds*m^{-2}, cheatgrass density and cover were more than 3 fold higher in the control than burned treatments (P = 0.04 and 0.08, respectively) (Fig 1). Total (perennial + annual)

herbaceous vegetation cover, density, and production increased with burning ($P < 0.01$, 0.02, and < 0.01, respectively). Perennial herbaceous cover was 1.4 fold greater in the burn compared to the control ($P = 0.01$) but, perennial herbaceous density did not differ between treatments ($P = 0.55$). Total and perennial herbaceous production values were 1.8 and 1.7 fold greater in the burned than control treatments ($P < 0.01$). Annual herbaceous cover was greater in the burn than control treatment ($P = 0.08$). Bare ground and was higher in the control than the burned treatment ($P = 0.02$ and < 0.01, respectively).

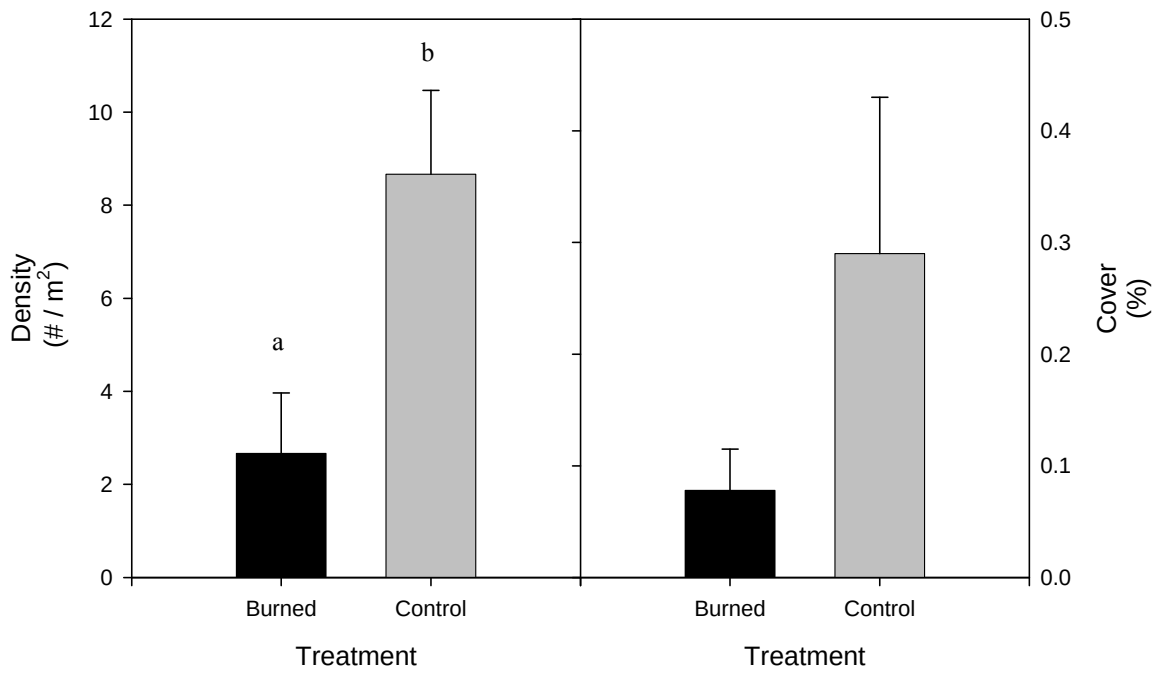

Figure 1. Cheatgrass density and cover (mean + SE) in the burned and control treatments in Wyoming big sagebrush-bunchgrass communities four years post-burn. Lower case letters indicate significant differences between treatments ($P < 0.10$).

Soil water content in the upper 20 cm did not differ between treatments ($P = 0.77$), but varied over time ($P < 0.01$). Over the growing season soil water generally decreased. Treatments effects did not vary with time ($P = 0.22$). Inorganic soil nitrogen was 1.6 fold greater in the control treatment compared to the burned treatment ($P < 0.01$) (Fig. 2). Soil phosphorous and potassium did not differ between treatments ($P = 0.36$ and 0.36, respectively).

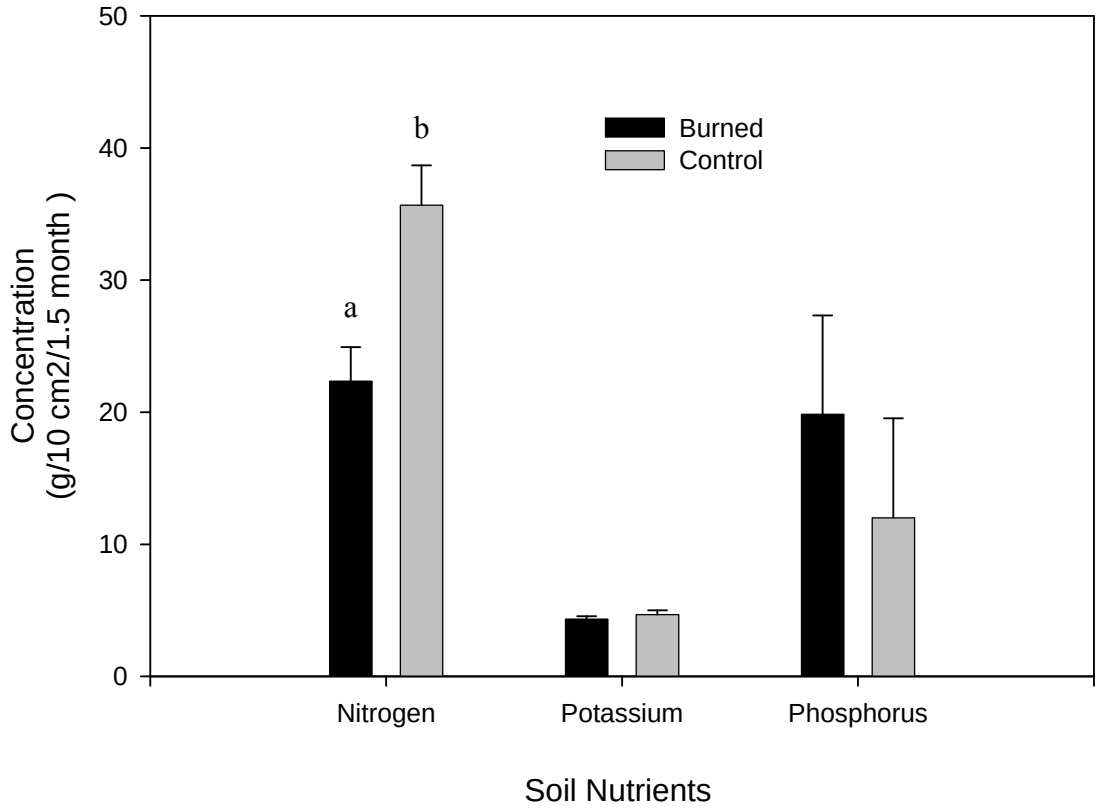

Figure 2. Soil potassium, phosphorus, and inorganic nitrogen concentrations (mean + SE) in the upper 20 cm of the soil profile over the growing season for the burned and control treatments in Wyoming big sagebrush-bunchgrass communities four years post-burn. Lower case letters indicate significant differences between treatments ($P < 0.10$).

Discussion

In our study, prescribed fall burning increased the resistance of Wyoming big sagebrush-bunchgrass steppe to cheatgrass invasion when the plant community had a three year recovery period prior to cheatgrass seed introduction. The increase in herbaceous vegetation cover, density, and production and decrease in bare ground in the burned relative to the control treatment may have interfered with the ability of cheatgrass to invade the burned treatment (Burke and Grime, 1996 Smith and Knapp, 1999; Troumbis et al., 2002; Knight and Reich, 2005). Stabilizing big sagebrush-bunchgrass communities in a big sagebrush dominated state may eliminate or decrease herbaceous components critical to maintaining resistance to invasion.

Our results combined with previous studies (Stewart and Hull, 1949; Young and Allen, 1997) imply that the implications of prescribed burning sagebrush-bunchgrass communities to cheatgrass invasion may vary with the status of the post-fire vegetation at the time of introduction of cheatgrass seed. Stewart and Hull (1949) reported that cheatgrass rapidly invades recently burned sites; however, most of their observations involved depleted states and/or had cheatgrass or its seeds available prior to the fire.

Conclusions

Our results should not be extrapolated to already depleted plant communities, locations infested with invasive plants, or landscapes that did not evolve with large scale disturbances. The initial increase in resource availability from prescribed burning Wyoming big sagebrush-bunchgrass communities (Davies et al., 2007) may decrease the resistance of the plant community in the short-term (Beckstead and Augspurger, 2004); however, if invasive plants are not available to establish at this time, prescribed fires can increase the ability of the community to repel future invasion attempts as resource and safe site availability is decreased. Caution should be exercised when planning to re-introduce disturbances into plant community because of the threat of exotic plant invasion. Exotic plant species presence or their ability to disperse to the plant community must be carefully analyzed prior to implementing a prescribed disturbance. Ensuring exotic invasive plants do not disperse to the site before desirable vegetation has reduced the initial flush of resources from the disturbance is needed to reduce the likelihood of invasive plants becoming established. The long-term influence of prescribed disturbances on invasion resistance of other plant communities that are experiencing extended disturbance return intervals should be investigated.

From: Davies, K.W., R.L. Sheley, and J.D. Bates. 2008. Does prescribed fall burning *Artemisia tridentata* steppe promote invasion or resistance to invasion after a recovery period? Journal of Arid Environments 72:1076-1085.

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Response of Thurber's needlegrass to fall prescribed burning in sagebrush steppe communities

Kirk W. Davies and Jonathan D. Bates

Thurber's needlegrass density and cover was not different between the burned and control treatments by the second year post-burning. However, photosynthetic rates and N isotopes of Thurber's needlegrass indicated that resources were generally more resources available in the burned than control treatment. Our results indicate that fall burns may be a viable management tool for shifting dominance from sagebrush to herbaceous vegetation in sagebrush-Thurber's needlegrass communities.

Introduction

Thurber's needlegrass (*Achnatherum thurberianum* (Piper) Barkworth) is an important component of many sagebrush communities in the Intermountain West. It may dominate or exist as a component of the herbaceous understory (Daubenmire 1970; Hironaka et al. 1983; Davies et al. 2006). Thurber's needlegrass is often found in association with Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis* (Beetle & A. Young) S.L. Welsh) (Passey et al. 1982; Hironaka et al. 1983; Davies et al. 2006).

Prescribed fall burning is often implemented in sagebrush plant communities to mimic historic wildfires, improve wildlife habitat, and increase livestock forage production. Burning is used because it shifts dominance from sagebrush to herbaceous vegetation. Wyoming big sagebrush is removed from the community with fall prescribed burning and thus, herbaceous vegetation becomes dominant (Wright and Bailey 1982; Davies et al. 2007). However, the response of Thurber's needlegrass to fall prescribed burning is relatively unknown.

Previous literature contains contradictions about the response of Thurber's needlegrass to burning. One study found that other than a slight reduction in basal area burning had little negative effect (Uresk et al., 1976). Other studies have reported decreases in basal area, phytomass production, and shortened culms and spikes and high mortality of Thurber's needlegrass in response to burning especially in response to early season burns (Wright and Klemmedson 1965; Uresk et al. 1980; Britton et al. 1990).

Methods

The study was conducted at six sites (blocks) consisting of a fall burned and unburned (control) Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis* (Beetle & A. Young) S.L. Welsh)-bunchgrass communities on the Northern Great Basin Experimental Range (NGBER) in southeastern Oregon. Response variables measured in the first and second post-burn years were Thurber's needlegrass community foliar cover and density, vegetative and reproductive biomass, photosynthetic rates, tissue carbon (C) and nitrogen (N) content, and N ($^{15}N/^{14}N$) and C ($^{13}C/^{12}C$) isotope ratios. All response variables were sampled in 2003 and 2004, the first and second post-burn years.

Results

Density of Thurber's needlegrass in both post-burn years (Fig. 1) and cover in the second post-burn year were not different between treatments ($P > 0.05$), but cover was less in the burned than control treatment in the first post-burn year ($P = 0.008$).

Vegetative biomass production was greater in the second post-burn year ($P = 0.003$), but did not differ between treatments ($P = 0.193$). Reproductive production and the ratio of reproductive to vegetative production were greater in the burned than control treatment in 2003 ($P < 0.001$); but did not differ between treatments in 2004 ($P = 0.772$ and 0.140, respectively).

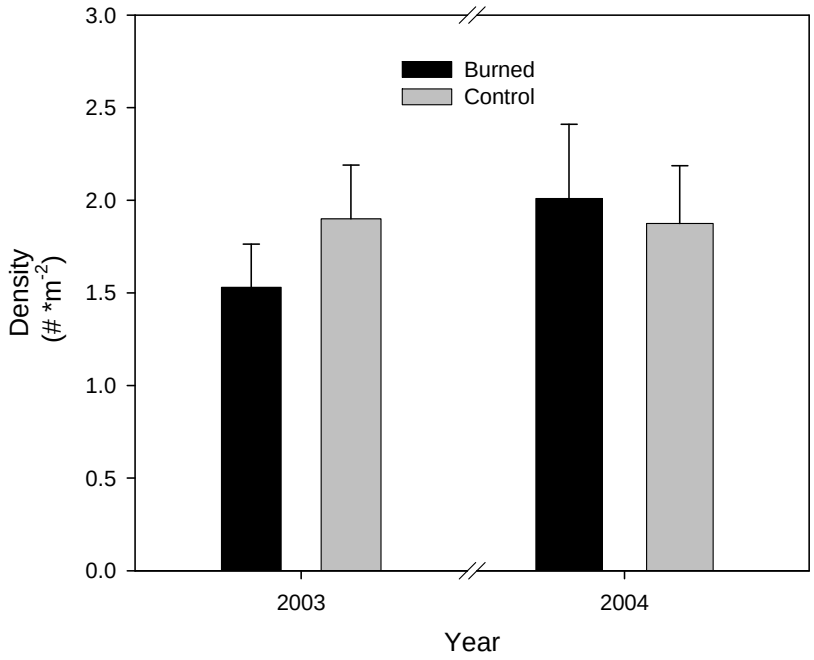

Figure 1. Density of Thurber's needlegrass (mean + standard error) in the burned and control treatments in 2003 and 2004. Different lower case letter indicates difference between treatments in that year ($P < 0.05$).

Carbon isotope ratios in Thurber's needlegrass differed between the burn (-25.9 ± 0.1) and control (-26.3 ± 0.1) treatments in the first post-burn year ($P = 0.019$). Nitrogen isotope ratios indicated nitrogen was more available in the burned than control treatment in both years ($P < 0.05$). Both tissue N and C did not differ between treatments in the first year post-burn, but N was greater in the burned compared the control treatment in 2004 ($P = 0.008$) and C was greater in 2003 than 2004 ($P = 0.016$). Photosynthetic rates of Thurber's needlegrass were also generally greater in the burned than control treatment ($P = 0.045$; Fig. 2).

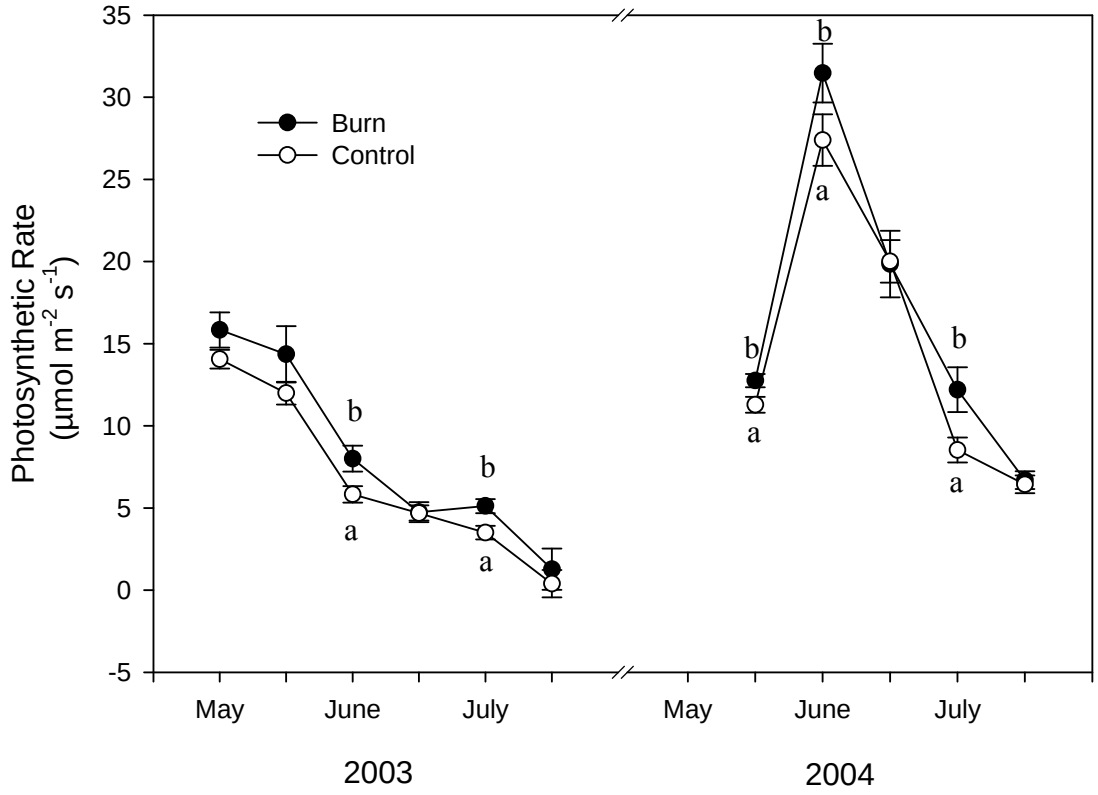

Figure 2. Photosynthetic rates (mean ± standard error) of Thurber's needlegrass in the burned and control treatments in 2003 and 2004. Different lower case letters indicate differences in photosynthetic rates between treatments on that sampling date ($P < 0.05$).

Discussion

At the community level, Thurber's needlegrass had a limited response to the prescribed fall burn. The greater cover in the control compared to the burned treatment was probably the result of the accumulation of previous years' growth. In the first post-burn year, the burned treatment had only the current year's growth contributing to its cover value. However, earlier season wildfire and prescribed burns have been shown to reduce the basal area of Thurber's needlegrass (Wright and Klemmedson 1965; Uresk et al. 1976, 1980), which would potentially also reduce foliar cover. Density was not different between treatments in either year suggesting that few Thurber's needlegrass plants suffered mortality. The lack of mortality was probably due to the late seasonality of the prescribed burn. Thurber's needlegrass becomes more resistant to burning as the growing season progressed to anthesis (Wright and Klemmedson 1965).

Prescribed fall burning did not negatively affect Thurber's needlegrass vegetative production and increased reproductive production in the first year post-burn. Our results

contradict research reporting a decrease in Thurber's needlegrass vegetative and reproductive production (Uresk et al. 1980; Britton et al. 1990). The contrast between our results and previous literature is probably because Thurber's needlegrass response to fire varies with the seasonality of the fire (Wright and Klemmedson 1965).

The isotopic ratios, N tissue concentration, and photosynthetic data suggest that prescribed fall burning altered resource availability to Thurber's needlegrass. Although alterations in resource availability to Thurber's needlegrass were not all positive in the first post-burn year, they suggest a general increase in resource availability with prescribed fall burning.

Conclusions

Under burn conditions similar to those in this study, prescribed fall burning can be used in late seral Wyoming big sagebrush-bunchgrass communities to shift dominance from sagebrush to herbaceous vegetation without negatively impacting Thurber's needlegrass. However, plant community dynamics following prescribed burning needs more and long-term evaluation to more fully understand the influence of fall burning on Thurber's needlegrass. Prescribed fall burning should not be implemented to increase Thurber's needlegrass because burning does not appear to have a substantial direct benefit to Thurber's needlegrass and indirect benefits may be expressed over greater temporal intervals than the duration of this study i.e., reduced sagebrush competition. Our results should not be extrapolated to wildfires or earlier season prescribed burns. However, comparing our results to previous studies (Wright and Klemmedson 1965; Uresk et al. 1980; Britton et al. 1990) suggests that fall prescribed burning is a better management tool for shifting dominance from sagebrush to herbaceous vegetation than earlier season burns. These results also only apply to late seral Wyoming big sagebrush-bunchgrass communities without cheatgrass or other invasive plants. If invasive plants had been a component of the pre-burn community our results may have been drastically different. The threat of invasive plants and potential impacts to sagebrush obligates should also be carefully considered before fall prescribed burning sagebrush-bunchgrass communities.

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Grazing after fire in sagebrush rangeland

Jon Bates, Ed Rhodes, Kirk W. Davies, and Rob N. Sharp

Introduction

In sagebrush rangelands of the western United States, fire has been a natural and prescribed disturbance temporarily shifting vegetation from shrub-grass co-dominance to grass dominance. There is limited information on the impacts of grazing to community dynamics following fire in sagebrush ecosystem. In 2001, we developed a study to evaluate post-fire herbaceous recovery of sagebrush steppe in eastern Oregon as influenced by time of grazing reintroduction.

Methods

The study was conducted at the Northern Great Basin Experimental Range, 35 m iles west of Burns, Oregon, USA. Annual precipitation has averaged 11.9 inches since the 1930's. Wyoming big sagebrush was the dominant shrub and Green rabbitbrush was a secondary shrub with cover. The understory was co-dominated by Idaho fescue and Thurber's needlegrass. Sandberg's bluegrass, bluebunch wheatgrass, prairie Junegrass, and bottlebrush squirreltail were present as subdominant grasses. Prescribed burning was applied in late September and early October, 2002. Fires were complete across burn plots, killing nearly 99% of the Wyoming sagebrush present.

Cattle grazing impacts to post-fire recovery of herbaceous vegetation was evaluated over four growing seasons. Thirty 4.5-5.0 acre plots were established in 2001. There were six treatments applied and all treatments were replicated 5 times. The treatments were;

SUMMER 1; graze the first 2 years after fire in early August 2003 and 2004.
SUMMER 2; graze the second and third summer after fire in August 2004 and 2005.
SPRING 1; graze the second and third spring after fire in May 2004 and 2005.
SPRING 2; graze the third spring after fire in May 2005. This treatment is equivalent to many post-fire grazing programs in the region.
BURN; no grazing after fire.
UNBURNED; no grazing.

The summer grazing treatments took place in early August when herbaceous plants were largely dormant or had completed that year's growth cycle. The spring grazing treatments took place in early to mid May during vegetative and early boot stages of growth of the main bunchgrass species, Idaho fescue and Thurber's needlegrass. No grazing was applied in 2006 as this was the main response year we used to compare herbaceous recovery among the treatments. Grazing was managed to remove 40-50% of herbaceous standing crop in all grazed treatments. This is considered a moderate to slightly higher than moderate level of use in the sagebrush steppe.

Vegetation responses to treatments were evaluated by quantifying plant cover, clipping for standing crop and production; and measuring perennial grass seed production.

Results

Fire Severity; Fire initially caused a reduction in cover of herbaceous perennials and green rabbitbrush. However, densities of herbaceous perennials and green rabbitbrush were unaffected by the fire indicating a fire of low severity. Sagebrush was severely affected by fire as most individuals were killed. Fire intensity was sufficient to reduce sagebrush to stumps less than 4 inches in height.

Utilization; Utilization in both summer grazing treatments and the SPRING 1 treatment in 2004 were close to the targeted level of 50%. In spring 2005, herbage was growing rapidly and grazed plants re-grew quickly while livestock were still grazing in the treatment plots. Measured utilization showed only light use (25%) in SPRING 1 and SPRING 2 treatments in 2005.

Bare ground; bare ground increased the first year after fire in all treatments that were burned (Fig 1). Bare ground was greater after fire in burn treatments (grazed and ungrazed) than the UNBURNED in 2003. By the second year after fire (2004) there were no longer any differences among treatments and in the burned treatments levels of bare ground did not differ from pre-burn conditions.

Litter; Litter was reduced by burning and litter cover was greater in the UNBURNED treatment compared to most of the burned grazed treatments the first three years after fire. (Fig. 1). By 2006 treatments did not differ in litter cover.

Moss and Biotic Crust; Moss and other biotic crust increased in the UNBURNED treatment between 2002 and 2003 and remained 3.5-4 times greater than the burned treatments (grazed and ungrazed) (Fig 1). Moss comprised most of the cover in this group and was mainly found within grass clumps and under sagebrush. At this point fire, not grazing negatively impacted moss and biotic crust.

Herbaceous Cover; Prior to burning cover values did not differ among treatments. The first year after burning (2003) cover was greater in the UNBURNED than all burned treatments (grazed and ungrazed) for most response variables (Fig 1). By the third growing season (2005) after fire herbaceous cover was twice as great in the burned treatments (grazed and ungrazed) than the UNBURNED. Cover remained greater in all burned treatments than the UNBURNED treatment in 2006 though the magnitude of difference was only about 20%. In all treatments, perennial grass cover was greater than pre-burn levels in 2005 and 2006 but did not differ among treatments. Annual forb cover was greater in burned (grazed and ungrazed) treatments from the second through fourth year after fire (2004-2006). Cheatgrass cover remained low (>0.01%) throughout the study on all treatments.

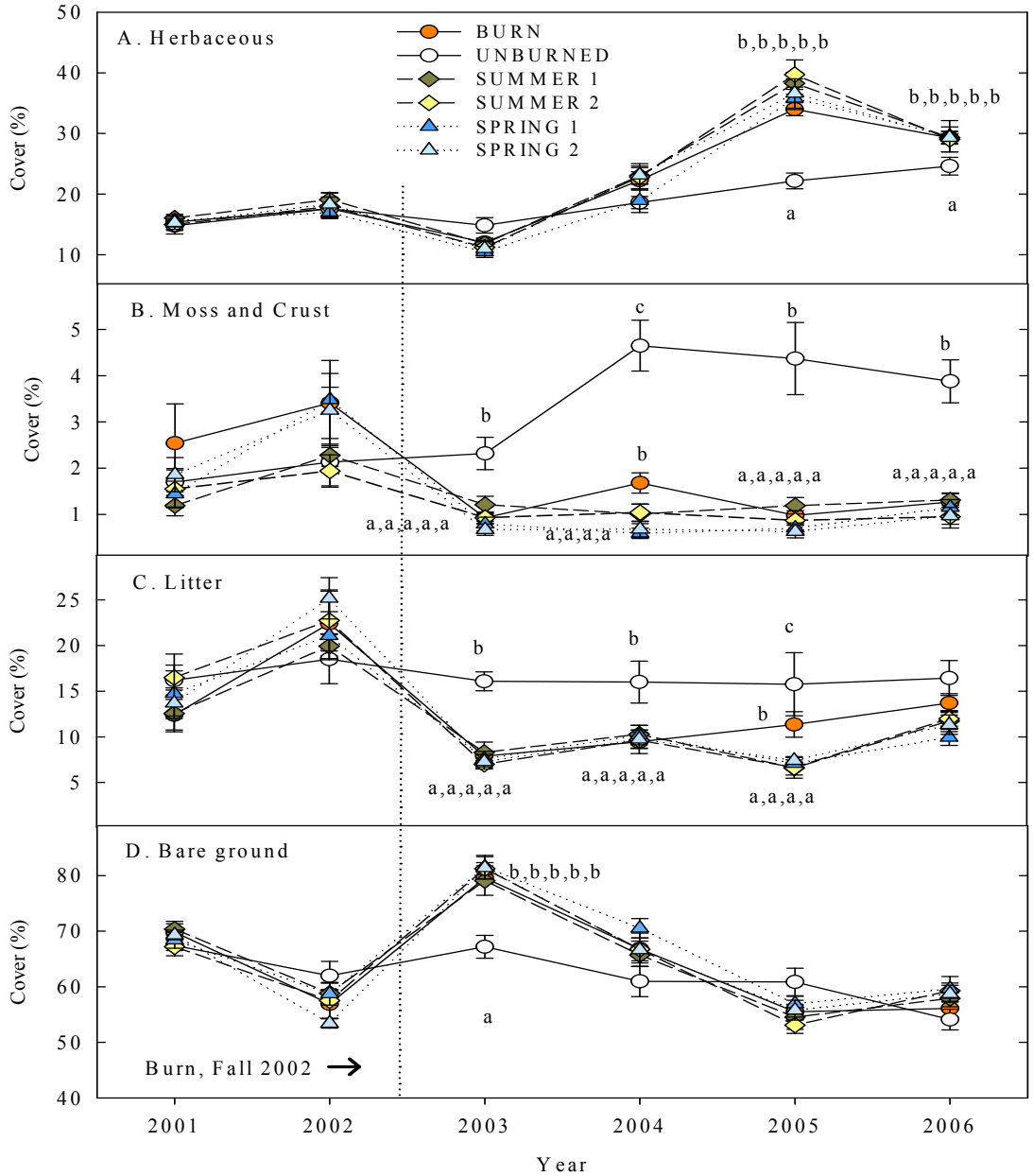

Figure 1. Ground cover values for the various burn and grazing treatments in Wyoming big sagebrush steppe, 2001-2006; A) herbaceous, B) litter, C) moss and biotic crust, and D) bare ground and rock.. Values represent means ± one standard error. Different lower-case letters indicate significant differences (p<0.05) among the treatments within year.

Herbaceous standing crop; Herbaceous and functional group standing crop did not differ among treatments prior to burning (Fig 2 and 3). By the third (2005) and fourth (2006) growing season after fire herbaceous and perennial grass standing crop was greater in all the burned treatments (grazed and no-graze) than the UNBURNED treatment. Standing crop in the BURN

treatment was about twice as great than the UNBURNED treatment and was greater than all the burned-grazed treatments (except the SUMMER 2 treatment) in 2005 and 2006. The lower amount of standing crop in the burn-grazed treatments than the BURN treatment in 2005 and 2006 reflects the removal of herbage by livestock which reduces the amount of carry over biomass from previous year's growth. Sandberg's bluegrass standing crop was reduced in all burn treatments after fire. In 2005, Sandberg's bluegrass standing crop was lowest in the SPRING 1 and SPRING 2 treatments, respectively, than other treatments. Perennial forb standing crop/production was reduced in all burn (grazed and ungrazed) treatments the first year after fire. Annual forb standing crop/production increased in all burn treatments (grazed and ungrazed) the second-growing season after fire and were greater than the UNBURNED treatment. Over 90% of annual forb production was comprised of pale alyssum, an introduced old world weed.

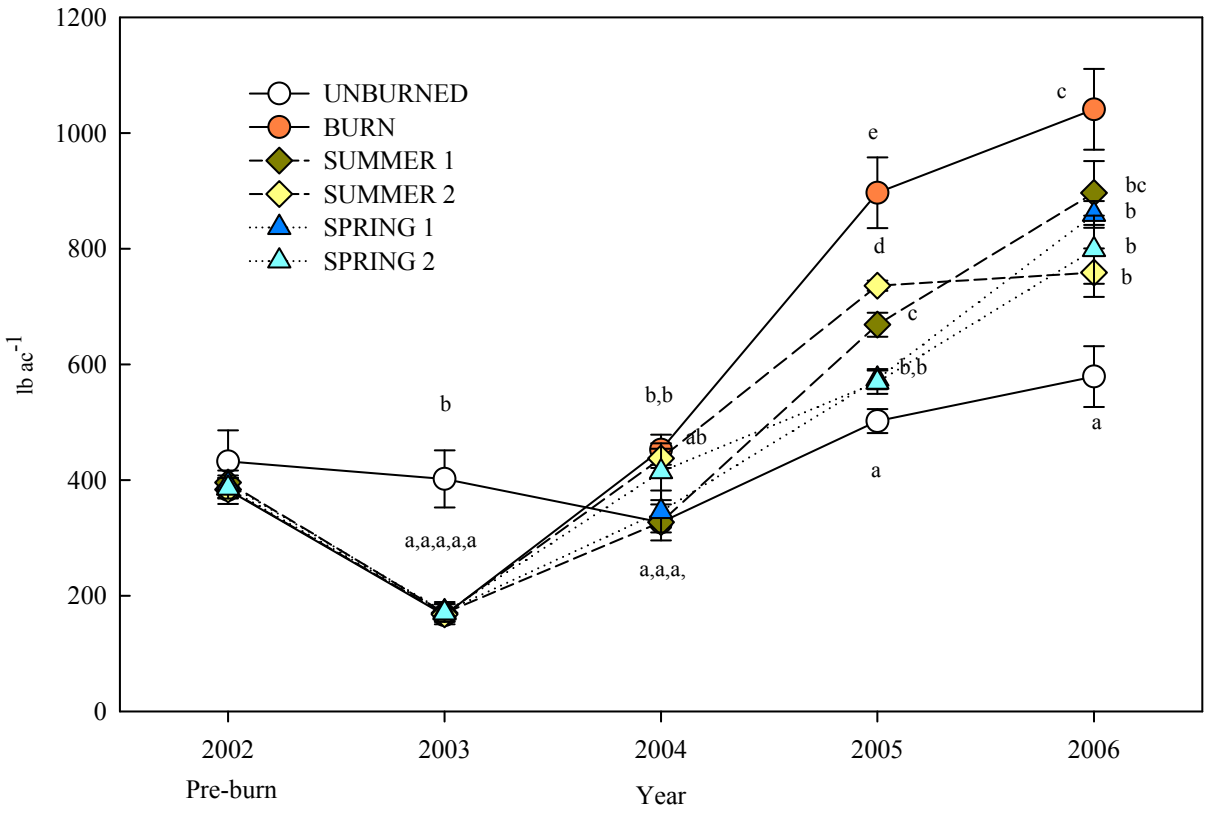

Figure 2. Herbaceous standing crop (lb ac^{-1}) for the various burn and grazing treatments in Wyoming big sagebrush steppe, 2001-2006. Values represent means ± one standard error. Different letters indicate significant differences among the treatments within year.

Herbaceous productivity; Production values provided a different perspective when evaluating impacts of grazing after fire because residual material from previous year's growth is removed prior to weighing (Fig. 4). In contrast to standing crop results, differences among the burn-grazed treatments and the BURN treatment were less apparent for total

herbaceous and perennial grass production in 2005 and 2006. Both summer grazing treatments did not differ from the BURN treatment for these response variables. Production in the SPRING 1 and SPRING 2 treatments were less than the BURN and both summer treatments because of herbage removal by livestock in 2005. Despite biomass removal, herbaceous and perennial grass production was greater in SPRING 1 and SPRING 2 treatments than the UNBURNED treatment in 2005. In 2006, herbaceous and perennial grass production did not differ among the burn (grazed and ungrazed) treatments. Herbaceous and perennial grass production was about two times greater in the BURN and burned-grazed treatments than the UNBURNED treatment in 2006.

Seed Production; Total seed production was greater in 2005 than 2004 for all treatments. Seed production was greater in the BURN and all burn-grazed treatments than the UNBURNED treatment in 2005 (Fig. 5). Within the burn treatments grazing influenced total seed production as well seed production of individual species. The BURN treatment had greater total seed production than the SUMMER 1, SPRING 1, and SPRING 2 treatments. Seed production of Idaho fescue was greatest in the BURN and SUMMER 2 treatments;
among the other treatments there were no differences. Seed production of squirreltail and Thurber's needlegrass were greater in the BURN and burn-grazed treatments compared to the UNBURNED treatment. The amount of seed produced in 2005 was 3 to 6 times that of recommended seeding rates for this plant community.

Discussion

The results from this study indicate that moderate grazing following completion of the first growth cycle after low severity fire does not limit herbaceous recovery in big sagebrush steppe.

Treatment differences were considered minor when evaluating community recovery after fire. For most measured variables (bare ground, litter cover, and herbaceous cover, density, and production) there were no differences among grazed and ungrazed burn treatments, particularly in the response year of 2006.

The response of herbaceous vegetation after fire, whether graze or not grazed, was comparable to results from other post-fire work in the sagebrush system. Herbaceous cover, standing crop and production in the BURN and burn-grazed treatments equaled or exceeded the UNBURNED treatment by the second or third year after fire.

A factor for the rapid and progressive herbaceous response was the low severity of the prescribed fire. Fire can negatively impact bunchgrass species by killing individuals and reducing plant size especially species with densely packed culms such as Idaho fescue and Thurber's needlegrass. These were the most common perennial grass species on our study sites; however, neither species was reduced in density, and both species demonstrated a positive response by the second year after fire.

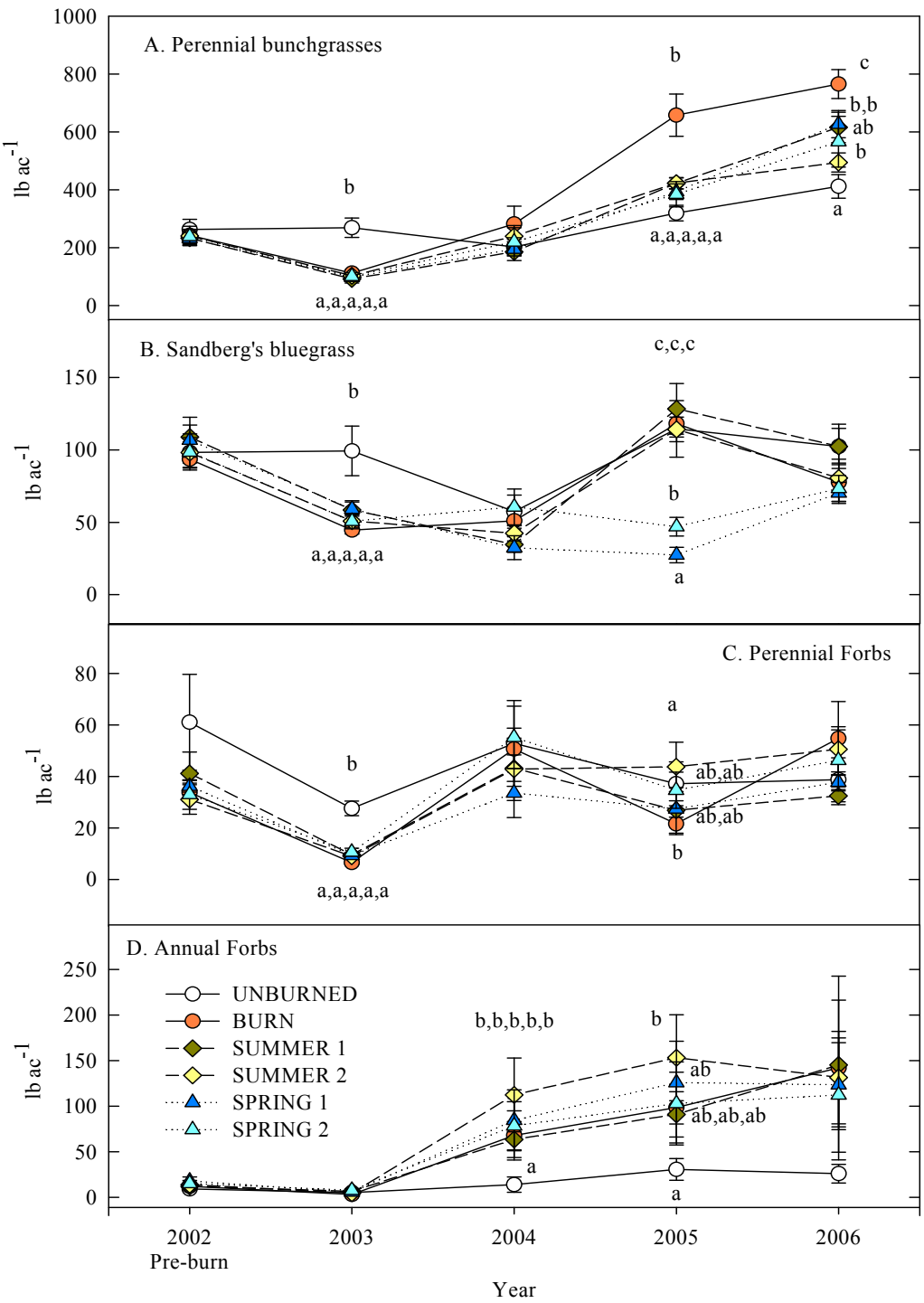

Figure 3.

Functional group standing crop values (lb ac^{-1}) for the various burn and grazing treatments in Wyoming big sagebrush steppe, 2001-2006; A) Perennial bunch grasses; B) Sandberg's bluegrass; C) Perennial Forbs; and D) Annual forbs. Values represent means ± one standard error. Different lower-case letters indicate significant differences among the treatments within year.

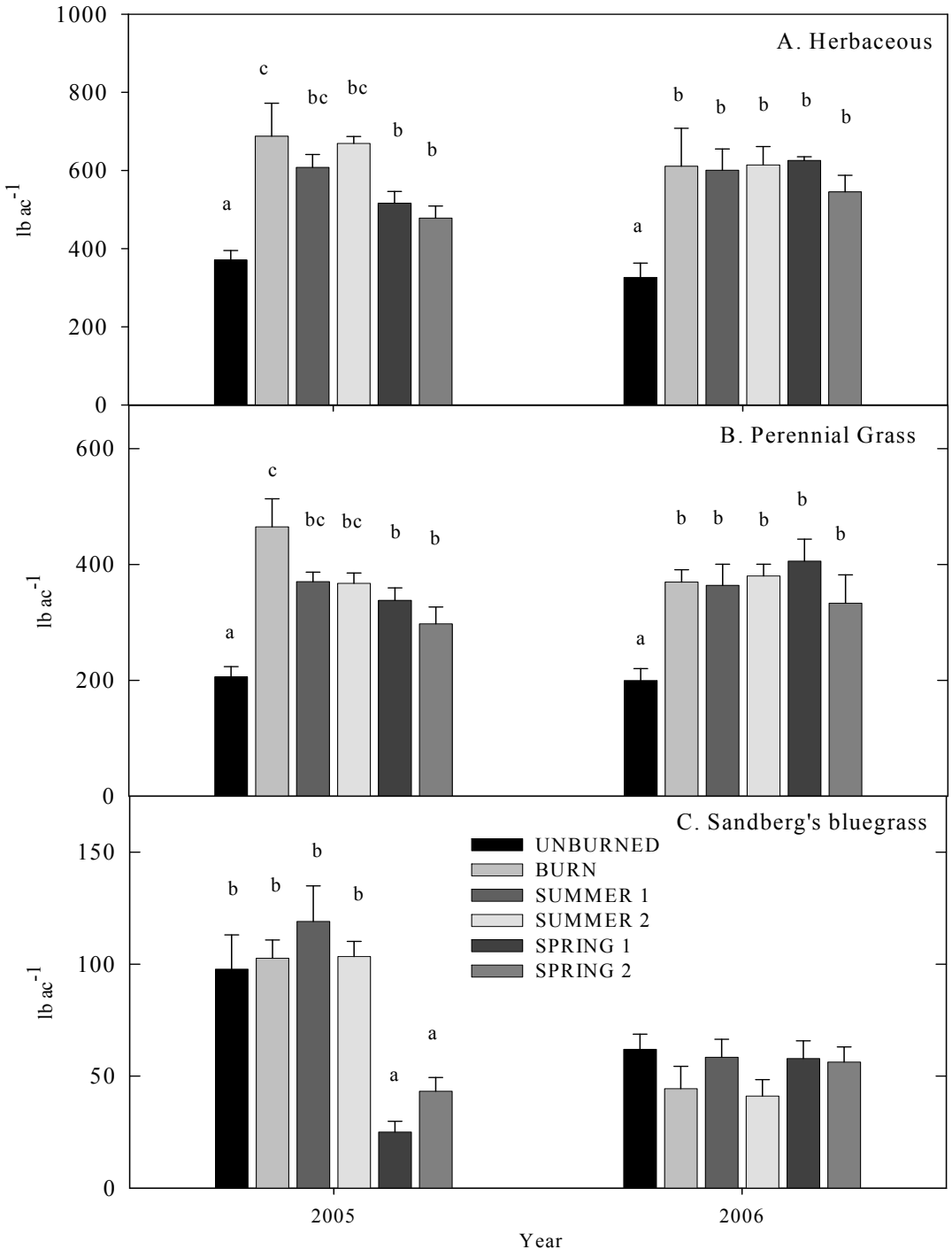

Figure 4. Production values (lb ac^{-1}) for A) Herbaceous, B) Perennial bunchgrasses, and C) Sandberg's bluegrass for the various burn and grazing treatments in Wyoming big sagebrush steppe, 2005-2006; Values represent means ± one standard error. Different lower-case letters indicate significant differences (p<0.05) among the treatments within year.

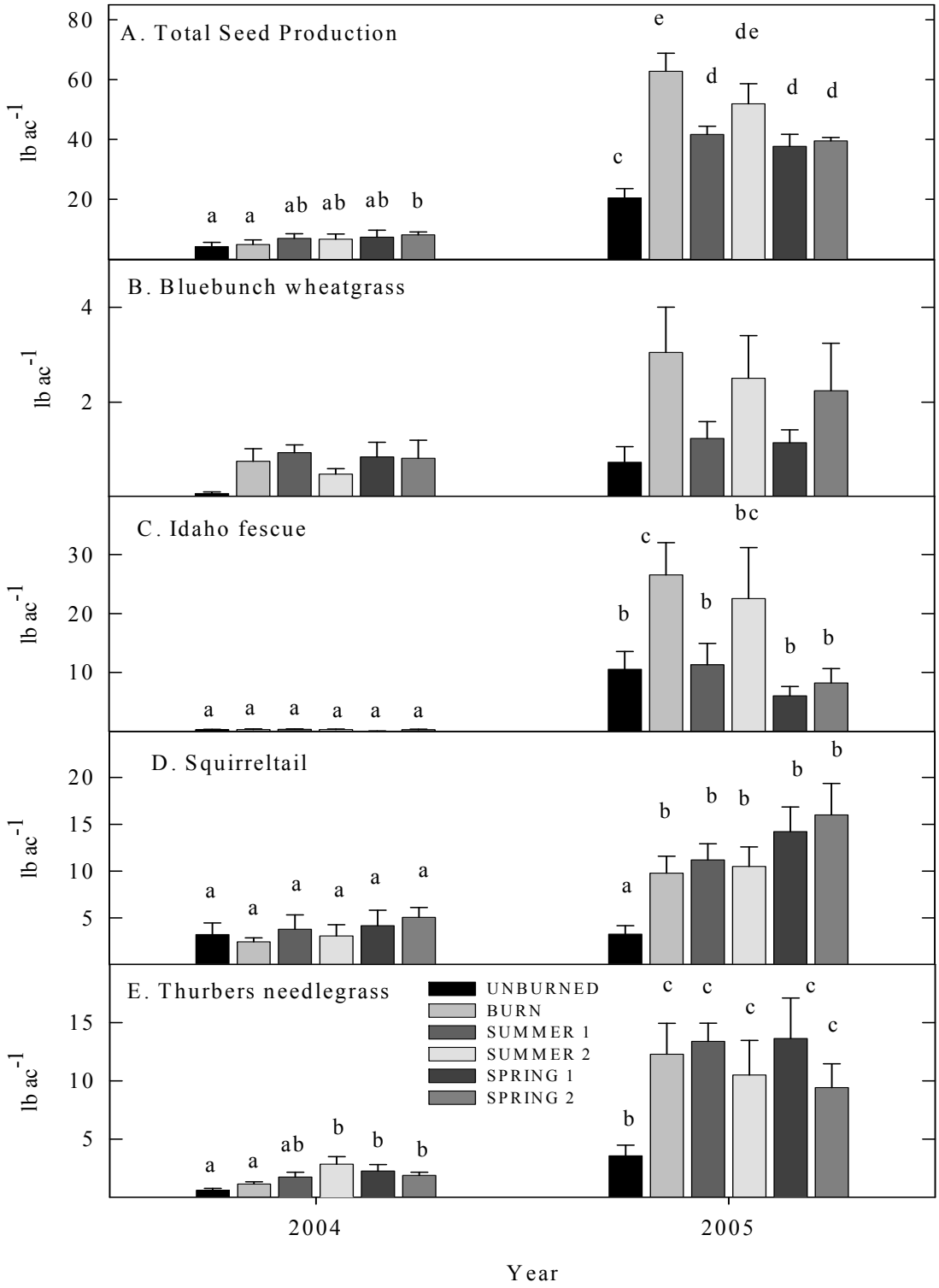

Figure 5. Seed production values (lb ac^{-1}) for the various burn and grazing treatments in Wyoming big sagebrush steppe, 2005-2006; A) Total Perennial Bunchgrasses; B) Bluebunch wheatgrass; C) Idaho fescue; D) Squirreltail; and E) Thurber's needlegrass.

Cheatgrass and other exotic species are a major threat to maintaining Wyoming big sagebrush communities. Our results demonstrated that burning can successfully stimulate herbaceous native species and not result in an increase of cheatgrass with or without grazing. There were likely two reasons for the lack of a cheatgrass response; the pre-fire community was largely composed of native perennials and there was limited mortality of perennial grasses. High mortality of perennials would like have created conditions that would allow cheatgrass to increase.

The main exotic that increased and comprised the bulk of forb productivity and composition after fire was pale alyssum. Information on the competitive abilities of alyssum is not available, though it likely interferes with native annual forbs since root characteristics and phenology appear to be similar. The presence of high densities of alyssum does not appear to obstruct the recovery of perennial grasses.

Moss and other biological crust had not recovered to pre-burn levels by the fourth year after fire. Recovery of mosses and biological crusts after fire varies depending on species and plant community composition but recovery appears to be a lengthy process. In our study, fire rather than grazing appears to have had the main impact on moss and biotic crust.

Management Implications

The primary goals of post-fire ecosystem management are the recovery of ecological processes (hydrologic function, energy capture, and resource capture), preferred plant communities, wildlife habitat, and economic use. In sagebrush steppe plant communities these goals are achieved by recovering the system to one comprised of perennial grasses, forbs, and shrubs. This study demonstrated that properly applied livestock grazing after one growth cycle following fire will not slow or reduce the recovery of herbaceous plant communities in Wyoming big sagebrush steppe. The study also demonstrated that grazing rest the first 2 years after fire to encourage herbaceous recovery may not be necessary in all situations.

The results and interpretations of this study must be considered under the conditions which it was conducted. The trials were performed on a distinct big sagebrush site; with fires causing minimal, if any, mortality to perennial bunchgrasses; a lack of a significant weed presence; and with strictly controlled grazing protocols. One or more of these elements will vary in other situations generating a host of post-fire recovery scenarios. Our study plots were small and we managed to obtain uniform grazing use. However, livestock also tend not to graze uniformly in large pastures in the Great Basin as distance to water and topography results in areas of high, moderate, low, and non-use. Grazing after fire in larger pastures and for longer duration would likely have resulted in areas of differential use and levels of herbaceous recovery.

The summer grazing treatments provided the most robust outcome regarding herbaceous recovery as our results were in agreement with recent post-fire grazing (Bruce et al. 2007) and defoliation trials (Bunting et al. 1998). Moderate grazing use after perennial grass dormancy/seed shatter the first couple summers after fire should not to reduce the recovery ability of post-fire herbaceous communities in sagebrush steppe.

This is the first such study of spring grazing in sagebrush steppe after fire and trials only evaluated defoliation during vegetative and early boot stages of growth of the larger perennial bunchgrasses. As alluded to earlier, defoliation of grasses in later boot or flower stages might have resulted in slower herbaceous recovery. At this point, grazing sagebrush steppe in the spring the first two years after fire should be applied cautiously until additional information becomes available.

Acknowledgments

We would like to thank the numerous summer crew individuals for assistance in the field and laboratory. Lori Ziegenhagen did much of the data compilation and running the field crews in 2003 and 2004. Many thanks to Matt Carlon, Lynn Carlon, and Clare Poulsen for helping on the burn team.

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The influence of Wyoming big sagebrush on microsite and herbaceous vegetation spatial heterogeneity

Kirk W. Davies, Jonathan D. Bates and Richard F. Miller

Summary

Microsite zonal differences exist between the canopy and interspaces of Wyoming big sagebrush. Wyoming big sagebrush subcanopy zones appear to produce a more conducive environment for herbaceous vegetation than interspace zones. However, the influence of Wyoming big sagebrush on zonal herbaceous vegetation heterogeneity appears to depend on site and is more pronounce as environments become warmer and drier.

Introduction

Underneath (subcanopy) big sagebrush (*Artemisia tridentata* Nutt.) canopies may provide a more conducive environment for herbaceous vegetation establishment and growth than between shrub canopies (interspace) (Charley and West, 1977; Doescher et al., 1984; Burke et al., 1987; Wight et al., 1992; Chambers, 2001). The establishment, early growth and development of many tree species were enhanced when situated underneath big sagebrush canopies. Some factors that may contribute to this facilitation are an increased availability of soil nutrients and water and a moderated micro-environment underneath big sagebrush canopies. Removal of sagebrush has had mixed results on the herbaceous understory. Consequently, the spatial arrangement of herbaceous vegetation structural and microsite characteristics in relation to under and between big sagebrush canopies is not well understood. Late seral Wyoming big sagebrush (*A.. tridentata* ssp. *wyomingensis* (Beetle & A. Young) S.L. Welsh) communities were chosen for evaluation because this alliance is the largest, most arid, least resilient to disturbance, and most endangered of the three common subspecies of big sagebrush (Beetle and Young, 1965; Morris et al., 1976; McArthur and Plummer, 1978; West et al., 1978; Miller and Eddleman, 2000).

Methods

Study sites were determined to be late seral Wyoming big sagebrush dominated plant communities. Six blocks were located at the Northern Great Basin Experimental Range (NGBER) and four blocks were located at Baker Pass in southeastern Oregon. Micro-environmental variables (soil and air temperature, relative humidity, and photosynthetically active radiation (PAR)) were measured in subcanopy and interspace zones at the NGBER site. In both zones of each block soil water content (0–15 cm and 15–30 cm depths), soil pH, total nitrogen, total carbon, and organic matter in the upper 15 cm of the soil profile were recorded. Also, herbaceous cover by species, biomass by functional group, density of perennial grass species, as well as, photosynthetic rate, carbon and nitrogen isotope ratios, and carbon and nitrogen content of Thurber's needlegrass (*Achnatherum thurberianum* (Piper) Barkworth) were measured in both zones.

Results

Maximum and minimum daily soil temperatures varied by sampling zone ($P < 0.05$; Fig. 1). Average daily PAR in the subcanopy was 297 µmol m^{-2} s^{-1} less than the interspace from April through October ($P < 0.0001$). Soil organic matter, pH, total C, and total N were greater in the subcanopy than the interspace zone ($P < 0.05$). Though NO_3^- and NH_4^+ varied between zones on a few select dates, they were not different between zones across the growing seasons ($P > 0.05$). The subcanopy had greater soil water content (0–15 cm) than the interspace during the growing season ($P < 0.01$) although the zones were not always different on individual sampling dates. Soil water content (15–30 cm) varied by zone ($P < 0.05$) although it was infrequently different between zones on individual sampling dates.

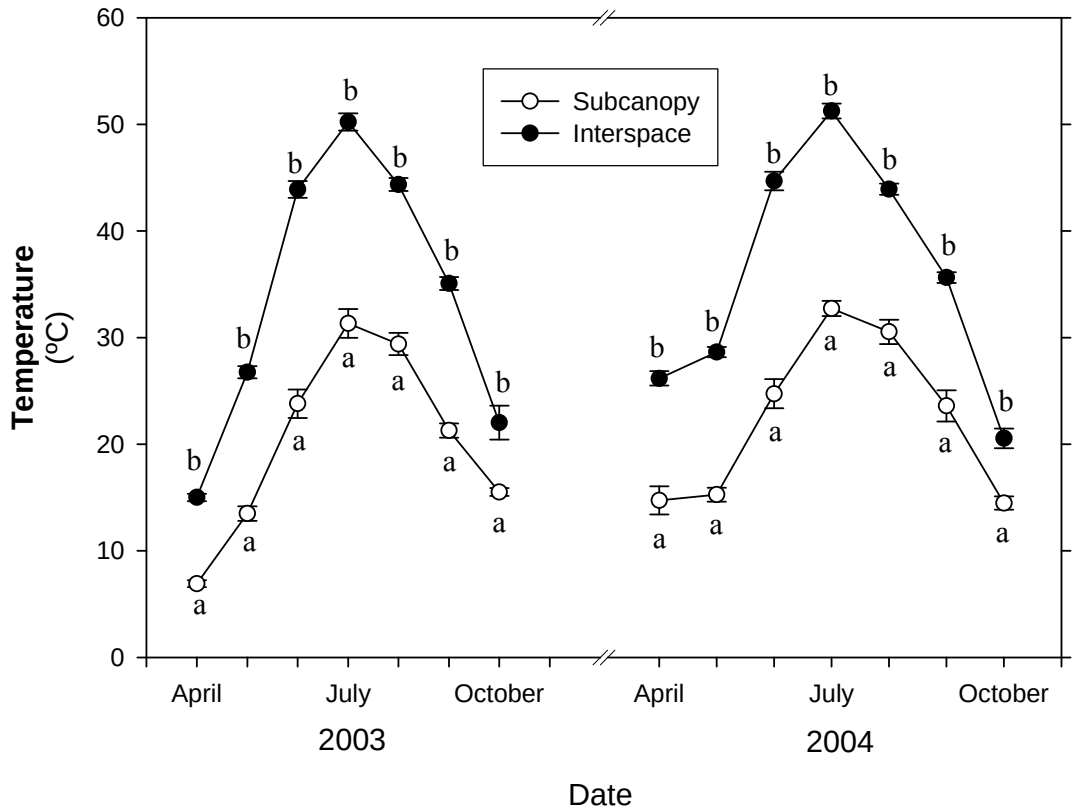

Figure 1. Subcanopy and interspace zone maximum daily soil temperatures (mean ± SE) at 4 cm depth. Different lower case letters indicate when there is a difference between zones at that date ($P < 0.05$).

At the NBGER site, zone influenced herbaceous cover values (Fig. 2). The subcanopy zone had greater tall tussock perennial grass, Sandberg bluegrass (*Poa sandbergii* Vasey), annual grass, total herbaceous, litter, and moss cover and less bare ground than the interspace ($P < 0.05$). Idaho fescue (*Festuca idahoensis* Elmer), prairie junegrass (*Koeleria macrantha* (Ledeb.)

J.A. Schultes), and squirreltail (*Elymus elymoides* (Raf.) Swezey) cover values were greater in the subcanopy than the interspace ($P < 0.05$). Bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) A. Löve), needle-and-thread (*Hesperostipa comata* (Trin. & Rupr.) Barkworth), and Thurber's needlegrass cover values did not differ between zones ($P > 0.05$). At Baker Pass, few zonal differences in cover were measured (Fig. 3). Litter and moss cover were greater and bare ground was less in the subcanopy compared to the interspace zone ($P < 0.05$). Except for squirreltail (P = 0.04), tall tussock perennial grass species cover values did not vary by zone ($P > 0.05$).

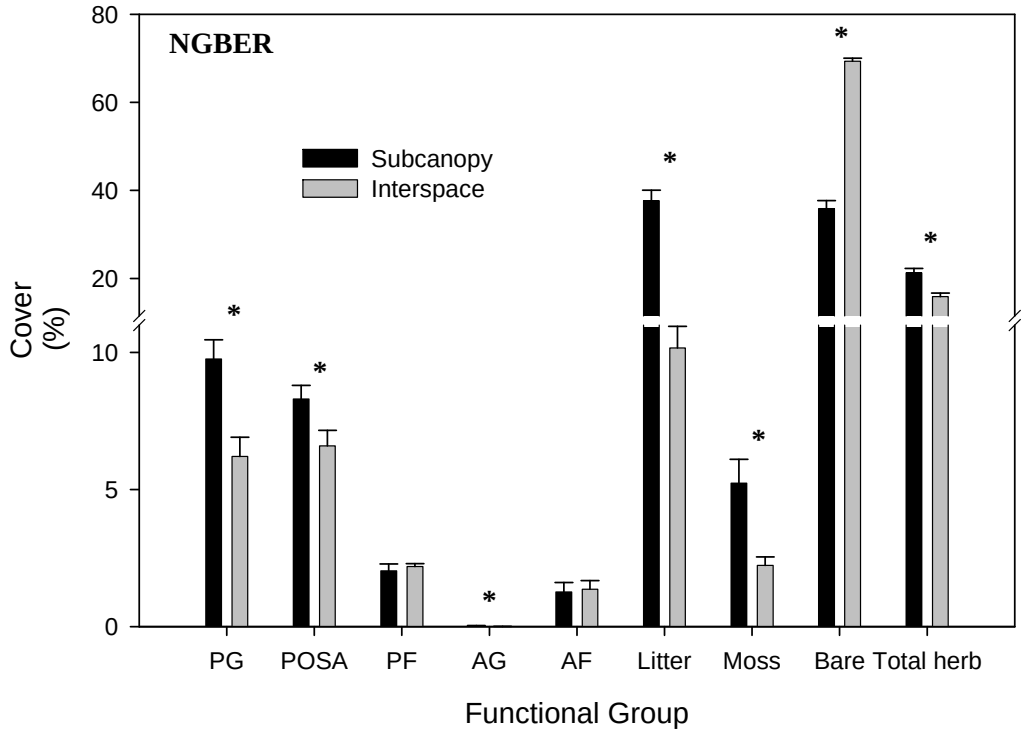

Figure 2. Zonal functional group cover values at NGBER (mean ± SE). Asterisk (*) indicates significant differences in zonal means ($P < 0.05$). PG = Tall tussock perennial grass, POSA = *P. sandbergii*, PF = Perennial forb, AG = Annual grass, AF = Annual forb, Bare = Bare ground, and Total herb = Total herbaceous.

At the NGBER plots, the subcanopy had greater density of Sandberg bluegrass, tall tussock perennial grass, and total perennial species than the interspace ($P < 0.05$). Idaho fescue, prairie junegrass, and squirreltail densities were greater in the subcanopy than interspace ($P < 0.05$). In contrast, at Baker Pass only Sandberg bluegrass and bluebunch wheatgrass densities differed between zones ($P < 0.05$).

Tall tussock perennial grass and total herbaceous biomass production were greater in the subcanopy than the interspace at the NGBER ($P = 0.04$ and 0.03, respectively). Annual forb biomass production was greater in the interspace than the subcanopy ($P = 0.05$).

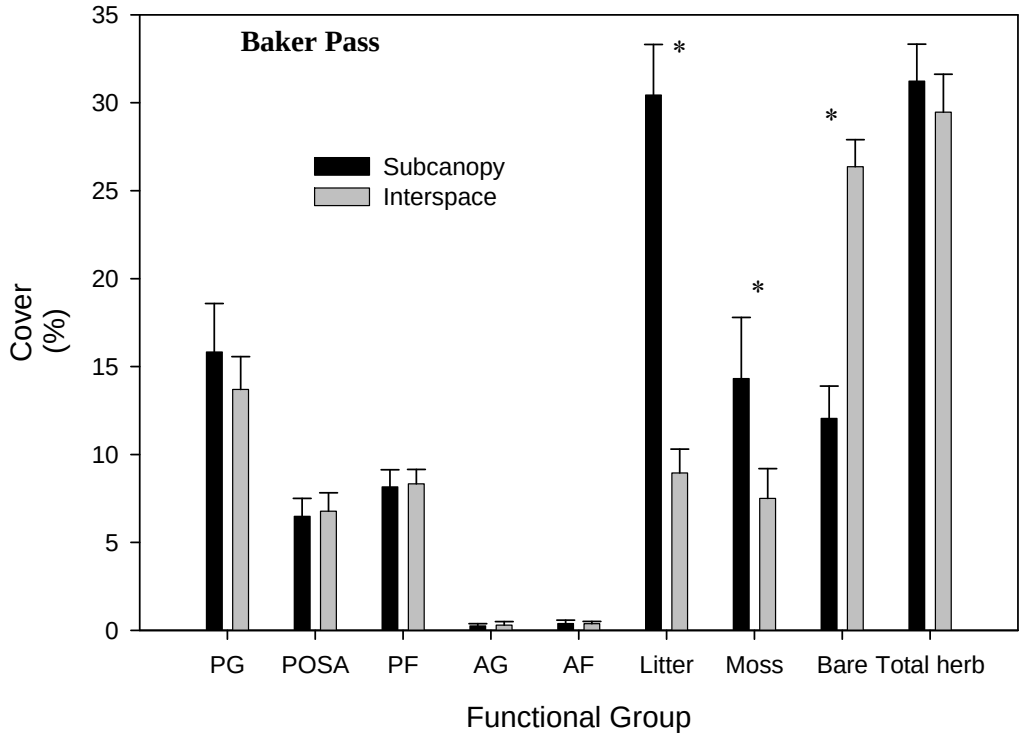

Figure 3. Subcanopy and interspace cover values at Baker Pass (mean ± SE). Asterisk (*) indicates significant differences in zonal means ($P < 0.05$). PG = Tall Tussock perennial grass, POSA = Sandberg bluegrass, PF = Perennial forb, AG = Annual grass, AF = Annual forb, Bare = Bare ground, and Total herb = Total herbaceous.

Discussion

There were measurable differences in Wyoming big sagebrush subcanopy and interspace microsites at the NGBER. Subcanopy zones have moderated soil temperatures, greater soil water content, lower average PAR, and higher soil C, N, pH, and OM than interspace zones. The microsite zonal differences appear to explain the zonal differences measured for herbaceous vegetation at the NGBER site.

Greater herbaceous cover, perennial grass densities, and total herbage production in the subcanopy suggested this zone provides a more favorable microsite for herbaceous growth than the interspace. Physiological response of Thurber's needlegrass indicated that Wyoming big sagebrush created zonal differences in the availability and use of resources. Greater discrimination by Thurber's needlegrass against ^{13}C when growing in the subcanopy zone indicated that water was more available to Thurber's needlegrass growing in the subcanopy than interspace. The results indicate that there is a zonal difference in the availability of resources to herbaceous vegetation.

In contrast to the NGBER site, the Baker Pass site had fewer measurable differences in zonal vegetation characteristics. This suggests the influence of microsite on the spatial distribution of herbaceous vegetation in Wyoming big sagebrush communities is site dependent. Microsite characteristics were not measured at Baker Pass, and it is possible that zonal differences for these variables were not as pronounced at this location compared to the NGBER site. However, the macro-environment at Baker Pass is less harsh for plant growth than the NGBER. At Baker Pass, aspect is north-facing and steep; thus, the site is less exposed (lower incident radiation) than the NGBER site. Lower incident radiation and/or other unmeasured site characteristics may also be responsible for the lack of zonal differences in herbaceous composition at Baker Pass. Though not conclusive, the results suggest that zonal differences may be greater and play a more influential role as site conditions become warmer and drier. As well as site dependency, measurements at the NGBER site suggest that zonal herbaceous distribution may also be species dependent as cover and density of some grass species were greater under the sagebrush canopy than the interspace, while other grass species exhibited no zonal preference.

Conclusions

Relationships between Wyoming big sagebrush and herbaceous species are complex; however, this study has advanced the understanding of Wyoming big sagebrush zonal influence within a plant community by investigating microsite and herbaceous zonal differences. Wyoming big sagebrush appears to modify microsite and resource availability within stands. Wyoming big sagebrush is an important component contributing to the heterogeneity of herbaceous vegetation within a community. However, by comparing zonal herbaceous characteristics from two different Wyoming big sagebrush communities, we found the influence of Wyoming big sagebrush on herbaceous spatial heterogeneity to be site dependent. Our result suggest the influence of Wyoming big sagebrush on microsite differences and subsequently herbaceous spatial heterogeneity may be greater as sites become warmer and drier, but more research investigating the influence of site environmental characteristics on the expression of zonal differences is needed to verify this hypothesis. This also indicates that herbaceous response to Wyoming big sagebrush removing disturbances may vary by site.

From: Davies, K.W., J.D. Bates, and R.F. Miller. 2007. The influence of *Artemsia tridentata* ssp. *wyomingensis* on microsite and herbaceous vegetation heterogeneity. Journal of Arid Environments 69:441-457.

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Microsite and herbaceous vegetation spatial heterogeneity after burning Wyoming big sagebrush steppe

Kirk W. Davies and Jonathan D. Bates

Summary

Prescribe burning Wyoming big sagebrush-bunchgrass steppe reduces the microsite and herbaceous vegetation heterogeneity within a stand. However, some zonal microsite and herbaceous differences remain after prescribed burning removed Wyoming big sagebrush communities.

Introduction

Arid and semi-arid plant communities are often characterized by high levels of bare ground interspersed by distinct patches of vegetation. Vegetation patches around big sagebrush plants are cause in part by the influence of sagebrush on associated vegetation. A more favorable environment for herbaceous vegetation may exist underneath (subcanopy zone) than between big sagebrush (*Artemisia tridentata* Nutt.) canopies (interspace zone) (Charley and West, 1977; Doescher et al., 1984; Burke et al., 1987; Wight et al., 1992; Chambers, 2001; Davies et al., 2007a).

Increased availability of soil resources and a moderated micro-environment underneath big sagebrush canopies may contribute to subcanopy facilitated herbaceous vegetation growth and establishment. However, burning can influence herbaceous vegetation and soil characteristics and thus, potentially influence the microsite and herbaceous vegetation heterogeneity created by the zones. The purpose of this study was to determine the impact of burning on zonal microsite and herbaceous vegetation heterogeneity.

Methods

The study was conducted at the Northern Great Basin Experimental Range (NGBER), in southeastern Oregon. Six sites (blocks) in late seral Wyoming big sagebrush dominated plant communities that had limited livestock use were used for the study. One half of each block was prescribed burned in October 2002. Tall tussock perennial bunchgrasses dominated the understory and exotic annual grasses are only a minor component (< 0.1% cover) of the plant communities. The microsites and herbaceous vegetation varied by zonal location in unburned portion of each block (Davies et al., 2007a). In general, the subcanopy had greater herbaceous vegetation and more favorable microsites characteristics for plant growth compared to the interspace (Davies et al., 2007a).

Relative humidity, air and soil temperature, and photosynthetically active radiation (PAR) measurements and soil surface texture were recorded in each zone and former zone per site. Soil pH, total carbon, total nitrogen, water content and organic matter in the upper 15 cm (water content also in the 15-30 cm) of the soil profile from each zone and former zone per site were measured. Vegetation parameters measured were herbaceous cover, biomass, density, photosynthetic rate, carbon and nitrogen isotope ratios, and carbon and nitrogen content.

Results

Microsite

Maximum daily soil temperatures varied between the subcanopy and former subcanopy zones ($P < 0.01$) and between the former zones ($P < 0.05$). The former subcanopy zone was on average 15.7˚C and 3.2˚C warmer than the subcanopy and former interspace zone, respectively. Average daily PAR in the subcanopy was 300 µmol m^{-2} s^{-1} less than the former subcanopy from April through early November and varied by sampling date ($P < 0.01$). Average daily PAR did not vary by former zone, between interspace and former interspace, or the interaction between sampling date and former zone or zone ($P > 0.05$). Soil organic matter, pH, total C, and total N were greater in the former subcanopy than the former interspace zone ($P < 0.05$). Soil organic matter, total C, and total nitrogen did not differ between the subcanopy and former subcanopy zones or between the interspace and former interspace zones ($P > 0.05$). Across the growing season the former subcanopy generally had greater NO_3^- and NH_4^+ concentrations than the former interspace. Soil water content (0-15 cm) varied by sampling date ($P < 0.01$), but did not differ between former zones, between interspace and former interspace, or between subcanopy and former subcanopy ($P > 0.05$).

Herbaceous vegetation

Thurber's needlegrass carbon and nitrogen isotope ratios did not differ among former zones ($P > 0.05$). Photosynthetic rates of Thurber's needlegrass did not vary between former zone, between subcanopy and former subcanopy, or between interspace and former interspace ($P > 0.05$).

Tall tussock perennial grass, *Poa sandbergii* Vasey (Sandberg bluegrass), perennial forb, annual grass, annual forb, total herbaceous, litter, and moss cover and bare ground did not differ between former zones ($P > 0.05$) (Fig. 1). Tall tussock perennial grass and total perennial grass (tall tussock perennial grass and *P. sandbergii*) densities were greater in the former subcanopy than the former interspace ($P = 0.04$ and 0.03, respectively). Herbaceous functional group and total herbaceous biomass production did not differ between former zones ($P > 0.05$).

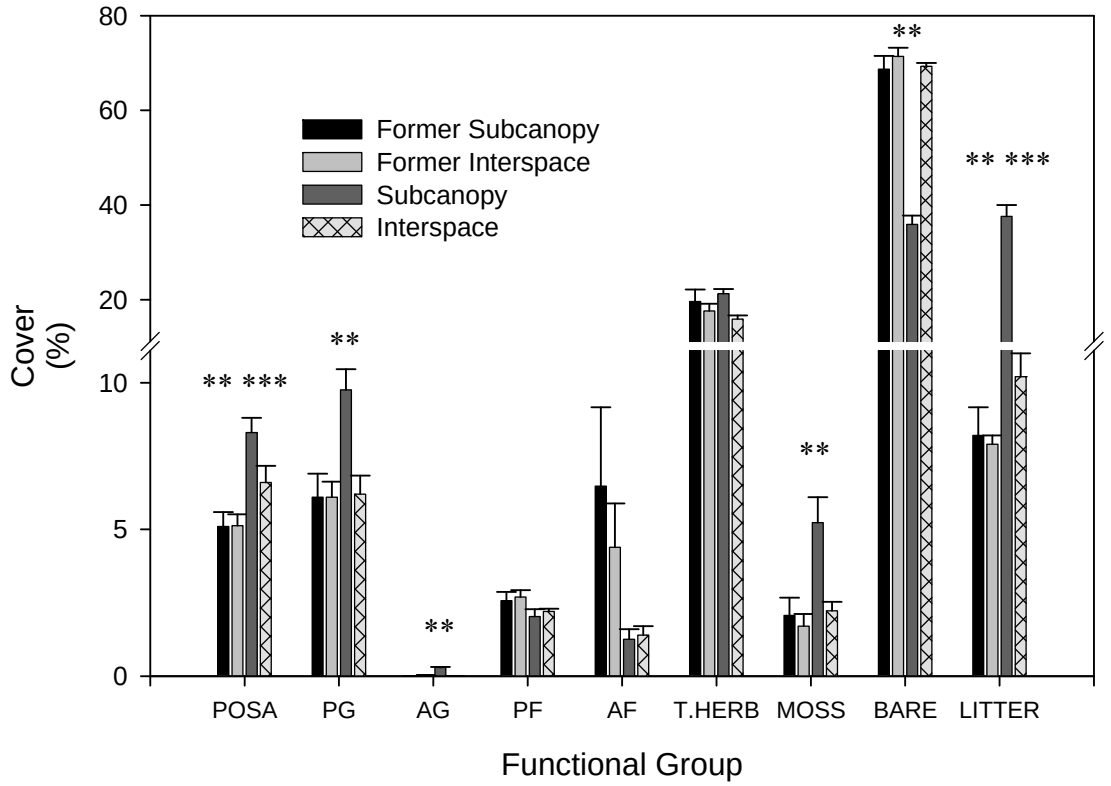

Figure 1. Subcanopy, interspace, former subcanopy, and former interspace zones functional group cover values (mean + SE). Asterisk (*), double asterisk (**), triple asterisk (***) indicates significant differences between former zones, between subcanopy and former subcanopy, and between interspace and former interspace, respectively ($P < 0.05$). PG = Tall tussock perennial grass, POSA = *P. sandbergii*, PF = Perennial forb, AG = Annual grass, AF = Annual forb, BARE = Bare ground, and T. HERB = Total herbaceous.

Discussion

Prescribe burning Wyoming big sagebrush-bunchgrass steppe reduces the microsite and herbaceous vegetation heterogeneity within a stand. However, burning did not completely eliminate the heterogeneity of resource concentrations created by Wyoming big sagebrush. Soil resource zonal differences were common after prescribed burning while micro-environmental differences were often lacking.

Prescribe burning resulted in the former subcanopy and former interspace being more similar in soil temperatures than subcanopy and interspace zones. Prescribe burned zones also generally did not differ in soil water content. Herbaceous vegetation characteristics differed between zones and former zones, suggesting that prescribed burning alters the spatial heterogeneity of herbaceous vegetation created by Wyoming big sagebrush. The lack of differences in herbaceous vegetation production and cover between former zones is probably due

to lack of significant differences in soil moisture content and soil temperatures. Similar to zonal herbaceous density differences reported by Davies et al. (2007a), tall tussock perennial grass and total perennial grass densities were greater in the former subcanopy than interspace. However, none of the perennial densities varied between zones and former zones. This suggests that zonal density differences were maintained after burning, because prescribed burning resulted in limited mortality of perennial herbaceous vegetation. Our results demonstrate that zones and former zones differ in microsite and herbaceous vegetation characteristics while former zones are relatively similar to each other. This suggests that prescribed burning alters the influence zonal locations have on herbaceous vegetation and microsites. Some zonal microsite differences remain after prescribed burning removed Wyoming big sagebrush, but appear to have little effect on herbaceous vegetation. Thus, prescribed burning appears to decrease the heterogeneity of herbaceous vegetation and microsite characteristics within burned Wyoming big sagebrush plant communities.

Conclusions

Prescribed burning appears to largely eliminate zonal micro-environmental differences and thus decreases herbaceous vegetation heterogeneity within a stand. However, former zones differed in soil resources which may promote vegetation composition and productivity heterogeneity over time. Longer term evaluation of the influence of prescribed burning on microsite characteristics and herbaceous vegetation heterogeneity is needed to better understand the relationship between Wyoming big sagebrush and associated herbaceous vegetation. To more fully understand plant community dynamics and develop strategies to protect native arid lands, the difference in soil resources between the former zones influence on invasibility of *A. tridentata* ssp. *wyomingensis* plant communities also needs to be investigated.

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Fire effects on cover and forb dietary resources of sage-grouse habitat

Ed C. Rhodes, Jon D. Bates, and Rob N. Sharp

Summary

In 2001, we developed a study to evaluate post-fire shrub and herbaceous recovery of Wyoming big sagebrush steppe in eastern Oregon. Measurements were taken to coincide with sage-grouse breeding and brood-rearing periods in Oregon. It was predicted that prescribed burning would increase productivity and nutritional quality of sage-grouse dietary forbs. However, sage-grouse dietary forb cover/yield was largely unresponsive to prescribed fall burning for 5 years following treatment. For management purposes, it is unlikely that even small prescribed fires or other big sage-brush reduction treatments will have any sustained benefits for improving sage-rouse habitat in intact Wyoming big sagebrush plant communities. On the contrary treatments targeting removal Wyoming big sagebrush will have a negative effect by reducing habitat cover as well as forage provided by big sagebrush for sage-grouse. Based on results from this study and others, we conclude that it is unnecessary to apply brush control treatments in intact Wyoming big sagebrush communities containing a balance of shrubs, native grasses, and native forbs.

Introduction

Prescribed fire is often applied in terrestrial ecosystems to increase the productivity and abundance of herbaceous and browse species and to create a mosaic of wildlife habitats or vegetation successional stages. Big sagebrush steppe plant communities are one of the major vegetation types of the Intermountain region of the western United States. Fire has been a natural and prescribed disturbance of big sagebrush communities that temporarily shift vegetation from shrub-grass co-dominance to herbaceous dominance. Estimates of recovery periods of big sagebrush are very broad and suffer from a lack of long-term and/or landscape level evaluations. In the interim, loss or reductions in cover, structure, and forage provided by big sagebrush after large scale fires result in decline of populations and diversity of sagebrush obligate and facultative wildlife species. Greater sage-grouse are sagebrush obligates and have declined throughout their range as sagebrush steppe habitat has been lost and fragmented. Consequently considerable emphasis has been placed on developing appropriate management of remaining intact sagebrush steppe to benefit sage-grouse and other wildlife.

Selective use of fire is a recommended management alternative for restoring sagebrush steppe in the context of preventing pinyon-juniper woodland encroachment into affected plant communities. However, at lower elevations in drier and more xeric big sagebrush communities (Wyoming big sagebrush and basin big sagebrush) large scale use of fire is not recommended as they are to sage grouse populations and other wildlife species. Loss of vertical structure provided by shrubs eliminates cover for successful nesting and concealment as well as forage provided by Wyoming big sagebrush. The number of active sage-grouse leks and breeding pairs decline following landscape level prescribed fire in Wyoming big sagebrush communities.

Use of small patch fires or other manipulations to reduce big sagebrush cover have been suggested as a management option to improve sage-grouse pre-nesting and brood rearing habitat. Thinning dense stands of big sagebrush or creating small open patches of herbaceous vegetation by removing brush may increase forb production. Forbs are a critical in sage-grouse diets during pre-laying and brood-rearing periods, constituting between 50-80% of the diet by weight.

The effects of sagebrush removal to forb productivity, abundance, and diversity have not produced consistent results. In Wyoming big sagebrush communities burning has not been effective in increase in overall forb diversity or abundance. However, productivity of several forb species increased as measured by reproductive effort and crown volume.

In 2001, we developed a study to evaluate post-fire shrub and herbaceous recovery of Wyoming big sagebrush steppe in eastern Oregon. Measurements were taken to coincide with sage-grouse breeding and brood-rearing periods in Oregon. It was predicted that prescribed burning would increase productivity and nutritional quality of sage-grouse dietary forbs. Forb abundance was not expected to increase immediately, taking several years for new plants to become established.

Methods

The study was conducted on the Northern Great Basin Experimental Range, about 32 miles west of Burns, Oregon. Wyoming big sagebrush was the dominant shrub. Basin big sagebrush and were subdominant. Idaho fescue and Thurber's needlegrass were the dominant perennial bunchgrasses. Sandberg's bluegrass, bluebunch wheatgrass, prairie Junegrass, and bottlebrush squirreltail were present as subdominant perennial grasses. Perennial forbs mainly consisted of taper-tip hawksbeard, milkvetch species, tailcup lupine, common yarrow and long-leafed phlox. Annual forbs mainly consisted of desert alyssum, little blue-eyed Mary and pink microsteris.

Sagebrush cover averaged 10% (range 6-17%) and grass-forb cover exceeded 15%. Sagebrush and herbaceous cover values were about average for Wyoming big sagebrush communities in eastern Oregon (Davies et al. 2006). The site was located in year-round occupied sage-grouse habitat and was within 5 km of active leks. Site cover values would meet sage-grouse brood rearing requirements for arid big sagebrush sites. Only portions of the area would meet sage-grouse breeding habitat guidelines for arid big sagebrush sites.

Treatments were burned (Burn) and not burned (No-burn) Wyoming big sagebrush steppe. Five, 10 acre plots were established in 2001. Within each plot two 5 acre subplots were established (10 subplots total). Five of the subplots were burned. in late September and early October 2002. Fires were complete across burn plots, killing nearly 99% of the sagebrush present. Plots have not been grazed since 1999. Prior to 1999, grazing by cattle was of light to moderate use in a rest-rotation management system.

Vegetation response to treatment was evaluated by quantifying plant cover and herbaceous standing production. Five 50-m transects were randomly placed within each treatment plot in 2001. Plant species cover was measured each year in June from 2001 to 2006. Herbaceous production was measured mid-June 2002-2007 by functional group; Functional groups perennial

bunchgrasses, perennial forbs, and annual forbs. From 2004-2007, forb production was measured by species in mid-April, mid-May, and mid-June.

Results

Habitat Cover

Herbaceous cover was greater in the Burn treatment than the Noburn treatment after fire. However, habitat cover (shrub and tall herbaceous cover) was reduced and remained lower in the Burn treatment than the NoBurn treatment after fire and primarily resulted from an almost total loss of Wyoming big sagebrush cover (Fig. 1A and B). After the first year following the fire tall herbaceous (Fig. 1D) and perennial grass (Fig. 1E) cover did not differ between treatments. Tall herbaceous cover mostly comprised perennial grasses as tall forb cover did not exceed 1% in either treatment in any year sampled. Perennial grass and tall herbaceous cover increased in 2006 in both treatments as a result of above average precipitation in 2005 and 2006. The greater total herbaceous cover in the Burn treatment than the NoBurn treatment was a result of annual forb response after fire. Annual forb cover was greater in the Burn treatment than the NoBurn treatment after fire (Fig. 2). Most annual forb cover in the Burn treatment was provided by pale alyssum, an introduced old world weed.

Biomass

Herbaceous biomass was greater in the Burn than the NoBurn treatment by the second year after fire (Fig 3A). Herbaceous biomass was in both treatments was mostly composed of perennial grasses. Perennial grass biomass was about twice as great in the Burn treatments than the NoBurn treatment from 2005-2007 (Fig 3B). Total forb biomass (perennial and annual) was greater in the Burn treatment than the NoBurn treatment in 4 of the 5 years after the burn (Fig 3C). However, perennial forb biomass did not increase after the fire and in two of the sampling periods perennial forb biomass was greater in the NoBurn treatment than the Burn treatment (Fig 4A). Annual forb biomass was greater in the Burn treatment than the NoBurn treatment throughout the study (though not every sample period) (Fig 4B).

Perennial forbs utilized by sage-grouse in their diets did not differ in yield among the Burn and Noburn treatments. Yield of milkvetch species, Cichorieae tribe, long-leaf phlox and other perennial forbs were not different between the treatments during the study period. The yield of annual forbs utilized by sage-grouse was greater in the Burn treatment than the NoBurn treatment in 2004 (Fig 5A). On other sample dates and across the study period sage-grouse dietary annual forbs did not differ in yield among the Burn and NoBurn treatments.

The main annual forb that increased and comprised the bulk of forb yield and composition after fire was pale alyssum, an introduced exotic species (Fig 5B). Over 90% of annual forb production was comprised of pale alyssum.

Discussion

Habitat Cover

As would be expected prescribed fire largely eliminated big sagebrush cover. The loss of sagebrush was not compensated by an increase in tall herbaceous cover which did not differ from the areas not burned. While herbaceous cover increased in the Burn treatment, these increases were largely composed of native perennial grasses and non-native pale alyssum. Cover from low-growing pale alyssum provides little in the way of hiding cover.

The recovery of Wyoming big sagebrush is dependent on establishment from seed. Wyoming big sagebrush is the slowest of the big sagebrush species to recover from fire resulting from a lack of reproductive effort in most years and because drier conditions make establishment of new individuals difficult. Literature suggests that recovery of Wyoming sagebrush will exceed 30 years. In our study, surviving sagebrush were scattered throughout the burn and provide a potential seed source.

Green rabbitbrush cover was reduced 10-fold the first year after fire, returning to pre-burn levels by the second year after fire. Green rabbitbrush is a vigorous sprouter, often increasing within a few years after fire. We would expect rabbitbrush cover to increase the next 5-10 years. The shrub architecture of green rabbitbrush does not provide the structural/vertical cover that big sagebrush conveys for nesting and roosting.

Biomass and Nutritional Quality

The results indicated that burning in Wyoming big sagebrush communities did not increase yields of perennial forbs important in the sage-grouse diet. These results are similar to other studies which found no increase in forb diversity or abundance after burning in Wyoming big sagebrush communities. Pyle & Crawford found that fall burning increased frequency of Cichorieae, but did not have an effect on other primary sage grouse foods. Wrobleski and Kauffman found that individual forbs increased in productivity and had lengthened growing seasons. Individual plants were not measured in this study, but yield of perennial forb species were not enhanced following fire.

The loss of sagebrush on this site reduced forage provided by big sagebrush about 450 lbs per acre (prior to ephemeral leaf drop). Approximately one third of the big sagebrush is retained after ephemeral leaf drop until the following growing season.

The increase in annual forbs consumed by sage-grouse in the Burn treatment was transient, occurring in only one year. Others have reported no change in dietary annual forbs after fall burning. The increase of pale alyssum yield after fire is not likely to provide any benefits to sage-grouse. Diet studies have not reported that sage-grouse consume this forb.

Management Implications and Conclusions

Notwithstanding the reduction of habitat cover provided by big sagebrush, a common assumption has been that burning big sagebrush communities will increase forb cover or productivity. Sage-grouse dietary forb cover/yield was largely unresponsive to prescribed fall burning. For management purposes, it appears unlikely that even small prescribed fires or other big sage-brush reduction treatments will have any sustained benefits for improving sage-rouse habitat in intact Wyoming big sagebrush plant communities. On the contrary treatments targeting removal Wyoming big sagebrush will have a negative effect by reducing habitat cover as well as forage provided by big sagebrush for sage-grouse. Based on results from this study and others we conclude that it is unnecessary to apply brush control treatments in intact Wyoming big sagebrush communities containing a balance of shrubs, native grasses, and native forbs.

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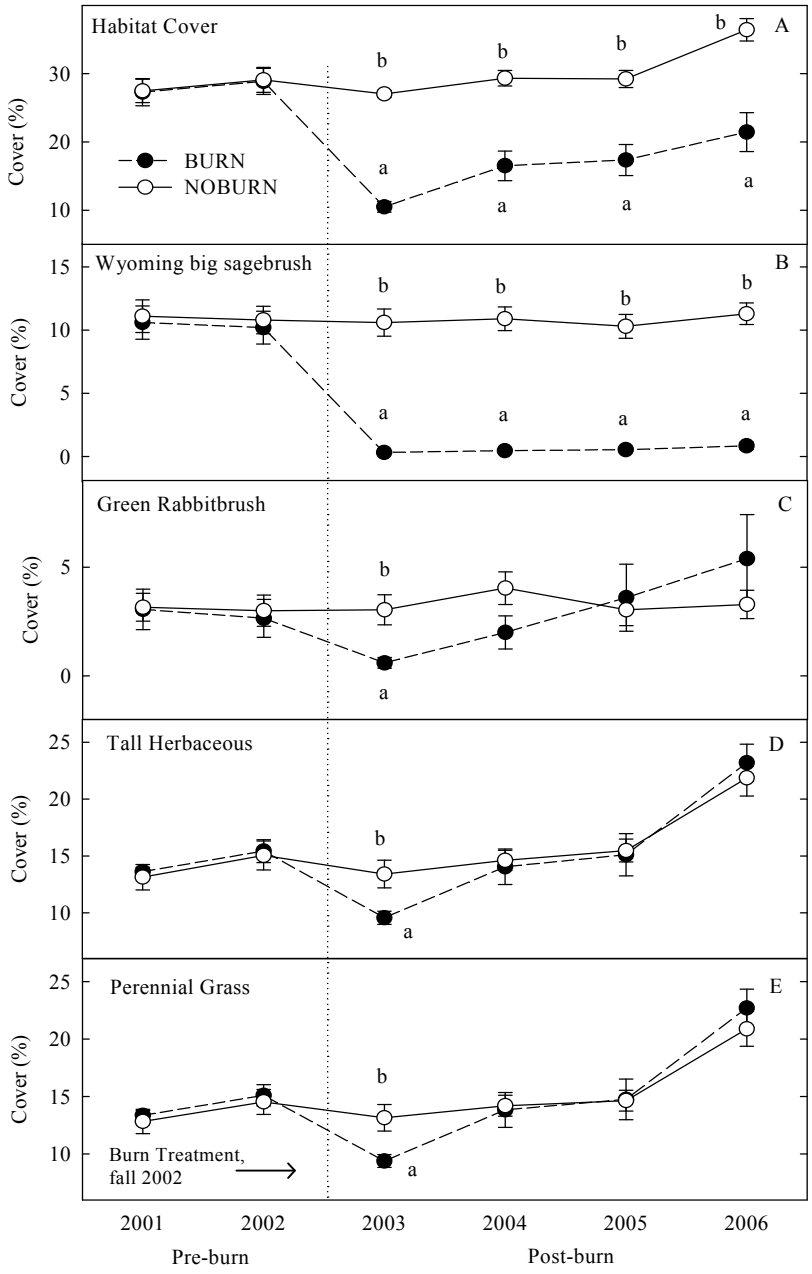

Figure 1. *Canopy cover (%) for the Burn and Noburn treatments on the Wyoming big sagebrush community: (A) Habitat cover (big sagebrush and tall herbaceous); (B)Wyoming big sagebrush; (C) green rabbitbrush; (D) tall herbaceous (plants > 7" height); and(E) perennial grass. Different lower case letters represent significant differences between means of the treatments.*

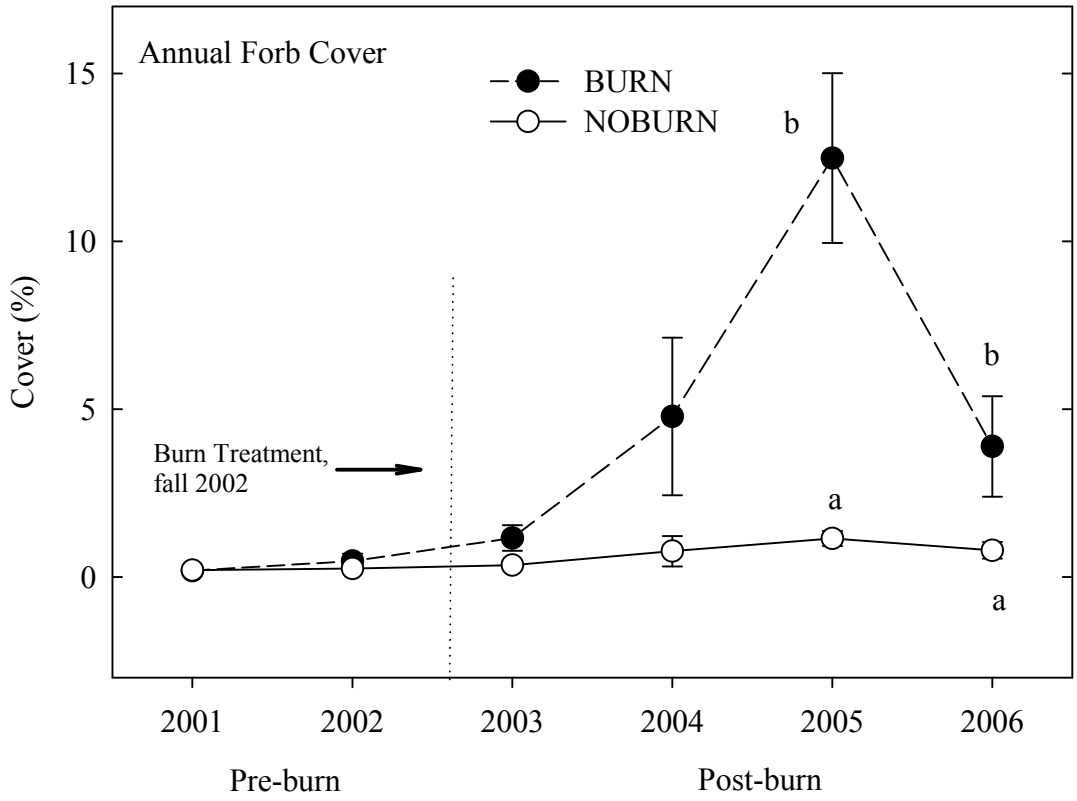

Figure 2. *Annual forb foliar cover (%) for the Burn and Noburn treatments. Different lower case letters represent significant differences between means of the treatments.*

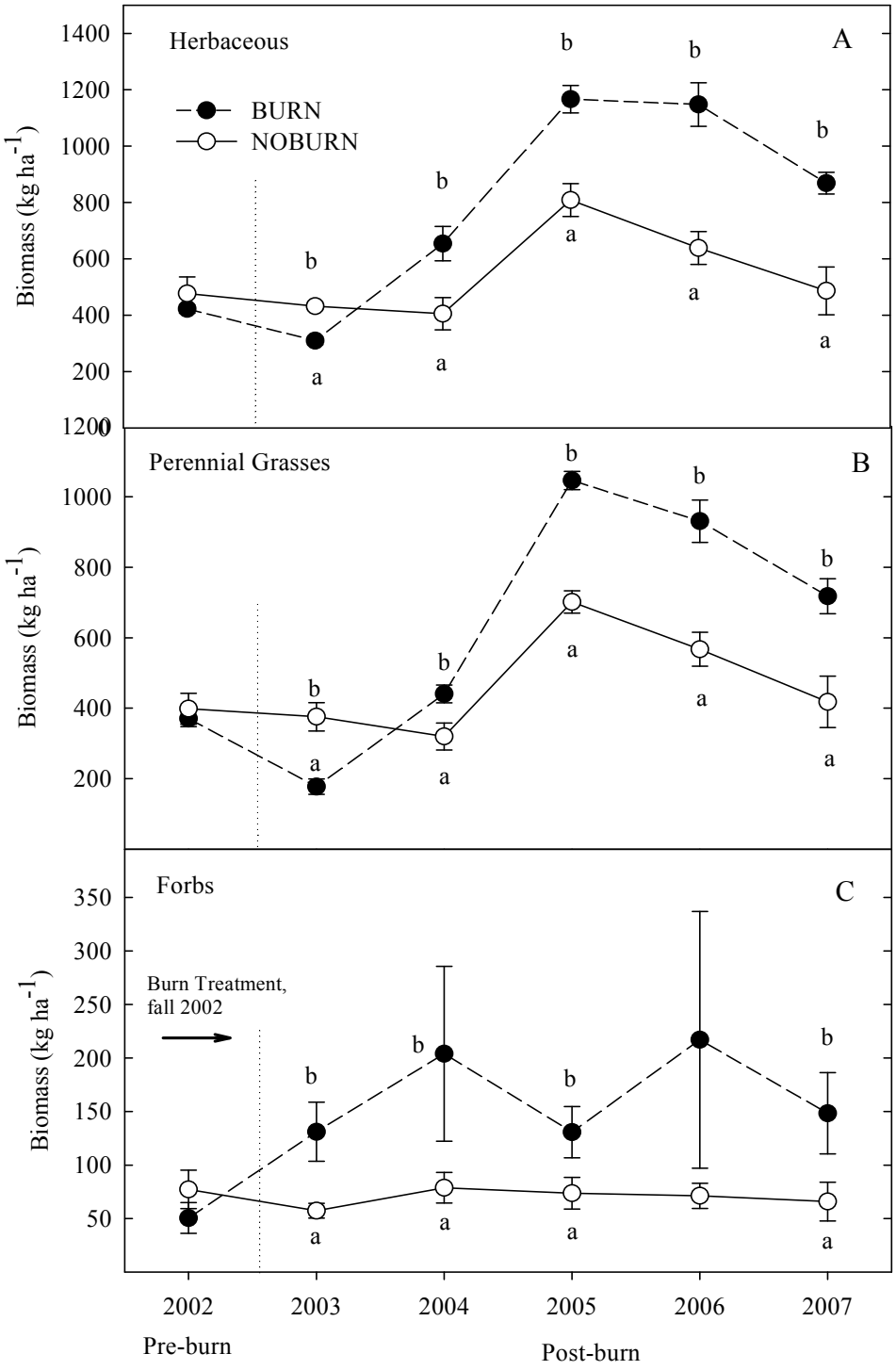

Figure 3. *Biomass (kg/ha) for the Burn and Noburn treatments on the Wyoming big sagebrush community: (A) total herbaceous; (B) perennial grasses; and (C) forbs (perennial and annual). Different lower case letters represent significant differences between means of the treatments.*

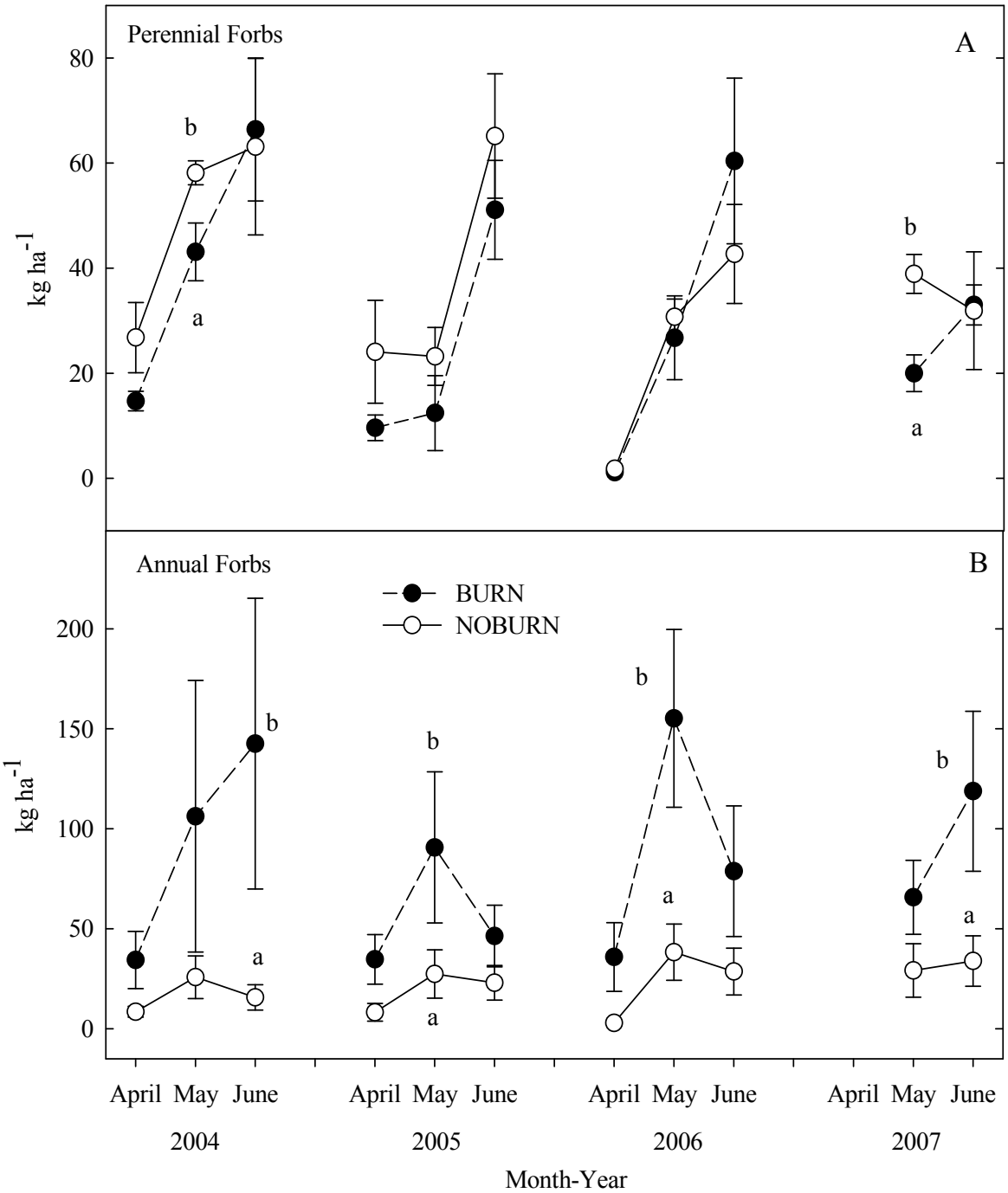

Figure 4. *Perennial (A) and annual (B) forb Biomass (kg/ha) for the Burn and Noburn treatments on the Wyoming big sagebrush community. Different lower case letters represent significant differences between means of the treatments.*

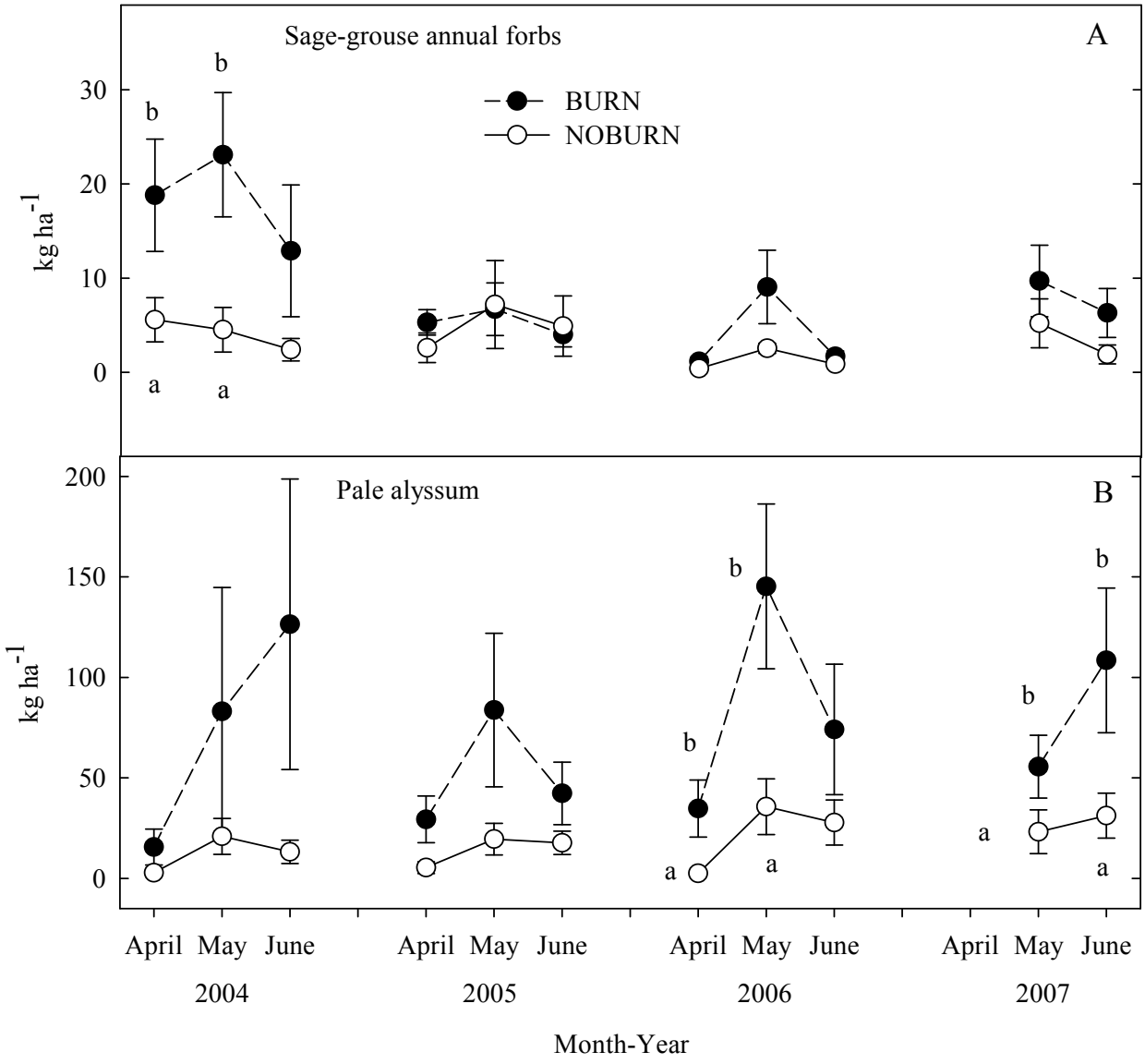

Figure 5. *Biomass (kg/ha) of sage-grouse dietary annual forbs (A) and pale alyssum (B) in the Burn and Noburn treatments on the Wyoming big sagebrush community. Different lower case letters represent significant differences between means of the treatments.*

Environmental-vegetation relationships of the Wyoming big sagebrush alliance

K.W. Davies, J.D. Bates and R.F. Miller

Summary

Environmental factors such as soil texture, soil water-holding capacity, depth to Bt horizon and incident radiation, provide some insight into the variation in plant species composition and vegetation characteristics in the Wyoming big sagebrush alliance.

Introduction

The Wyoming big sagebrush (*Artemisia tridentata* spp. *wyomingensis* (Beetle & A. Young) S.L. Welsh) alliance is the most extensive of the big sagebrush complex in the Intermountain West and is characterized by a wide range of environments and vegetation heterogeneity. Difficulties in identifying relationships among environmental and vegetation characteristics in sagebrush systems have arisen because: (1) plant species exhibit wide ecological amplitudes and ecotypic variability (Doescher et al., 1985; Jensen et al., 1990; Passey et al., 1982; West, 1988), (2) detailed climate data is usually lacking, thus important site information is missing in analyses (Jensen et al., 1990), (3) a lack of precision in field observations, especially soil characteristics (Lentz and Simonson, 1987a), and (4) limited detail in vegetation and soils descriptions (Lentz and Simonson, 1987a). Improving measurement detail may provide greater insight into environmental–vegetation relationships in Wyoming big sagebrush alliance.

The purpose of this study was to identify environmental factors driving variation in plant species composition and determine the potential for using environmental factors to explain vegetation characteristics of the Wyoming big sagebrush alliance. The Wyoming big sagebrush alliance was selected because it is the most extensive, least resilient to disturbance, most endangered of the big sagebrush (*A. tridentata* Nutt.) complex in the Intermountain West (Barker and McKell, 1983; Beetle and Young, 1965; McArthur and Plummer, 1978; Miller and Eddleman, 2000; Morris et al., 1976; Tisdale, 1994; West et al., 1978), and the alliance occurs within a relatively narrow band (180–300 mm) of precipitation (Goodrich et al., 1999; Tisdale, 1994).

Methods

Seventeen environmental factors and seven vegetation response variables (Table 1) were measured on 107 relatively undisturbed, late seral Wyoming big sagebrush sites across southeastern Oregon and northern Nevada. Non-metric multidimensional scaling (NMS) was used to identify environmental factors correlated with plant species composition as indexed by canopy cover. Stepwise multiple linear regressions were used to develop models correlating plant cover and structural characteristics with environmental factors. For these analyses, herbaceous cover was grouped into four functional groups: tall tussock perennial grasses, annual grasses, perennial forbs, and annual forbs. Sandberg bluegrass (*Poa sandbergii* Vasey),

bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) A. Löve), squirreltail (*Elymus elymoides* (Raf.) Swezey), Thurber's needlegrass (*Achnatherum thurberianum* (Piper) Barkworth), needle-and-thread (*Hesperostipa comata* (Trin. & Rupr.) Barkworth), and Idaho fescue (*Festuca idahoensis* Elmer) were also analyzed separately because of their importance across this alliance. Total herbaceous cover was the sum of all herbaceous species and total vegetation cover was the summation of the total herbaceous and shrub cover.

Table 1. Environmental factors and vegetation characteristics measured at each site.

Vegetation Characteristics	Environmental Factors
Shrub Cover	Precipitation
Shrub Density	Elevation
A. tridentata spp. *wyomingensis* Canopy Volume	Soil Water Holding Capacity
A. tridentata spp. *wyomingensis* Height	Soil Texture
Herbaceous Cover	Effective Rooting Depth
Herbaceous Composition	Depth to Bt horizon
Horizontal Visual Obstruction	Soil Total Carbon and Nitrogen
	Carbon:Nitrogen Ratio
	Soil pH
	Soil Depth
	Slope
	Aspect
	Landscape Position
	Direct Incident Radiation
	Universal Transverse Mercator
	Latitude

Results

Vegetation composition variation appears to be largely driven by soil characteristics. Canopy cover of perennial grasses and forbs was moderately correlated with direct incident radiation (calculated from slope, aspect, and latitude) and soil characteristics, particularly soil texture in the upper 15 cm of the profile. About half the variation in canopy cover of total herbaceous, total vegetation, and needle-n-thread was explained by environmental factors (R^2 = 0.52, 0.45, and 0.46, respectively) (Table 2). Total herbaceous cover variation was better explained by environmental factors (soil water-holding capacity, incident radiation, depth to Bt horizon, and percent sand in the upper 15 cm of the soil profile) ($P < 0.0001$, $R^2 = 0.52$) than any

other vegetation characteristic. Vegetation structural characteristics (e.g. sagebrush height, canopy volume and canopy cover, density, and plant visual obstruction) exhibited weak or no relationships with measured environmental variables.

Table 2. Regression models for vegetation cover.

Regression Model w/ standard errors in parentheses below coefficients	**Residual Standard Error**	***P*-value**	**R^2**
PG = 30.55 + 0.32(SWHC) – 18.92(IR) – 0.09(S) (5.23) (0.10) (5.37) (0.04)	3.97	< 0.0001	0.20
PF = 17.16 – 13.19(IR) – 0.04(Bt) (2.82) (3.14) (0.01)	2.45	< 0.0001	0.25
THerb = 63.34 + 0.49(SWHC) – 38.25(IR) – 0.08(Bt) – 0.17(S) (6.13) (0.12) (6.27) (0.02) (0.05)	4.73	< 0.0001	0.52
TVeg = 34.01 + 60.30(N) + 0.31(Si) + 0.68(SWHC) – 22.36(IR) (9.07) (23.09) (0.08) (0.16) (8.40)	6.17	< 0.0001	0.45
ARTRW8 = 15.50 + 0.04(ERD) – 0.12(S) (1.84) (0.01) (0.04)	7.54	0.0009	0.12
POSA = 10.74 + 0.08(Si) – 8.89(IR) – 0.2(Bt) (3.01) (0.03) (2.73) (0.02)	2.06	< 0.0001	0.26
PSSP6 = 5.00 – 0.18(S) + 0.88(C:N) (3.71) (0.04) (0.29)	4.45	< 0.0001	0.19
FEID = -33.15 + 631.48(N) + 36.81(IR) – 675.85(N*IR) (13.82) (155.45) (15.53) (176.88)	4.32	< 0.0001	0.26
ELEL5 = -0.41 + 0.0009(Elev) – 0.04(Slope) (0.67) (0.0004) (0.01)	0.75	< 0.0001	0.15
HECO26 = 0.98 – 0.03(S) – 0.06(Bt) + 0.002(S*Bt) (1.09) (0.02) (0.02) (0.001)	1.32	< 0.0001	0.46
ACTH7 = 2.97 – 0.13(Slope) (0.33) (0.03)	2.20	0.0002	0.12

PG = tall tussock perennial bunchgrasses, PF = perennial forbs, THerb = total herbaceous, TVeg = total vegetation, ARTRW8 = *A. tridentata* spp. *wyomingensis*, POSA = *P. sandbergii*, PSSP6 = *P. spicata*, FEID = *F. idahoensis*, ELEL5 = *E. elymoides* , HECO26 = *H. comata*, ACTH7 = *A. thurberianum*, SWHC = soil water holding capacity (cm), IR = direct incident radiation, S = percent sand in upper 15 cm of the soil profile, Bt = depth to Bt horizon (cm), N = percent total nitrogen in the upper 15 cm of the soil profile, ERD = effective rooting depth (cm), Si = percent silt in the upper 15 cm of the soil profile, C:N = carbon:nitrogen ratio, Elev = elevation (m).

Discussion

This study demonstrates that soil characteristics, direct incident radiation, and other environmental factors explain some of the variation in vegetation characteristics across the Wyoming big sagebrush alliance. The amount of variation in vegetation characteristics not explained by measured environmental attributes suggests other factors or interactions not taken into account in this study also influence vegetation characteristics in this alliance. The lack of or weak relationships among environmental factors and vegetation structure and Wyoming big sagebrush cover indicate that the relationships are too complex to be used for management purposes.

Variation in plant species composition was correlated mainly with soil characteristics. However, the general weak correlations between most vegetation species and environmental factors indicates edaphic characteristics are some of the more important factors driving plant species composition in this portion of the Wyoming big sagebrush alliance. Slope was the only non-soil factor we found to be at least moderately correlated with plant species composition. Vegetation cover values were most consistently correlated with texture-related soil characteristics (percent sand and silt in the upper 15 cm, and soil water-holding capacity), direct incident radiation, and depth to a Bt horizon.

The relative importance of soil characteristics to vegetation cover is probably related to the amount, length of time, and location where soil water is available for plant use, because soil characteristics (texture, Bt horizon depth, etc.) exert a major influence over infiltration rates and soil water retention characteristics (Brady and Weil, 2002). The negative correlation of direct incident radiation to perennial functional groups, total herbaceous vegetation, and total vegetation canopy cover is related partially to the influence of direct incident radiation on temperature. Higher direct incident radiation results in warmer temperatures (McCune and Keon, 2002) that may increase plant water stress, thereby limiting plant growth and cover potential. The lack of correlation between annual forb or grass canopy cover and measured environmental factors may be the result of annuals being opportunistic and highly responsive to current year's climatic conditions.

Our results indicate environments with favorable soil characteristics (loamy surface texture, greater soil water-holding capacity, etc.) and lower direct incident radiation can be expected to produce more total herbaceous and total vegetation canopy cover than environments with higher direct incident radiation and less favorable soil characteristics in the Wyoming big sagebrush alliance.

The lack of strong correlations among environmental factors and vegetation characteristics are potentially related to several factors. First, various combinations of environmental factors can produce relatively equivalent environments for plant growth (Daubenmire, 1968; Jensen et al., 1990). Second, many plant species common to the sagebrush steppe possess wide ecological amplitudes and large ecotypic variation (Jensen et al., 1990; Passey et al., 1982; West, 1988). Third, interactions between plant species or functional groups can mask the relationships among environmental factors and vegetation characteristics. For example, Rittenhouse and Sneva (1976) documented a 1% increase in Wyoming big sagebrush

cover resulted in a production decrease of between 37 and 61 kg/ha in desert wheatgrass (*Agropyron desertorum* (Fisch. ex Link) J.A. Schultes) in southeastern Oregon. Lastly, our study was lacking detailed climate data, which might have improved our ability to predict vegetation characteristics with environmental factors.

Conclusions

This study suggests soil characteristics are important factors driving variation in species composition in the Wyoming big sagebrush alliance and elucidates the complexity of describing relationships between environmental attributes and vegetation cover and structure. We also demonstrated the influence of direct incident radiation on vegetation cover and reaffirmed soil as an important factor influencing variation in vegetation cover in the Wyoming big sagebrush alliance. The influence of direct incident radiation on vegetation characteristics of other sagebrush alliances should be investigated because its correlation with many of the vegetation characteristics in our study suggests direct incident radiation has potential for explaining vegetation variation in other sagebrush alliances. The environmental–vegetation relationships in the Wyoming big sagebrush alliance are complex; however, this study has advanced our understanding of the influence of environmental attributes on vegetation cover and structure. The information provided by this study could be used to develop stronger models by accounting for factors (i.e. detailed climatic data) or interactions not included in this study.

From: Davies, K.W., J.D. Bates and R.F. Miller. 2007. Environmental and vegetation relationships of the *Artemisia tridentata* spp. *wyomingensis* alliance. *Journal of Arid Environments* 70: 478-494.

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Structural and browse attributes of mowed Wyoming big sagebrush

Kirk W. Davies, Jonathan D. Bates, Dustin D. Johnson, Aleta M. Nafus

Summary

Although the stands were recovering, mowing sagebrush reduced sagebrush density and size for at least 6 years post-treatment. Sagebrush leaf tissue concentrations of crude protein were greater and acid detergent fiber concentrations were less in mowed compared to the control treatments. Mowing altered stand structure and nutritional quality of Wyoming big sagebrush communities.

Introduction

Big sagebrush (*Artemisia tridentata* Nutt.) plant communities occupy vast portions of the western United States (Küchler 1970; Miller et al. 1994; West and Young 2000). These communities provide important habitat for wildlife and forage for domestic livestock. However, in some big sagebrush plant communities increased levels of sagebrush cover and density can reduce or eliminate the herbaceous component (West 1983). Mechanical treatment is commonly used to reduce big sagebrush cover and density to increase herbaceous production and habitat diversity (Hedrick et al. 1996; Dahlgren et al. 2006). Advantages of mechanical treatments include the ability to retain shrub and herbaceous components while controlling the size and shape of the treatment (Urness 1979).

The nutritional quality of sagebrush is important for many wildlife species that consume sagebrush. Mechanical treatment may influence leaf nutritional quality by decreasing the age of sagebrush in the stand. Mature sagebrush plants frequently suffer mortality from mechanical treatments while younger, smaller individuals often survive (Wambolt and Payne 1986). Younger plants are generally more nutritious than older individuals (Marschner 1998). Relative leaf nutrition may be especially important to sage-grouse as their winter diets are almost exclusively comprised of sagebrush leaves (Patterson 1952; Wallestad et al. 1975). Other species such as mule deer may be affected as big sagebrush can comprise more than 50% of their diets in January and February (Austin and Urness 1983).

Methods

The study area encompassed 350 000 ha in the High Desert Ecological Province (Anderson et al. 1998) in eastern Oregon. Wyoming big sagebrush was roto-cut at various locations across the study area zero, two, four, and six years prior to sampling. Six sites per post-treatment time interval were randomly selected for sampling. Each mowed treated plot was blocked with an adjacent untreated (control) plot. Each blocked treated and control plot had uniform soil and topography. Mechanical treatments were implemented in September and October with a John Deere 1418 rotary cutter (Deere & Company, Moline, IL, USA). Sagebrush was mowed at 20 cm height above the soil surface. Response variables include Wyoming big sagebrush cover, density, height, canopy elliptical area, canopy volume, and leaf nutritional quality and green rabbitbrush (*Chrysothamnus viscidiflorus* (Hook.) Nutt.) density and cover.

Results

Cover and Density

Sagebrush cover and density in the mowed treatments was less than the controls in every post-treatment time interval ($P < 0.01$, Fig. 1). Recovery of sagebrush cover and density were positively correlated to amount of time since the mowing treatment ($P < 0.01$, Fig. 2). Time since treatment explained 74% of the variation in the recovery of sagebrush cover ($R^2 = 0.74$). Time since treatment explained 42% of the variation recovery in sagebrush density ($R^2 = 0.42$).

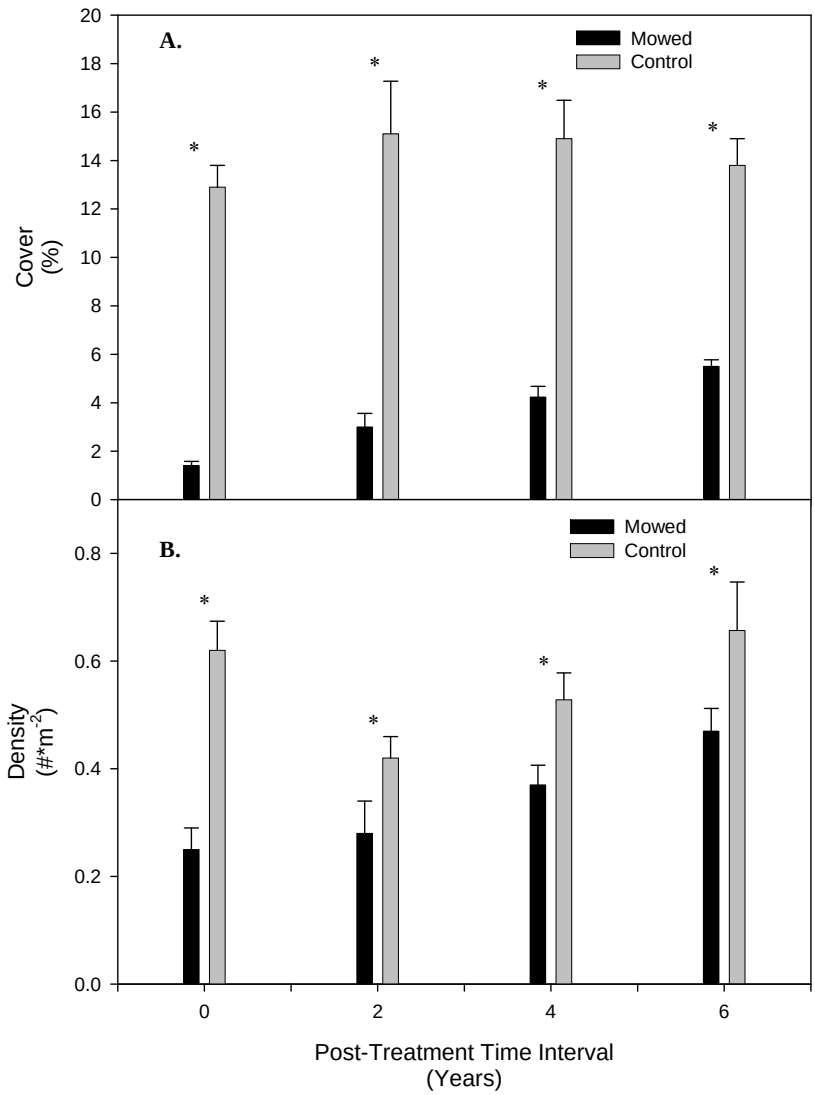

Figure 1. Sagebrush cover (A) and density (B) (mean + SE) in the mowed compared to the control treatment in 0, 2, 4, and 6 years post-treatment in southeastern Oregon in 2007. Asterisks (*) indicate significant difference between means ($P < 0.05$) for each post-treatment time interval.

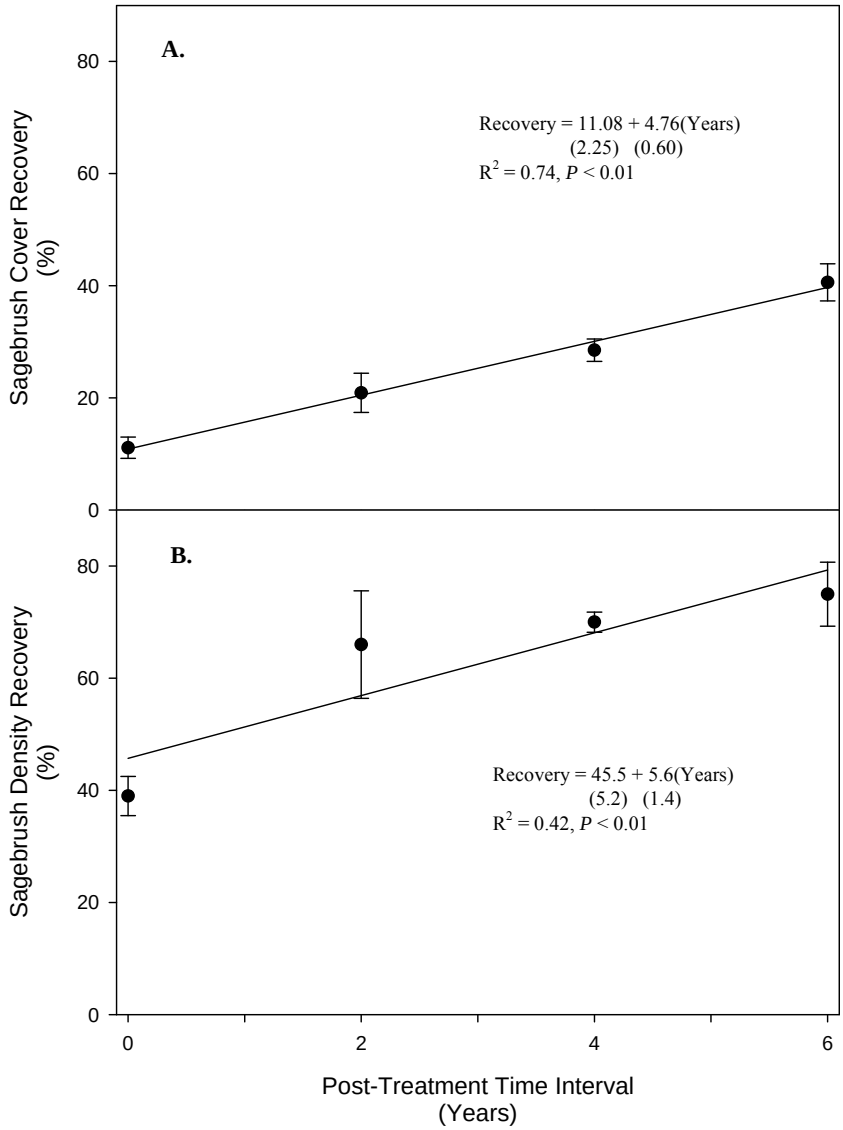

Figure 2. Recovery of sagebrush cover (A) and density (B) (Mean ± SE) in the mowed treatments at 0, 2, 4, and 6 years post-treatment in southeastern Oregon in 2007. Recovery is the percent the treated plots are of the control plots. Recovery regression is based on individual block differences.

Height, Elliptical Area, and Volume

Sagebrush height, elliptical area, and canopy volume were less in the mowed treatment than the control treatment in all the post-treatment time intervals ($P < 0.01$). Sagebrush height, elliptical area, and canopy volume recovery were positively correlated to the length of time since treatment ($P < 0.01$).

CP, ADF, and NDF

Crude protein concentrations in sagebrush leaves were greater in the mowed compared to control treatments in all post-treatment time intervals ($P < 0.05$ except for the winter immediately after treatment ($P = 0.09$). Averaged across the six, four, and two years since treatment, CP was 15.7 ± 0.26% and 14.0 ± 0.13% in the mowed and control treatments, respectively. ADF was less in the mowed treatments in all post-treatment time intervals ($P < 0.05$), except for the winter immediately after treatment ($P < 0.10$). Averaged across the six, four, and two years since treatment, ADF was 21.3 ± 0.22% in the mowed treatment and 22.3 ± 0.17% in the control treatment. NDF did not differ between treatments in any of the post-treatment time intervals ($P > 0.05$).

Discussion

Mowing of Wyoming big sagebrush alters stand structure and browse characteristics for greater than six years post-treatment although the influence does appear to be limited in duration as all structural characteristics measured were recovering. Sagebrush density was almost fully recovered in the mowed treatment after six years; although sagebrush cover was still less than half of the control treatment. Although by the sixth year post-treatment sagebrush height in the mowed treatment was 68% of the control treatment, the overall size of sagebrush individuals was considerably smaller in the mowed compared to the control treatment. Sagebrush canopy volume and elliptical surface area were more negatively affected by mowed than height and subsequently have further to recover.

The majority of sites sampled contained little rabbitbrush so the lack of measured treatment effects on green rabbitbrush density and cover does not necessarily imply that mowing does not have an effect on green rabbitbrush. Although not conclusively tested, these results suggest that if green rabbitbrush is absent prior to roto-cutting that it will not be a significant component of the post-treatment plant community.

Other than the winter immediately after treatment, mowing appears to increase the nutritional value of Wyoming big sagebrush plants. The decrease in ADF with mowing suggests that mowing increased digestibility and energy content (Reid et al. 1988). The increase in CP leaf concentration with mowing was probably caused by a decrease in the age of the Wyoming big sagebrush stand (Wambolt and Payne 1986; Wambolt 2004).

The increase in CP from mowing may or may not be biologically significant. Wambolt (2004) speculated that a difference of 1.2% CP between younger and mature Wyoming big sagebrush leaves was not biologically significant because both exceeded the CP requirements for mule deer maintenance and gestation. However, other than sage-grouse (Patterson 1952; Wallestad et al. 1975) and pygmy rabbits (Green and Flinders 1980; Shipley et al. 2006), most animals' diets are not solely comprised of sagebrush leaves. Biological significance may depend on the amount of sagebrush consumed and the quality of other forage ingested. Furthermore, the combination of a slight increase in CP and decrease in ADF may be biologically significant while individually their responses to mowing may not be.

Greater CP and decreased ADF concentrations in leaf tissues in 2, 4, and 6 years post-treatment apply to perennial sagebrush leaves but not ephemeral leaves because sampling

occurred in the winter (Miller and Schultz 1987). The lack of difference in sagebrush leaf tissue CP and ADF concentrations between treatments in the winter immediately after treatment was the result of sagebrush plants not having an opportunity to respond to the treatment.

Assuming the current rate of recovery sagebrush density and cover will be fully recovered in approximately 9.7 and 18.7 years post-treatment, respectively.

Conclusions

Mowing Wyoming big sagebrush communities can alter wildlife habitat for greater than six years post-treatment. It can be used to increase the diversity of stand structure and improve nutritional quality of sagebrush leaves. Large continuous areas should generally not be mowed because initial reductions in sagebrush could be detrimental to sagebrush obligate and facultative wildlife species. Mowing is probably best suited to applications as small patches or strips to increase stand diversity across a landscape. In areas where an increase in winter Wyoming big sagebrush leaf nutritional quality is a specific management objective, mowing can be an effective management option. Mowing is also an effective tool to reduce Wyoming big sagebrush cover, density, and size and may be especially desirable where long-term reductions in sagebrush are not desired. Impacts of mowing sagebrush on herbaceous vegetation and wildlife habitat across all seasons should also be considered before implementing treatments.

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Comparison of medusahead invaded and non-invaded sagebrush communities

K.W. Davies and T. Svejcar

Summary

Medusahead invaded communities produce only 13% of the native biomass production of the non-invaded plant communities and the negative impact of medusahead on invaded sites has not reached its potential. Cover and density of all native functional groups was lower in medusahead invaded compared to non-invaded sagebrush communities. Medusahead invaded compared to non-invaded sagebrush communities also had less biodiversity. These results demonstrate that medusahead has substantial negative impacts on wildlife habitat, livestock forage, and ecosystem function.

Introduction

Medusahead (*Taeniatherum caput-medusae* (L.) Nevski) is an exotic, annual grass invading sagebrush steppe rangelands in the western United States. Large expanses of sagebrush (*Artemisia* L.) steppe in the Intermountain West have been or are threatened by medusahead invasion. The rapid spread of medusahead is a serious management concern (Dalh and Tisdale 1975; Monaco et al. 2005), especially since most revegetation efforts in the Intermountain West fail (Young 1992; Young et al. 1999).

The invasion of medusahead can reduce grazing capacity by 50 to 80% (Hironaka 1961) and often result in near monocultures of medusahead (George 1992). Medusahead alters the plant communities it invades by competition, suppression, and increasing fire frequency. Davies (2008) reported that large perennial bunchgrass density was negatively correlated to medusahead invasion, but sagebrush, perennial forbs, and annual forbs did not influence the ability of medusahead to invade a sagebrush-bunchgrass community. However, the response of sagebrush and forbs to medusahead invasion is largely unknown. Understanding the influence of medusahead invasion on sagebrush and forbs is important because they are a critical food source for many sagebrush obligate and facultative wildlife species such as sage-grouse (Patterson 1952; Wallestad et al. 1975), pygmy rabbits (Green and Flinders 1980; Shipley et al. 2006), deer (MacCracken and Hansen 1981; Austin and Urness 1983), and elk (MacCracken and Hansen 1981). In addition, plant diversity is important to preventing ecosystem nutrient loss, nutrient cycling, carbon storing, and community productivity (Tilman et al. 1997; Hooper and Vitousek 1998).

Methods

The study was conducted in southeastern Oregon in Wyoming big sagebrush steppe rangeland between Buchanan, Princeton, Juntura, and Burns Junction, OR. The study area encompasses 160,000 ha of the western edge of the Snake River Ecological Province and eastern edge of the High Desert Ecological Province (Anderson et al. 1998). Nineteen blocks consisting of a medusahead invaded and a non-invaded Wyoming big sagebrush community matched by location, topography, soils, and management were selected. Shrub density and canopy cover and herbaceous species canopy cover, density, biomass production (current year biomass), standing

crop biomass (current year + previous year's biomass), richness and vegetation diversity were measured.

Results

Cover, density, species richness and diversity of sagebrush, Sandberg bluegrass, large perennial bunchgrass, native perennial forbs, and annual forbs were dramatically reduced on medusahead invaded communities compared to non-invaded Wyoming big sagebrush communities ($P < 0.01$) (Fig. 1). Bare ground and moss-crust cover were higher in non-invaded compared to medusahead invaded communities but litter was lower ($P < 0.01$). In medusahead invaded sites, medusahead and exotic perennial forb cover and density were greater than non-invaded sagebrush plant communities ($P < 0.01$). Cheatgrass and other shrub cover and density did not differ between invaded and non-invaded plant communities ($P = 0.28$ and 0.30, respectively).

Biomass production by native plant functional groups were greater in non-invaded than invaded plant communities (Fig. 2). Total native herbaceous production and standing crop were 7.8 and 1.6-fold greater, respectively, in the non-invaded compared to the medusahead invaded community ($P < 0.01$). Annual grass production, mainly medusahead, was 42 -fold greater in the invaded compared to the non-invaded plant communities ($P < 0.01$). Total herbaceous production did not differ between plant communities ($P = 0.61$).

Discussion

Medusahead invasion of Wyoming big sagebrush plant communities appears to degrade wildlife habitat, reduce livestock forage, and negatively impact ecosystem function. Based on the results of this study, we also speculate that the negative impact of medusahead on invaded sites has not reached its potential. Medusahead invaded sagebrush steppe produces less desirable habitat for most Intermountain West wildlife species compared to non-invaded sagebrush steppe.

Medusahead invaded communities produce only 13% of the native biomass production of the non-invaded plant communities. The loss of sagebrush with medusahead invasion negatively affects sagebrush obligates (e.g. sage-grouse and pygmy rabbits) and sagebrush facultative wildlife species through loss of food and cover. Medusahead invaded compared to non-invaded plant communities also produce less livestock forage. Because of the low to non-existent value of medusahead as livestock forage (Bovey et al. 1961; George 1992), the low native biomass production in the invaded communities suggests that medusahead invasion can reduce livestock forage by almost 90%.

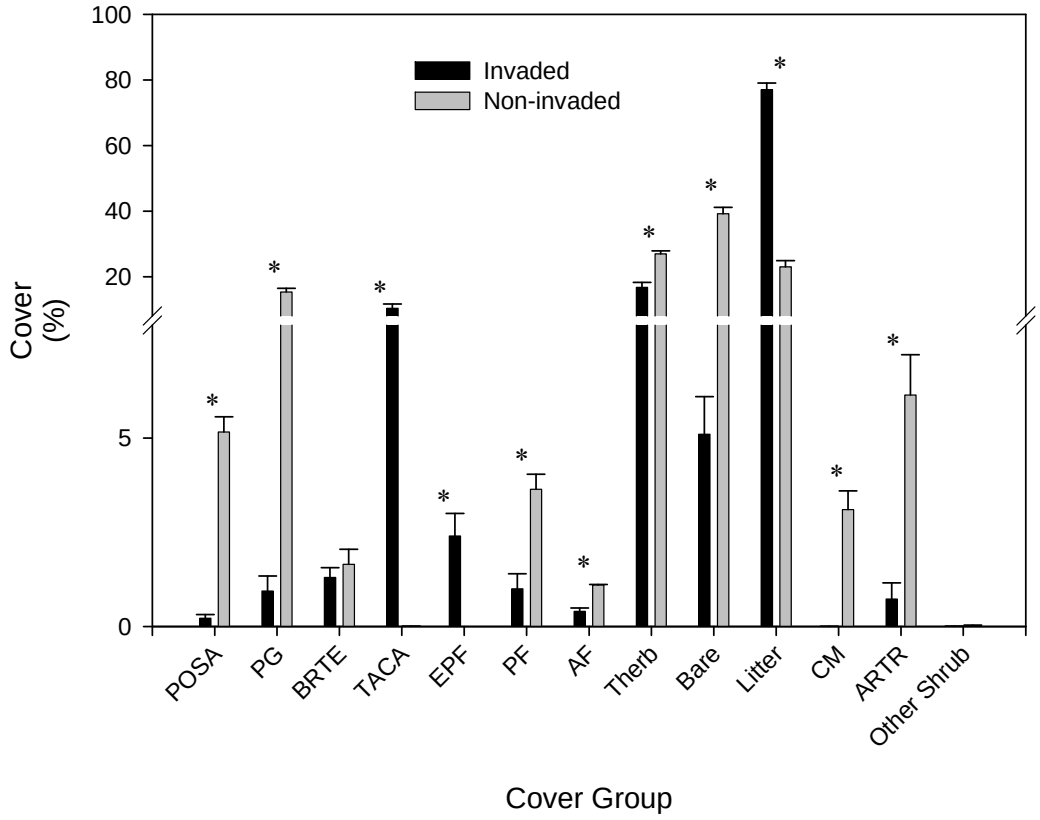

Figure 1. Cover (mean + SE) in medusahead invaded and non-invaded Wyoming big sagebrush plant communities. POSA = Sandberg bluegrass, PG = Large perennial bunchgrass, BRTE = Cheatgrass, TACA = Medusahead, EPF = Exotic perennial forbs, PF = Perennial forbs, AF = Annual forbs, Therb = Total herbaceous, Bare = bare ground, Litter = Litter, CM = Crust and moss, ARTR = Wyoming big sagebrush, and Other shrub = Other shrub. Asterisk (*) indicates a significant difference ($P \leq 0.05$) in cover for that attribute between medusahead invaded and non-invaded plant communities.

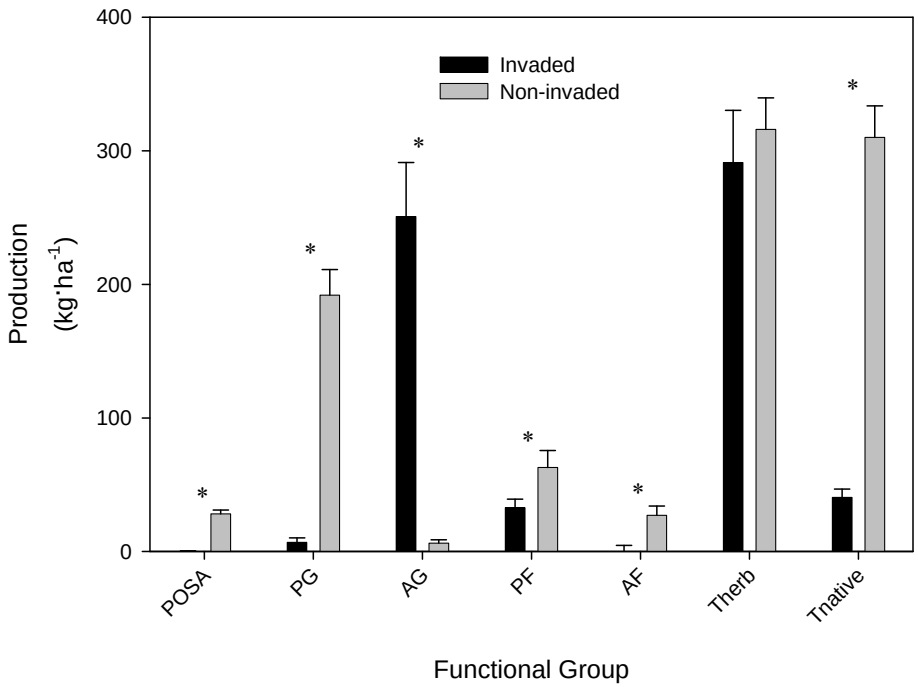

Figure 2. Functional group biomass production (mean + SE) in medusahead invaded and non-invaded Wyoming big sagebrush plant communities. POSA = Sandberg bluegrass, PG = Large perennial bunchgrass, PF = Perennial forbs, AG = Exotic annual grass (mainly composed of medusahead), AF = Annual forbs, Therb = Total herbaceous, and Tnative = total native herbaceous. Asterisk (*) indicates a significant difference ($P \leq 0.05$) in production for that functional group between medusahead invaded and non-invaded plant communities.

In addition to reducing vital habitat for wildlife and livestock, reduced diversity can result in ecosystem nutrient loss, altered nutrient cycling, long-term decreases in carbon stores, and decreased productivity (Tilman et al. 1997; Hooper and Vitousek 1998). The loss of diversity also decreases the probability of being able to fully restore medusahead infested plant communities. Because commercial seed sources do not exist for many native forbs that are lost with medusahead invasion, restoration efforts would have to depend on natural dispersal or expensive hand collected seeds. Neither option may be a reasonable method to restore large infestations either because of low probability of success and/or high expense.

The negative impact of medusahead invasion on native vegetation may continue to increase in severity even at sites that are near-monocultures of medusahead. The high litter cover on the medusahead invaded communities suggests invasion has increased the fine fuel loads and continuity, which would increase fire frequencies and further negatively impact remaining native vegetation. Suppression by medusahead litter (Bovey et al. 1961; Harris 1965) and medusahead's highly competitive nature (Hironaka and Sindelar 1975; Goebel et al. 1988; George 1992) may also lead to further reductions in native plant cover, density, and biomass production and diversity.

Conclusions

Medusahead invasion appears to greatly reduce wildlife habitat, livestock forage, and diversity. The potential of medusahead to escalate the plight of sagebrush obligate wildlife species by degrading their habitat is a serious concern for rangeland and wildlife managers. Comparing the habitat needs of sage-grouse to the vegetation characteristics of medusahead invaded sagebrush communities demonstrates that each hectare invaded by medusahead is a hectare of habitat lost. Lower diversity on medusahead invaded plants communities is also a very serious concern because of its potential influence on ecosystem functions. The broad negative effects of medusahead invasion suggest that there are substantial benefits to preventing and revegetating medusahead invasions. However, revegetation of medusahead infestations is rarely successful in the Intermountain West (Young 1992; Young et al. 1999), thus current management should focus on containment, prevention, and control of infestations where revegetation will not be required. More resources need to be directed to protecting sagebrush steppe from medusahead invasion.

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Medusahead dispersal and establishment in Wyoming big sagebrush communities

K.W. Davies

Summary

Medusahead is an invasive annual grass that reduces biodiversity and production of rangelands. To prevent medusahead invasion land managers need to know more about its invasion process. Specifically, 1) the timing and spatial extent of medusahead seed dispersal and 2) the establishment rates and interactions with plant communities being invaded. Medusahead seeds dispersed between July and October and did not disperse more than 2 m from their source, without human or animal transport, suggesting relatively narrow containment barriers around medusahead infestations may be sufficient to significantly slow spread. The ability of medusahead to establish in a plant community was negatively correlated to large perennial grass density. Thus, maintaining large perennial grass is critical to preventing medusahead invasion and increasing large perennial grass density should reduce the susceptibility of a site to medusahead invasion.

Introduction

Medusahead (*Taeniatherum caput-medusae* (L.) Nevski) is an exotic annual grass invading rangelands in the western United States (Young 1992). Its rapid spread into previously uninfested areas is a serious management concern (Dalh and Tisdale 1975; Monaco et al. 2005) as medusahead invasion has reduced the grazing capacity of rangelands by as much as 80% (Hironaka 1961). Medusahead litter also has a slow decomposition rate allowing it to build up over time and suppress native plants (Bovey et al. 1961). The accumulation of medusahead litter also increases the amount and continuity of fine fuel, thus increasing fire frequency to the detriment of native vegetation (Torell et al. 1961; Young 1992). The result is often a loss of native species and dense monocultures of medusahead (George 1992). To prevent medusahead invasion land managers need to know more about its invasion process. Specifically, 1) the timing and spatial extent of medusahead seed dispersal and 2) the establishment rates and interactions with plant communities being invaded.

Methods

The study was conducted in the northwest foothills of Steens Mountain in southeast Oregon. Medusahead dispersal was measured using sticky seed traps placed along 23 transects at 0, 0.5, 1, 2, 3, 4, 5, 10, 15, 20, 25, 30, and 35 m distances from the medusahead invasion front. Seeds captured on the traps were counted and removed every week. Sticky trap transects were established on 1 June 2006 and maintained until 30 November 2006. Medusahead density was measured on transects placed perpendicular to, and centered upon, the seed-trap transects. Medusahead establishment was evaluated by broadcast seeding medusahead at 1, 10, 100, 1000, and 10 000 seeds·m^{-2} on 12 sites.

The timing and distance medusahead seeds dispersed from invasion fronts were measured using seed traps along 23, 35-m transects. Medusahead establishment was evaluated by introducing medusahead at 1, 10, 100, 1000, and 10 000 seeds·m^{-2} at 12 sites. Herbaceous cover

and density by species and sagebrush cover and density were measured over the areas seeded with medusahead.

Results

Most medusahead seeds (449 ± 90 seed·m^{-2}) dispersed less than 0.5 m from the invasion front ($P < 0.01$) (Fig 1). From 0.5 to 2 m distances from the invasion front medusahead seed dispersal decreased from 148 ± 42 seed·m^{-2} to 11 ± 6.3 seed·m^{-2}, respectively and none were captured beyond 2 m. Medusahead seeds dispersed from the parent plants from early July (2.3 ± 0.6 seed·transect^{-1}) to the end of October (2.3 ± 0.8 seed·transect^{-1}). More seeds were trapped in August than the other months (20 ± 4.9 seed·transect^{-1}) ($P < 0.01$).

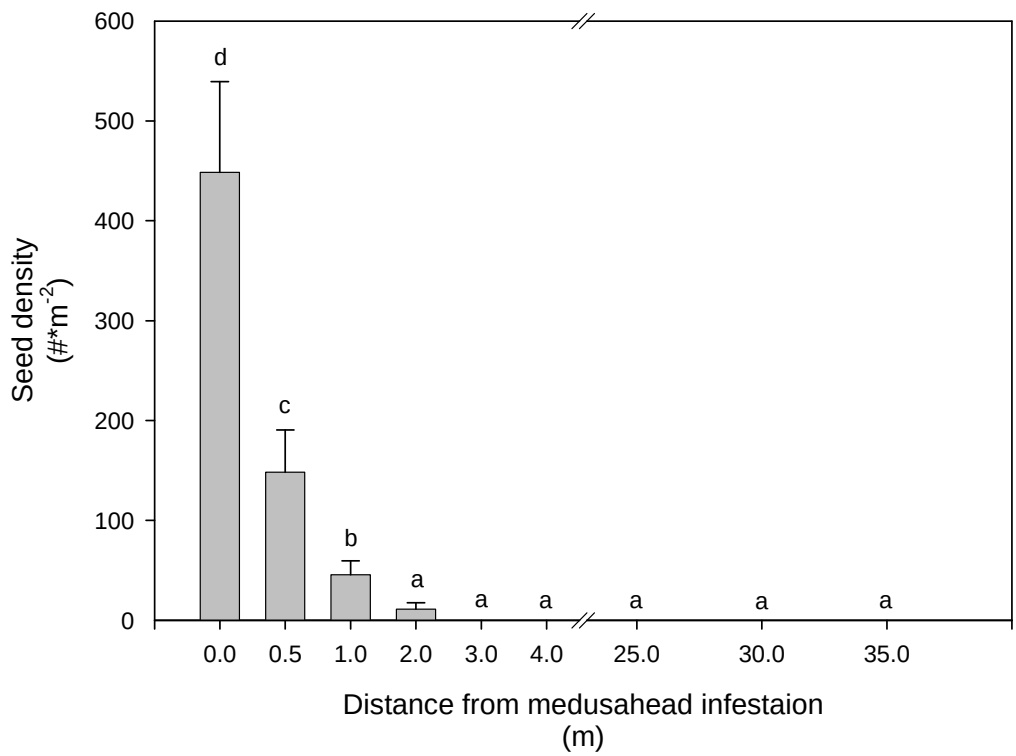

Figure 1. Medusahead seed density (mean + S.E.) trapped at different distances from the medusahead invasion summed across sampling dates. Different lower case letters indicate differences among distances ($P < 0.05$).

Medusahead establishment increased with higher seed introduction rates ($P < 0.01$). Medusahead density was negatively correlated to tall tussock perennial grass density and positively correlated to annual grass density of the preexisting plant communities ($P = 0.02$, Fig. 2). These correlations explain 82% of the variation in medusahead density ($R^2 = 0.82$, $P < 0.01$). Medusahead density was not correlated to density or cover of Sandberg bluegrass and forb functional groups, or to bare ground and litter values ($P > 0.05$). Medusahead cover was also negatively correlated with tall tussock perennial grass density ($R^2 = 0.44$, $P = 0.03$).

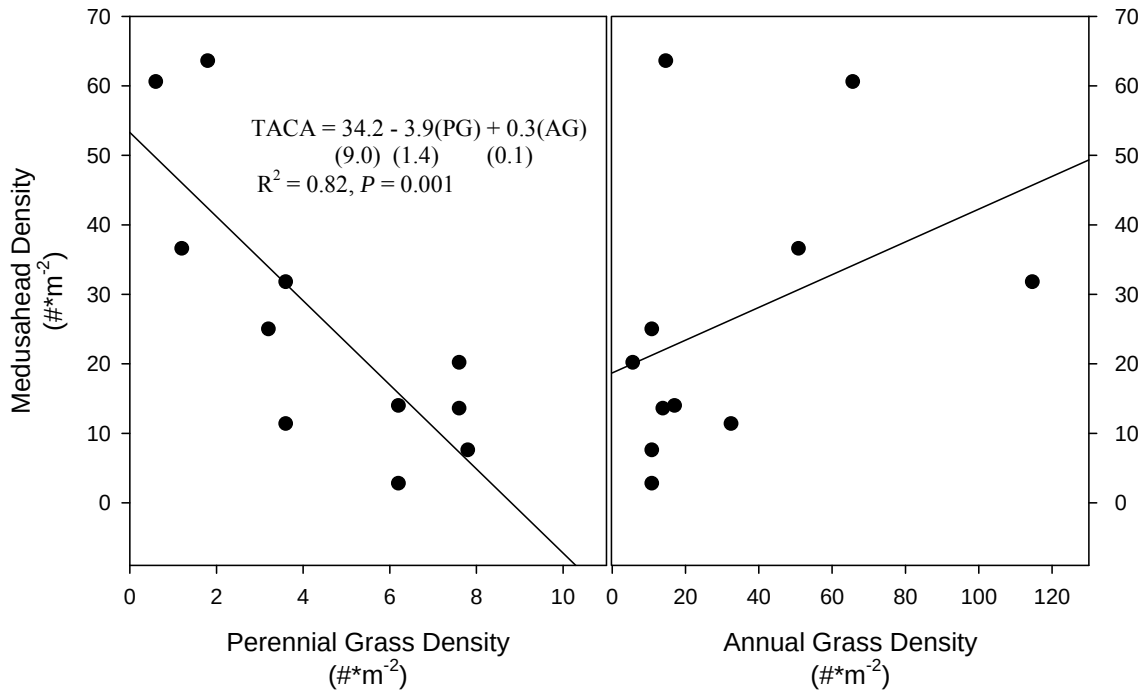

Figure 2. Scatter plot of medusahead density across tall tussock perennial grass and annual grass densities of the preexisting plant community with regression lines. TACA8 = medusahead, PG = tall tussock perennial grass, and AG = annual grass.

Discussion

Understanding the dispersal of an invasive species is critical to limiting its spatial expansion (Davies and Sheley 2007). Medusahead seeds are well adapted for dispersal by adhesion to moving objects (Monaco et al. 2005). In the absence of vehicle and large animal traffic, medusahead seeds disperse relatively short distances. This suggests that narrow (~3 m) containment zones around medusahead infestations would successfully suppress invasion into surrounding plant communities. The relatively long period of medusahead seed dispersal from July to October may be an adaptation to increase the likelihood of adhesion to animals. This long period of disarticulation has not been previously reported and has significant impacts to management of plant communities with patch invasions of medusahead. Livestock, humans, and vehicles should probably be prevented from traversing medusahead infestations during the months medusahead seeds disarticulate to limit dispersal of medusahead seeds.

Establishment rate of medusahead increased with seeding rate suggesting that as the medusahead invasion progresses (i.e. more individuals and seeds per unit area) the percent of seeds establishing increases. The increasing establishment rate of medusahead with increased propagule pressure (introduction rate) suggests that biotic factors are limiting invasion. The negative correlation of medusahead cover and density with tall tussock perennial grass density also supports the conclusions of Dahl and Tisdale (1975) who speculated that tall tussock

perennial grass was the best barrier to medusahead invasion. This suggests maintaining tall tussock perennial grass is critical to preventing medusahead invasion and increasing tall tussock perennial grass density would reduce the susceptibility of a site to medusahead invasion. The lack of correlation between Sandberg bluegrass and medusahead establishment suggests that Sandberg bluegrass does not compete very effectively with medusahead. The positive correlation between medusahead density and annual grass density of the preexisting plant community also supports the conclusion of Dahl and Tisdale (1975) that medusahead appears to invade areas previously dominated by annuals.

Conclusions

Livestock and vehicle traffic should probably be removed from medusahead infested sagebrush steppe rangelands during the period of seed disarticulation to reduce the dispersal of medusahead seeds. Site differences and inter-annual variability in precipitation can be expected to influence medusahead seed development and disarticulation and thus, when livestock and vehicles should be excluded from infestations may vary from year to year and site to site. Containment zones around infestations can probably be relatively narrow; however, correctly identifying the edge of the infestation is critical. Many medusahead infestations have a diffuse boundary that requires careful scrutiny to identify. Systematic searching for and eradication of new satellite populations will still be necessary to successfully contain medusahead infestations. More research is needed to quantify the dispersal of medusahead by vehicles and animals, especially when soils are adhesive due to moisture accumulation. Tall tussock perennial grasses appear to be a critical component of sagebrush rangelands that are resistant to medusahead invasion. Promoting and maintaining tall tussock perennial grass should be a management priority on rangelands susceptible to medusahead invasion. Perennial grass and annual grass density may be useful indicators of sites susceptible to medusahead invasion.

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Other Sagebrush Steppe Research Projects:

Response of herbaceous vegetation to mowing of Wyoming big sagebrush
K.W. Davies
This study is evaluating if mowing Wyoming big sagebrush increases herbaceous vegetation cover, density, and production. Of particular interest is how plant species important in sage-grouse diets are influenced by mowing sagebrush.

Comparing the herbaceous and insect response to mowing and burning of mountain big sagebrush
K.W. Davies & J.D. Bates
Mountain big sagebrush plant communities with greater than 30% cover were either mowed or fall prescribed burned in 2007. The purpose of this study is to determine the impacts of these treatments on herbaceous vegetation and insects that are important to sage-grouse. This study will also compare the impacts of the treatments on long-term recovery of sagebrush and livestock forage production.

Fire associated mortality of perennial grasses influence on site recovery
K.W. Davies, J.J. James, & E. Vasquez
This study is evaluating the ability of sagebrush-bunchgrass communities to recover after fire at varying mortality rates of perennial grasses.

Influence of long-term livestock grazing exclusion on the response of sagebrush steppe plant communities to fire
K.W. Davies, T. Svejcar, & J.D. Bates
Livestock grazing of sagebrush steppe plant communities has been considered to have negative impacts because these communities did not evolve with large herbivores. However, research has found relatively few differences between ungrazed and moderate to light grazing sagebrush steppe communities. This study is comparing the plant community response to fire between long-term (70 years) grazing excluded and moderately grazed sagebrush steppe.

Comparison of vegetation characteristics between Wyoming and mountain big sagebrush plant communities
K.W. Davies & J.D. Bates
Little data exists comparing the vegetation characteristics between Wyoming and mountain big sagebrush communities. Especially lacking is a comparison of their value as habitat. This study is comparing vegetation cover, density, diversity, and production in Wyoming and mountain big sagebrush plant communities across southeastern Oregon.

Long-term vegetation dynamics in Wyoming big sagebrush plant communities
J.D. Bates & K.W. Davies
This study is evaluating the fluctuation of vegetation characteristics in Wyoming big sagebrush plant communities over a 10+ year period. The objective is to correlate variation in plant functional groups cover, density, and production with interannual variation in climatic conditions.

Impacts of feral (wild) horses on riparian and adjacent sagebrush steppe uplands
K.W. Davies & C.S. Boyd
The impacts of wildhorses on plant communities are relatively unknown because their impacts can rarely be differentiated from domestic livestock use. This study will evaluate the impacts of wildhorses by erecting six riparian and upland exclosures in a 500,000 acre area without domestic livestock use.

Medusahead control with burning and Plateau® application in sagebrush steppe
K.W. Davies & R.L. Sheley
Medusahead infestations were treated with spring burning, fall burning, Plateau® application, spring burning with Plateau® application, and fall burning with Plateau® application. The control of medusahead and the response of desirable plants are being evaluated among treatments.

Reoccupying medusahead infested sagebrush steppe
K.W. Davies, D.D. Johnson, & A.M. Nafus
This study will determine the density of perennial bunchgrasses require to successfully occupy previously medusahead infested sagebrush steppe plant communities. This study will also compare whether crested wheatgrass or bluebunch wheatgrass plants are more effective at preventing the re-invasion of medusahead.

Preventing medusahead seed dispersal with crested wheatgrass
K.W. Davies
The purpose of this study is to determine if crested wheatgrass can prevent the spatial dispersal of medusahead seeds. This study will also evaluate the impacts of different defoliation heights on crested wheatgrass' ability to limit dispersal.

Revegetation success with wildfire and seeding in medusahead dominated sagebrush steppe
K.W. Davies
In 2007, vegetation characteristics were measure on 19 medusahead dominated sites. Later that year wildfires burned six of those sites. Those sites were seeded with a rangeland drill in the fall of 2007. The purpose of this study is to compare the burned and seeded sites with the untreated sites to determine if wildfire followed by seeding is a viable management option for restoring medusahead invaded sites.

Increase fire frequency with and without grazing affects on productivity and diversity of sagebrush steppe
J.D. Bates, K.W. Davies, & C.S. Boyd
This study will evaluate the impact of increased fire frequency with and without livestock use influence on sagebrush steppe vegetation characteristics.