Postfire Succession in Big Sagebrush Steppe With Livestock Grazing

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Abstract

Prescribed fire in rangeland ecosystems is applied for a variety of management objectives, including enhancing productivity of forage species for domestic livestock. In the big sagebrush (*Artemisia tridentata* Nutt.) steppe of the western United States, fire has been a natural and prescribed disturbance, temporarily shifting vegetation from shrub–grass codominance to grass dominance. There is limited information on the impacts of grazing to community dynamics following fire in big sagebrush steppe. This study evaluated cattle grazing impacts over four growing seasons after prescribed fire on Wyoming big sagebrush (*Artemisia tridentata* subsp. *Wyomingensis* [Beetle & Young] Welsh) steppe in eastern Oregon. Treatments included no grazing on burned and unburned sagebrush steppe, two summer-grazing applications after fire, and two spring-grazing applications after fire. Treatment plots were burned in fall 2002. Grazing trials were applied from 2003 to 2005. Vegetation dynamics in the treatments were evaluated by quantifying herbaceous canopy cover, density, annual yield, and perennial grass seed yield. Seed production was greater in the ungrazed burn treatments than in all burn–grazed treatments; however, these differences did not affect community recovery after fire. Other herbaceous response variables (cover, density, composition, and annual yield), bare ground, and soil surface litter did not differ among grazed and ungrazed burn treatments. All burn treatments (grazed and ungrazed) had greater herbaceous cover, herbaceous standing crop, herbaceous annual yield, and grass seed production than the unburned treatment by the second or third year after fire. The results demonstrated that properly applied livestock grazing after low-severity, prescribed fire will not hinder the recovery of herbaceous plant communities in Wyoming big sagebrush steppe.

Resumen

El fuego prescrito en los ecosistemas de pastizales se aplica para una variedad de objetivos de manejo que incluyen mejorar la productividad de especies de forraje para el ganado doméstico. En un estepa de artemisa (*Artemisia tridentaza* Nutt.) del oeste de los Estados Unidos, el fuego ha sido un disturbio natural y preescrito temporalmente intercambiando la vegetación de una codominancia de arbusto-grama a una dominancia de grama. Hay información limitada sobre los impactos del pastoreo en las dinámicas de la comunidad posterior al fuego en una estepa de artemisa. Este estudio evaluó los impactos del pastoreo de ganado por sobre cuatro temporadas de crecimiento después un fuego prescrito en una estepa de artemisa tridentata de Wyoming (*Artemisia tridentaza* subsp. *Wyomingensis* [Beetle & Young] Welsh) en el este de Oregón. Los tratamientos incluyeron: no pastoreo en estepa de artemisa quemada y no quemada, dos aplicaciones de pastoreo en el verano luego del fuego y dos aplicaciones de pastoreo en la primavera luego del fuego. Las parcelas de tratamientos fueron quemadas en el otoño del 2002. Los transectos de pastoreo se aplicaron a partir de 2003–2005. La dinámica de la vegetación en los tratamientos fue evaluada mediante la cuantificación de la cubierta del dosel herbáceo, densidad, rendimiento anual, y el rendimiento de semillas de gramas perennes. La producción de semillas fue mayor en el tratamiento quemado sin pastoreo que en todos los tratamientos quemados con pastoreo; sin embargo, estas diferencias no afectaron la recuperación de la comunidad después del fuego. Otras respuestas variables de las herbáceas (cubierta, densidad, composición, y rendimiento anual), suelo desnudo y la materia orgánica en la superficie del suelo no difieren entre los tratamientos quemados pastados y no pastados. Todos los tratamientos quemados (pastado y no pastado) tuvieron mayor cobertura de herbáceas, cultivo de herbáceas permanente, rendimiento anual de herbáceas y producción de semillas de grama que el tratamiento no quemado por segundo ó tercer año después del fuego. Los resultados demuestran que el pastoreo de ganado propiamente aplicado después de un fuego prescrito de baja intensidad no debe entorpecer con la recuperación de las comunidades de herbáceas en la estepa de artemisa tridentata de Wyoming.

Key Words: bunchgrass, Idaho fescue, prescribed burning, secondary succession, Thurber's needlegrass, utilization, Wyoming big sagebrush

INTRODUCTION

Prescribed fire in rangeland ecosystems is a practical management tool for reducing the abundance of woody plants, preventing conifer encroachment, enhancing biodiversity, and increasing yield and abundance of herbaceous species (Holechek et al. 2004). Grazing by wild and domestic ungulates after fire has been evaluated in many of the world's rangelands. In shrub and grassland systems that evolved with fire and ungulate

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grazing, the combination of these two disturbances was important for generating a mosaic of successional communities supporting a wider array of species (Engle and Bidwell 2001; Fulendorf and Engle 2004). The combined impacts of fire and grazing on rangelands without a long history of domestic ungulate use as found in the Intermountain Region of the western United States (Mack and Thompson 1982) and Australia (Griffin and Friedel 1985) have received limited attention. Determining the effects of postfire grazing is important for developing strategies to successfully restore or rehabilitate Intermountain plant communities.

Big sagebrush (*Artemisia tridentata* Nutt.) steppe is one of the major vegetation types of the Intermountain Region (West and Young 2000). Fire has been a natural and prescribed disturbance of big sagebrush communities that temporarily shifts vegetation from shrub–grass codominance to grass dominance (Wright and Bailey 1982). There has been large volume of research documenting the effects of wildfire and prescribed burning on big sagebrush communities and their subsequent recovery (Blaisdell 1953; Wright and Klemmedson 1965; Harniss and Murray 1973; Humphrey 1984; Bunting et al. 1987; Wambolt et al. 2001; West and Yorks 2002; Davies et al. 2007). After fire, it has been recommended that sagebrush steppe receive a period of grazing rest to foster recovery of herbaceous vegetation, permit seeded species to establish undisturbed, and allow surface litter to accumulate to stabilize soil surfaces (Wright et al. 1979; Bureau of Land Management 2007). A typical management policy adopted on publicly administered rangelands of the Intermountain Region is that following prescribed burning or wildfire, rangelands are rested from livestock grazing for a minimum of 2 yr. Defoliation studies of individual species' response to fire suggested that this is a prudent management course of action. Native bunchgrasses can be detrimentally affected by early growing season defoliation (Blaisdell and Pechanec 1949; Ganskopp 1988), and yield, density, and cover are typically reduced the first year after fire (Wright and Klemmedson 1965; Uresk et al. 1976, 1980; Wright et al. 1979; Britton et al. 1990). Heavy defoliation during spring growth the first year postfire has reduced bunchgrass recovery and caused high mortality of bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] A. Löve) and Idaho fescue (*Festuca idahoensis* Elmer; Bunting et al. 1998). However, late-season defoliation when plants had stopped growth did not affect subsequent year's yield of Idaho fescue, bluebunch wheatgrass, or squirreltail (*Elymus elymoides* [Raf.] Swezey; Jirik and Bunting 1994; Bunting et al. 1998). At plant community scales, Pickford (1932) measured lower perennial grass densities and higher weed cover in burned–grazed big sagebrush steppe compared with burned–ungrazed and unburned sites. West and Yorks (2002) reported less perennial grass cover in grazed vs. ungrazed areas 18 yr after fire on big sagebrush steppe in Utah. Bruce et al. (2007) determined there were no differences in herbaceous recovery between moderately grazed and ungrazed pastures the second and third summer after wildfire in Nevada. The results from postfire defoliation and grazing studies suggest that timing, use, and duration of grazing of burned rangelands are more important than a specific period of rest after fire.

In 2001, we developed a study to evaluate postfire herbaceous recovery of sagebrush steppe in eastern Oregon, as influenced by season of grazing. Four moderate-grazing treatments after fire were compared with burned and unburned treatments in Wyoming big sagebrush (*Artemisia tridentata* subsp. *wyomingensis* [Beetle & Young] Welsh) steppe. Grazing treatments comprised two summer and two spring scenarios. We hypothesized postfire rest interval and season of use would influence recovery of herbaceous vegetation. Specifically, we expected that 1) grazing in the spring during the second year after fire (1 yr of rest) would reduce herbaceous recovery compared with other grazed and no-graze burn treatments, 2) summer-grazing treatments and spring-grazing (with 2 yr of postfire rest) would have similar herbaceous recovery compared with the no-graze burn treatment, and 3) herbaceous cover, density, and production in the summer-grazing treatments, spring-grazing (with 2 yr postfire rest) treatment, and the no-graze burn treatment would exceed the unburned treatment within 3 yr following fire.

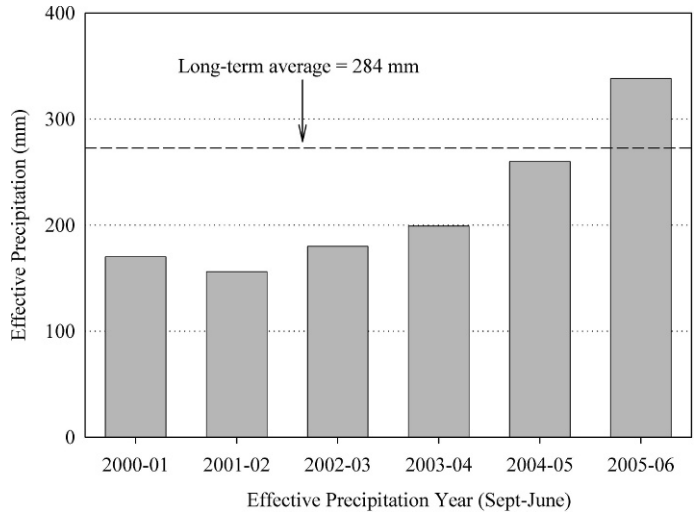

Figure 1. Crop-year precipitation (September to June) at the Northern Great Basin Experimental Range, Oregon.

METHODS

Study Area

The study was conducted at the Northern Great Basin Experimental Range (lat 43°29′N, long 119°43′W), 56 km west of Burns, Oregon. Elevation at the site is 1 400 m, and slope was less than 2%. Crop year (October to September) precipitation has averaged 284 mm since the 1930s (Fig. 1). The majority of annual precipitation falls between November and late May. The first 4 yr of the study precipitation was below average; in the final 2 yr of the study, precipitation was above average. Soils are a complex of four series, sharing several attributes; all are Durixerolls, soil surface texture is sandy loam to loamy sand, and soils are well drained, with a duripan beginning at depths between 40 cm and 75 cm (Lentz and Simonson 1986).

Wyoming big sagebrush was the dominant shrub, with canopy cover averaging $11.7 \pm 0.6\%$ (range, 9.8–27.0%). Green rabbitbrush (*Chrysothamnus viscidiflorus* [Hook.] Nutt.) was a secondary shrub, with cover averaging

Table 1. Stocking rates and grazing use by cattle in the various burn–grazing treatments in Wyoming big sagebrush steppe, 2003–2005, at the Northern Great Basin Experimental Range, Oregon.[1,2]

Treatment/year	No. livestock · plot^{-1}	Grazed (d)	Stocking rate (acres · AUM^{-1})	Available forage (kg · ha^{-1})	Remaining forage (kg · ha^{-1})	Measured use (%)
Summer 1						
2003	2–4 dry cows	4.9 ± 0.1	6.6–14.4	180 ± 21	87 ± 9	51.2
2004	4–6 dry cows	4.9 ± 0.1	4.7–6.3	291 ± 18	138 ± 18	53.2
Summer 2						
2004	3–8 dry cows	5.0 ± 0.2	3.2–8.2	358 ± 51	169 ± 25	52.0
2005	5–7 dry cows	9.6 ± 0.2	2.1–2.9	640 ± 37	294 ± 10	53.8
Spring 1						
2004	3–5 cow–calf pairs	6.4 ± 0.1	4.5–7.7	325 ± 29	130 ± 13	58.2
2005	3–6 cow–calf pairs	7.9 ± 0.1	2.8–5.4	422 ± 76	295 ± 25	22.8
Spring 2						
2005	5–7 cow–calf pairs	8.1 ± 0.2	2.3–3.7	596 ± 46	420 ± 33	27.7

[1]AUM indicates animal unit months.
[2]Values are mean ± SE.

3.3 ± 0.4%. The understory was codominated by Idaho fescue and Thurber's needlegrass (*Achnatherum thurberianum* [Piper] Barkworth). Sandberg's bluegrass (*Poa secunda* J. Presl.), bluebunch wheatgrass, prairie Junegrass (*Koeleria macrantha* [Ledeb.] J.A. Schultes), and bottlebrush squirreltail were subordinate grasses. Sandberg's bluegrass was the most common grass species (e.g., density), but because of its small stature comprised a small portion of total standing crop (Davies et al. 2007). All species at the study site are cool-season species.

Experimental Design and Burn Application

The effects of cattle grazing to postfire recovery of herbaceous vegetation were evaluated during four growing seasons. Five 12.6-ha blocks were established in 2001. Blocking was done to remove differences associated with soils described for the site and to increase precision of the results. Within each block, six 2.1-ha treatment plots were randomly assigned to the treatments. All treatments were replicated five times. The treatments were 1) Summer 1, grazed the first 2 yr after fire in early August 2003 and 2004; 2) Summer 2, grazed the second and third summer after fire in August 2004 and 2005; 3) Spring 1, grazed the second and third spring after fire in May 2004 and 2005; 4) Spring 2, grazed the third spring after fire in May 2005, which is equivalent to many current postfire grazing programs; 5) Burn, no grazing after fire; and 6) Unburned, not burned or grazed.

Prescribed burning was completed during a period of 10 d in late September and early October 2002. The prescribed burn was applied as a strip-head fire. A gel-fuel terra torch (Firecon, Inc., Ontario, OR) served as the ignition source. The fires were complete across burn plots, killing about 90% of the Wyoming sagebrush present. Wind speeds varied between 5 km · h^{-1} and 20 km · h^{-1}, air temperatures were 20–25°C, and relative humidities varied between 10–25% during burning. Moisture content of fine fuels (bunchgrasses) was between 8% and 12%, and fine fuel loads varied from 350 kg · ha^{-1} to 420 kg · ha^{-1}.

Grazing, Stocking Rates, and Use

The summer-grazing treatments occurred in early August, when herbaceous plants were largely dormant or had completed their growth cycle. The spring-grazing treatments occurred in early to mid May during vegetative and early boot stages of primary grass species (Idaho fescue and Thurber's needlegrass). No grazing was applied in 2006 because this was the main response year we used to compare herbaceous recovery among the treatments. Grazing the first spring after fire was not applied because 1) available forage was low in early May 2003 ($<$ 20 kg · ha^{-1}) as a result of drought and removal of standing crop by the 2002 burn, and 2) Bunting et al. (1998) indicated that high mortality would occur to Idaho fescue and bluebunch wheatgrass, when plants were defoliated the first spring after fire.

Treatment plots were individually fenced to control livestock. 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 big sagebrush steppe (Holechek et al. 2004). Stocking rate and grazing duration was based on available forage, calculated by clipping standing crop (perennial grasses and forbs) in 15 randomly located 1-m^2 frames before cattle turnout. Use was determined immediately after cattle were removed by harvesting standing crop in 15 randomly located 1-m^2 frames in each plot (Society for Range Management 1962). Grazing periods were of short duration because of the small plot size. Stocking rates varied and were adjusted so that plots were grazed approximately the same number of days for each grazing cycle (Table 1).

Vegetation Measurements

Vegetation responses to treatments were evaluated by quantifying herbaceous canopy cover, density, and species count; clipping for standing crop and herbage yield; and measuring perennial grass seed production. Except for seed production all vegetation sampling took place in mid-June of each year after completion of growth by herbaceous plants. Two years of

pretreatment vegetation measurements (2001, 2002) and 4 yr of postfire (2003–2006) vegetation measurements were gathered. Six permanent 50-m transects were randomly placed within each treatment plot in 2001. Transects were marked using rebar stakes. Shrub canopy cover by species was measured by line intercept (Canfield 1941) along each 50-m transect. Canopy gaps less than 15 cm were included in the canopy cover measurements (Boyd et al. 2007). Herbaceous canopy cover, bare ground/rock, surface soil litter (litter directly contacting ground surface), and herbaceous perennial densities were estimated inside 40 × 50 cm frames (0.2 m^2) at 3-m intervals on each transect line (starting at 3 m and ending at 45 m). A species list was compiled for each treatment.

Standing crop biomass was determined by herbaceous functional group in mid June 2001–2006 by clipping 15 1-m^2 frames · treatment $plot^{-1}$. Functional groups were Sandberg's bluegrass, deep-rooted perennial bunchgrasses (e.g., Idaho fescue, Thurber's needlegrass, and bluebunch wheatgrass), cheatgrass (*Bromus tectorum* L.), perennial forbs, and annual forbs. Perennial bunchgrasses were clipped to a 2-cm stubble. Sandberg's bluegrass and other functional groups were clipped to ground level. Harvested herbage was dried at 48°C for 48 h before weighing.

In 2005 and 2006, annual herbaceous yield (or current year's growth) was determined by separating current year's growth from collected standing crop (see above) for Sandberg's bluegrass and perennial bunchgrasses. Standing crop biomass comprises current year's growth and residual biomass remaining from previous years' growth. Six 10–15-g subsamples of Sandberg's bluegrass and perennial bunchgrasses per treatment replication were separated into current year's growth (annual yield) and residual (previous years' growth). The percentage of current year's growth was then calculated by dividing current year's growth by standing crop. Standing crop values of Sandberg's bluegrass and deep rooted perennial bunchgrasses were multiplied by the respective percentages of current year's growth to derive annual yield of these two functional groups. Standing crop of perennial forbs, annual forbs, and cheatgrass were equivalent to annual yield and required no separations.

Seed yields were measured for Idaho fescue, Thurber's needlegrass, prairie Junegrass, bluebunch wheatgrass, and bottlebrush squirreltail. Ripe seed was collected by species inside five 9-m^2 (3 × 3 m) frames per plot, from early June to late July in 2004 and 2005. Seed was hand-stripped into paper sacks. Seed purity was determined by separating pure seed and inert matter. Seed viability was tested by tetrazolium method at the Oregon State University Seed Laboratory.

Statistical Analysis and Data Presentation

Repeated measures using the PROC MIXED procedure (SAS Institute 2003) for a randomized complete-block design was used to test for year, treatment, and year-by-treatment effects for herbaceous response variables. Response variables in all analyses were standing crop (total herbaceous), herbaceous annual yield (functional group and total), seed production (species and total), cover (species and functional group, bare ground, and surface soil litter), and density (species and functional group). An autoregressive, first-order covariance structure was used because it provided the best fit for data analysis (Littell et al. 1996). Mean separation involved comparison of least squares using the LSMEANS statement (SAS Institute 2002). The model included block (5 blocks; df = 4), year (2001–2006; df = 5), treatment (Summer 1, Summer 2, Spring 1, Spring 2, Burn, Unburned; df = 5), and year-by-treatment interaction (df = 20; error-term df = 116). Because of a strong year effect, years were analyzed separately using analysis of variance (ANOVA) for a randomized complete-block design to simplify presentation of the results and to assist in explaining interactions. Statistical significance of ANOVA models was set at $P < 0.05$, and mean separations were done using Fisher's Protected LSD test. To simplify presentation of the results, only cover data for 2002, 2004, and 2006 are shown in the figures.

RESULTS

Utilization

Herbage use in both summer-grazing treatments and the Spring 1 treatment in 2004 were close to the targeted level of 50% (Table 1). In spring 2005, herbage was growing rapidly, and grazed plants regrew while cattle were still grazing the treatment plots. Therefore, measured use was light (25%) in Spring 1 and Spring 2 treatments in 2005.

Herbaceous Standing Crop and Annual Yield

Herbaceous standing crop did not differ among treatments before burning (Fig. 2). The first year after burning (2003), standing crop was greater in the Unburned treatment than all burned treatments (grazed and not grazed). By the third growing season (2005), herbaceous standing crop was greater in all the burned treatments (grazed and not grazed) than the Unburned treatment. Standing crop in the Burn treatment was about twice that of the Unburned treatment and was greater than all the burned–grazed treatments (except the Summer 2 treatment) in 2005 and 2006. Lower standing crop in the burn–grazed treatments than the Burn treatment in 2005 and 2006 reflects the removal of herbage, which reduced the amount of residual biomass from previous years' growth.

Herbaceous annual yields provided a better comparison for evaluating effects of grazing after fire to production. 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 yields in 2005 and 2006 (Figs. 3A and 3B). Herbaceous and perennial grass annual yields in the summer-grazing treatments did not differ from the Burn treatment in 2005 and 2006. In the Spring 1 and Spring 2 treatments, herbaceous and perennial grass annual yields were less than the Burn and both summer treatments in 2005 because of herbage removal by cattle. However, if biomass removed by cattle (Table 1) in the Spring 1 and Spring 2 treatments are included in the herbaceous and perennial grass totals then these treatments did not differ ($P > 0.10$) from the Burn treatment in 2005. Despite biomass removal, herbaceous and perennial grass annual yields were greater in Spring 1 and Spring 2 treatments than the unburned treatment in 2005. In 2006, herbaceous and perennial grass annual yield did not differ among the burn (grazed and ungrazed) treatments. Herbaceous and perennial grass annual yields were about two times greater in the Burn and

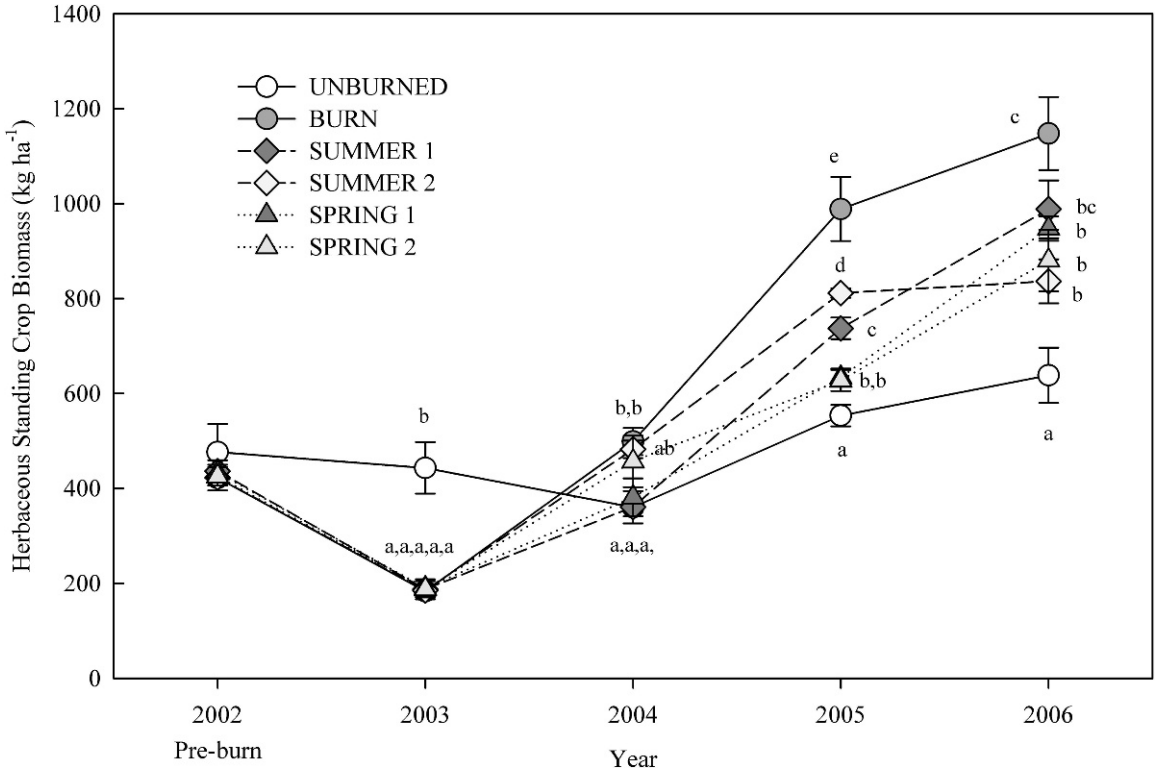

Figure 2. Herbaceous standing crop (kg · ha^{-1}) for the burn–grazing treatments (Burn, Spring 1, Spring 2, Summer 1, Summer 2) and unburned treatment in Wyoming big sagebrush steppe, Northern Great Basin Experimental Range, Oregon, June 2001–2006. Values represent means ± one standard error. Different letters indicate significant differences ($P < 0.05$) among the treatments within year.

burned–grazed treatments than the Unburned treatment in 2006. In 2005, Sandberg's bluegrass annual yield was lowest in both spring-grazing treatments (Fig. 3C). In 2006, Sandberg's bluegrass annual yield did not differ among all the treatments. Grazing treatment did not affect perennial forb annual yield for the study (Fig. 3D). Annual forb annual yield increased in all burn treatments (grazed and ungrazed) after fire and were greater than the Unburned treatment during the study (Fig. 3E). However, in 2006, variability in annual forb yield increased in the burn treatments, and treatment differences did not occur. Cheatgrass annual yield was less than 0.5 kg · ha^{-1} in all treatments and did not differ among treatments.

Treatment and year influenced perennial bunchgrass seed production (Fig. 4). Total seed production was greater in 2005 than 2004 for all treatments ($P < 0.0001$). Seed production was greater in the Burn and all burn–grazed treatments than the Unburned treatment in 2005 (Fig. 4A). Within the burn treatments, grazing effected total seed production as well as seed production of individual species. The Burn treatment had greater total seed production than the Summer 1, Spring 1, and Spring 2 treatments. Bluebunch wheatgrass seed production did not differ among treatments in either year (Fig. 4B). Seed production of Idaho fescue was greatest in the Burn and Summer 2 treatments (Fig. 4C). Seed production of squirreltail (Fig. 4D) and Thurber's needlegrass (Fig. 4E) were greater in the Burn and burn–grazed treatments than the Unburned treatment.

Functional Group Canopy Cover, Density, and Species Presence

Before fire and grazing applications functional group canopy covers, perennial densities, and species presence did not differ among the treatments (Fig. 5). Burning perennial grass cover was reduced the first year postfire (2003) in all the burned (grazed or ungrazed) treatments compared with the Unburned treatment. Thereafter, perennial grass cover increased in burned (grazed or ungrazed) treatments; however, unlike annual yield, cover values did not differ from the Unburned treatment (Fig. 5A). This difference in response variable dynamics (annual yield and canopy cover) may result from higher tiller density, reproductive effort, and taller plants in the Burn treatment than the Unburned treatment, and also, because canopy cover estimates are less precise than biomass measurements, Sandberg's bluegrass and perennial forb cover differed among the treatments within some individual years; however, there were no differences during the overall study (Figs. 5B and 5C). Annual forb cover was greater in burned (grazed and ungrazed) treatments than the Unburned treatment from the second through fourth year after fire (2004–2006; Fig. 5D). Cheatgrass cover was less than 0.01% throughout the study and did not differ among the treatments ($P > 0.05$).

Perennial grass and perennial forb densities were unaffected by treatment and did not change during the study. Sandberg bluegrass density increased in all treatment in 2003 ($P < 0.05$); although by 2005 and 2006 bluegrass density had returned to pretreatment levels. It is not clear why Sandberg bluegrass density temporarily increased. It is possible that drought and/or fire caused bluegrass clumps to become more fragmented, resulting in higher density counts. There were no differences among treatments in the numbers of species present ($P > 0.05$). Numbers of herbaceous species increased in all treatments in 2005 and 2006 when precipitation was greater than average ($P < 0.05$).

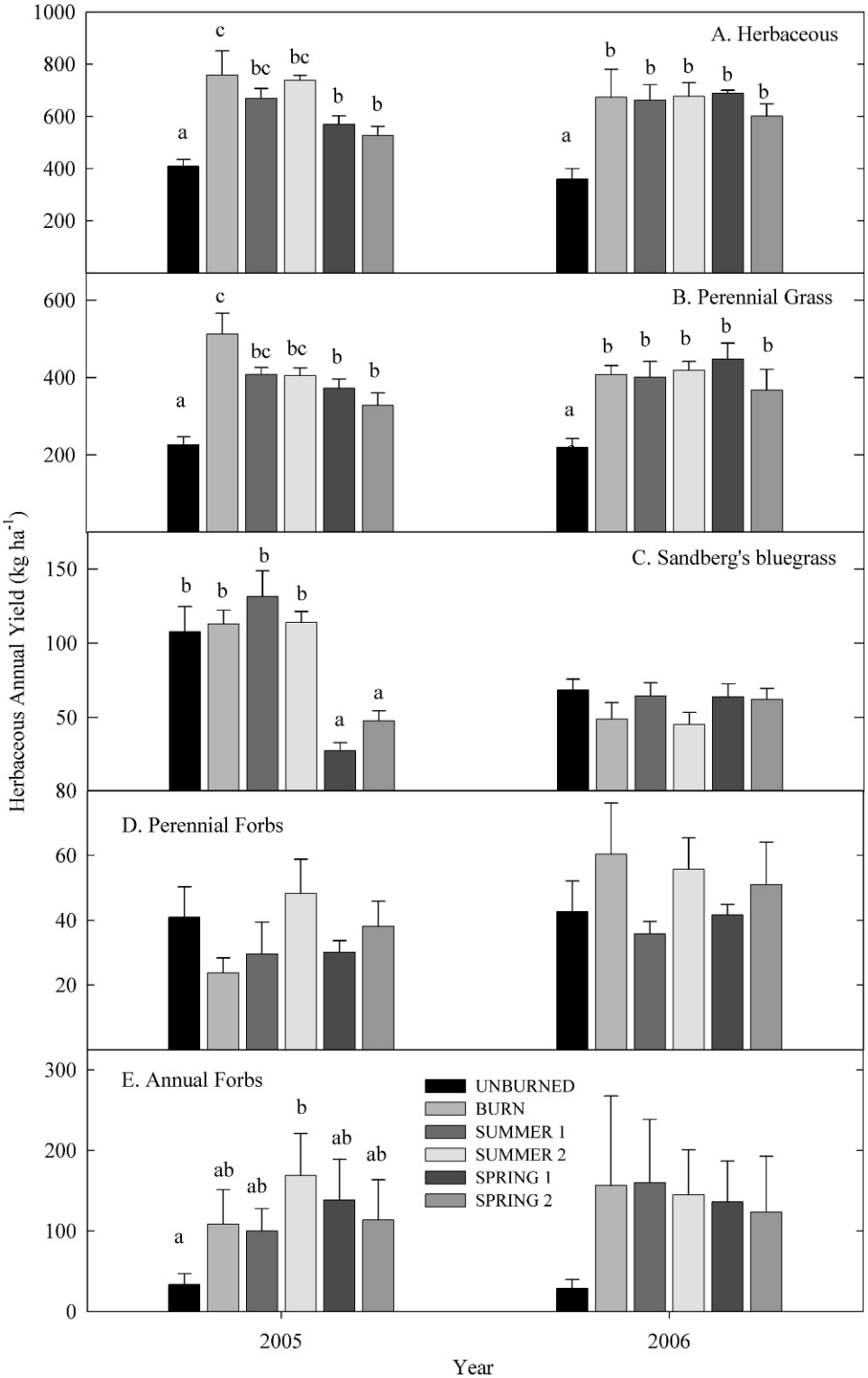

Figure 3. Annual yield values (kg · ha^{-1}) for **A,** herbaceous, **B,** perennial bunchgrasses, **C,** Sandberg's bluegrass, **D,** perennial forbs, and **E,** annual forbs for the burn–grazing treatments (Burn, Spring 1, Spring 2, Summer 1, Summer 2) and unburned treatment in Wyoming big sagebrush steppe, Northern Great Basin Experimental Range, Oregon, June 2005–2006. Values represent means ± one standard error. Different lowercase letters indicate significant differences ($P < 0.05$) among the treatments within year.

Ground Cover

Before burning, ground cover attributes (herbaceous cover, moss and crust, soil surface litter, bare ground) did not differ among treatments (Fig. 6). The first year after burning (2003), herbaceous cover was greater in the Unburned than all burned treatments (grazed and ungrazed). By the second growing season after fire (2004) herbaceous cover was not different among the treatments (Fig. 6A). In 2005 and 2006, herbaceous

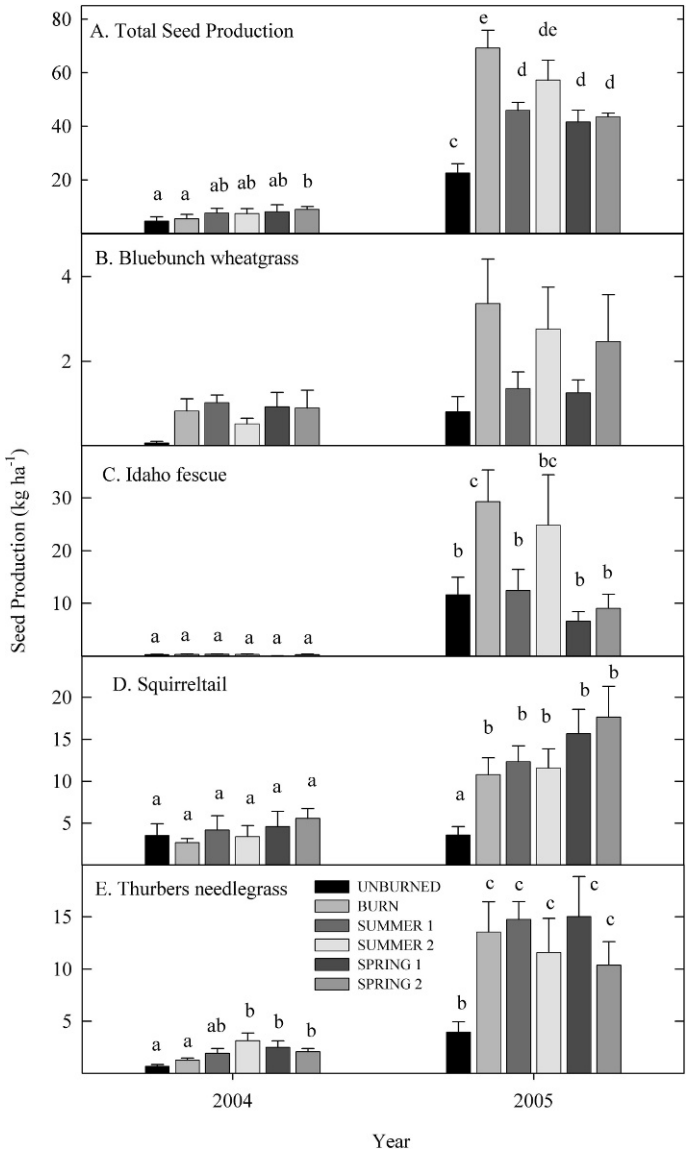

Figure 4. Seed production values ($kg \cdot ha^{-1}$) for the burn–grazing treatments (Burn, Spring 1, Spring 2, Summer 1, Summer 2) and unburned treatment in Wyoming big sagebrush steppe, Northern Great Basin Experimental Range, Oregon, 2004–2005. **A,** Total perennial bunchgrasses, **B,** bluebunch wheatgrass, **C,** Idaho fescue, **D,** squirreltail, and **E,** Thurber's needlegrass. Values represent means ± one standard error. Different lowercase letters indicate significant differences ($P < 0.05$) among the treatments within year.

cover was greater in all the burned treatments than the Unburned treatment (Fig. 6A), primarily as a result of greater annual forb cover (Fig. 5D). Moss and other biotic crust increased in the Unburned treatment between 2002 and 2004 and remained 3.5–4 times greater than the burned treatments (grazed and ungrazed; Fig. 6B). Moss comprised most of the cover in this group and was mainly found within grass clumps and under sagebrush. Soil surface litter was reduced by burning. Litter cover was greater in the Unburned treatment compared with most of the burned grazed treatments the first 3 yr after the fire (Fig. 6C). In 2006, treatments did not differ in soil surface litter cover. Bare ground initially increased the first year after fire in all burned treatments (Fig. 6D). By the second year after fire (2004), there were no longer any differences among treatments in levels of bare ground.

Shrub Dynamics

Fire reduced Wyoming big sagebrush cover and density in all the burned treatments (Fig. 7). Wyoming big sagebrush cover was reduced by greater than 95% (Fig. 7A), and sagebrush density was reduced between 89–92% from preburn conditions (Fig. 7B; $P < 0.001$). Green rabbitbrush cover (Fig. 8A) was reduced after the fire, but density was unaffected (Fig. 8B; $P > 0.01$). By 2004, rabbitbrush cover returned to preburn conditions and did not differ among treatments. In 2006, the Spring 2 treatment had greater rabbitbrush cover and density than the Summer 1 treatment ($P < 0.01$).

DISCUSSION

Grazing Effects and Herbaceous Recovery

Livestock grazing during the first several years after prescribed fire in the big sagebrush steppe has often been considered to be incompatible with herbaceous recovery. This study suggests that moderate grazing, following completion of the first growth cycle after fire, does not limit herbaceous recovery in Wyoming big sagebrush steppe. In fact, herbaceous recovery in all the burned–grazed treatments was similar to the Burn treatment. For most measured variables, including bare ground, soil surface litter cover, and herbaceous cover, density, and yield, there were no differences among grazed and ungrazed burn treatments, particularly in the response year of 2006. Grass seed production differed in 2005 among treatments largely because of grazing of Idaho fescue. Potentially, the lower seed production in several of the grazing treatments could affect future recruitment of new plants. However, the amount of seed produced in 2005 was three to six times that of recommended seeding rates for this plant community (Jensen et al. 2003). In addition, herbaceous cover and yield of grazed and ungrazed burn treatments exceeded the unburned treatment within 3 yr following fire. Thus, treatment differences in standing crop and seed production were considered minor when evaluating community recovery after fire.

Summer Grazing Following Fire

The summer-grazing results were similar to those reported by Bruce et al. (2007) for herbaceous recovery after wildfire and summer grazing in central Nevada and for individual species' responses to defoliation after burning in Idaho sagebrush steppe (Jirik and Bunting 1994; Bunting et al. 1998). Bruce et al. (2007) measured no differences in herbaceous cover and density between ungrazed and summer grazed pasture (second and third year after fire). Grazing in our study was of short duration (5–10 d) and with higher stocking rates than Bruce et al. (2007), where grazing duration was set for a 60-d period (July 1 to August 31). This is a more typical grazing scenario in the Great Basin and Intermountain Region. Despite the differences in grazing duration, utilization targets of about 50% were achieved in both studies. Because plants were not growing during these summer periods, grazing duration is not important when comparing herbaceous response between our two studies. This conclusion is supported by postfire clipping

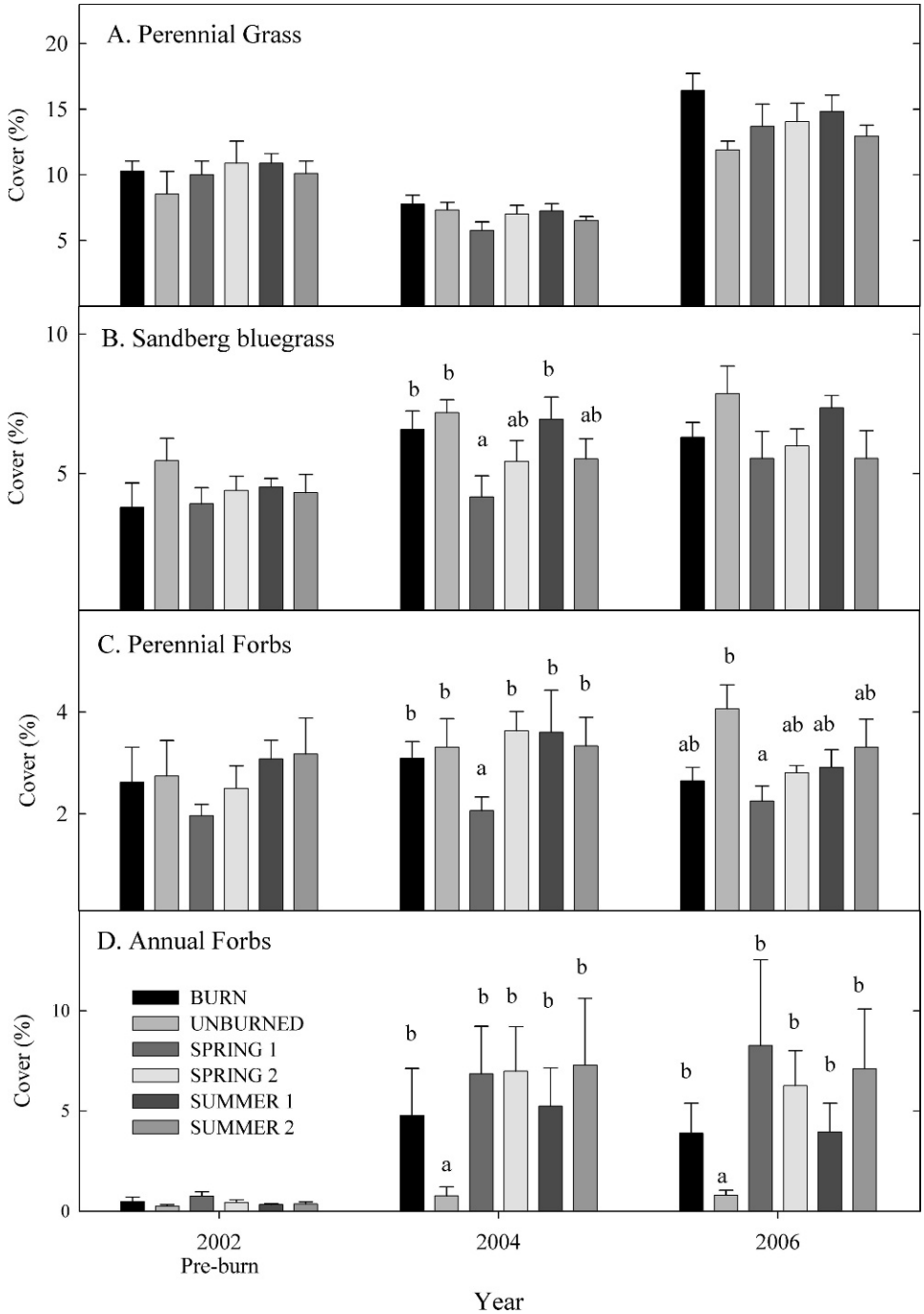

Figure 5. Canopy cover values (%) for the burn–grazing treatments (Burn, Spring 1, Spring 2, Summer 1, Summer 2) and unburned treatment in Wyoming big sagebrush steppe, Northern Great Basin Experimental Range, Oregon, June 2002, 2004, and 2006. **A,** Perennial bunchgrasses, **B,** Sandberg's bluegrass, **C,** perennial forbs, and **D,** annual forbs. Values represent means ± one standard error. Different lowercase letters indicate significant differences ($P < 0.05$) among the treatments within year.

trials conducted by Bunting et al. (1998) and Jirik and Bunting (1994). In their work, heavy defoliation (equivalent to 90% use) by a single clipping of individual bunchgrasses after seed development did not affect yield the following year of bluebunch wheatgrass, Idaho fescue, and squirreltail when compared with undefoliated plants. We did not measure individual species' yields; however, annual yield of the perennial grass group was similar between summer-grazed and ungrazed burn treatments.

Spring Grazing Following Fire

There was no indication that spring grazing after 1 yr or 2 yr of rest adversely affected the response of the herbaceous community. Although standing crop and seed production were reduced by the spring-grazing applications (Spring 1 and Spring 2), the main response year of 2006 indicated no carryover effect from spring grazing because annual yield did not differ among the Burn and burn–grazed treatments (Fig. 3A). The lack of an effect may result from timing of grazing in the spring of 2004

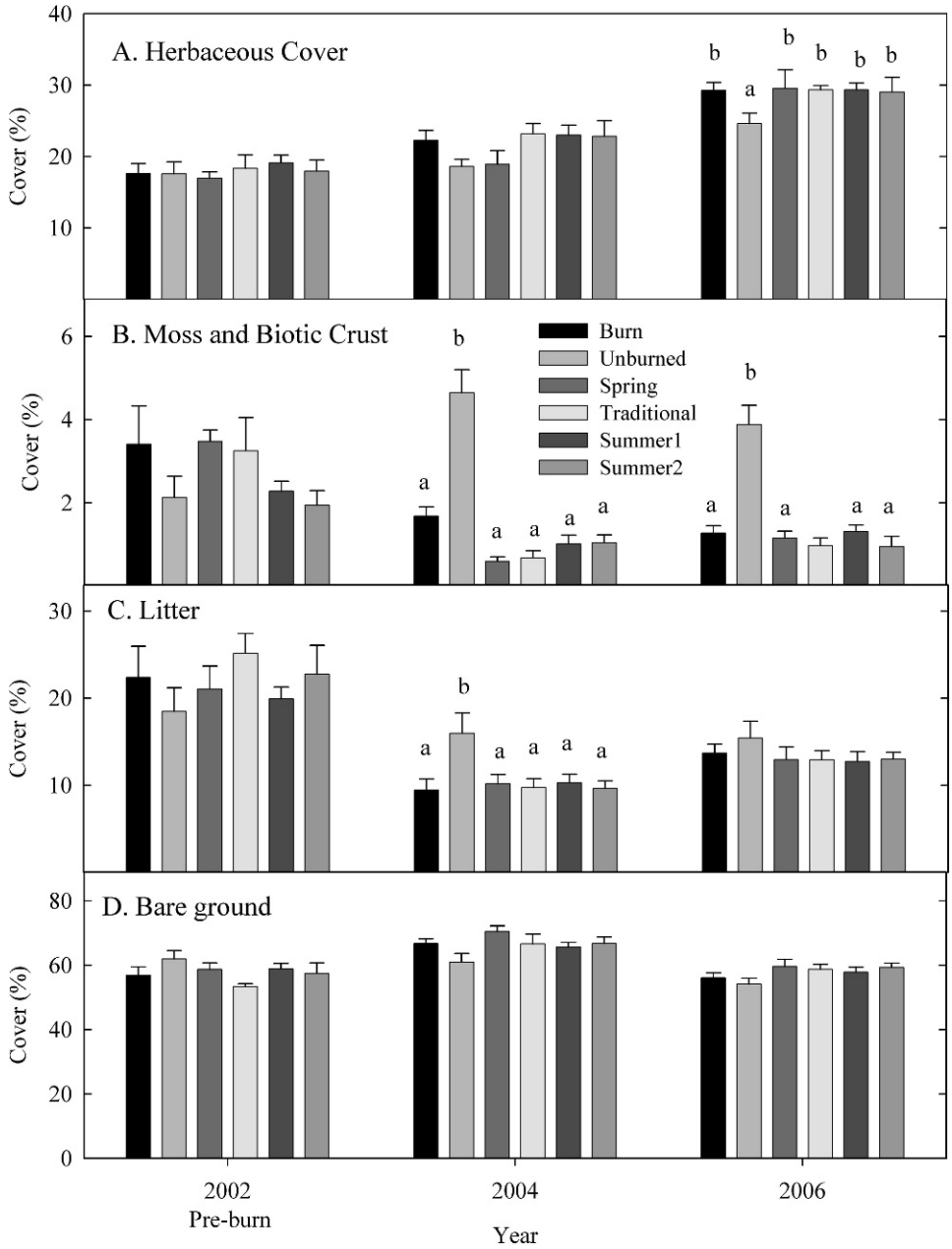

Figure 6. Ground cover values for the burn–grazing treatments (Burn, Spring 1, Spring 2, Summer 1, Summer 2) and unburned treatment in Wyoming big sagebrush steppe, Northern Great Basin Experimental Range, Oregon, June 2002, 2004, 2006. **A,** Herbaceous, **B,** soil surface litter, **C,** moss and biotic crust, and **D,** bare ground and rock. Values represent means ± one standard error. Different lowercase letters indicate significant differences ($P < 0.05$) among the treatments within year.

and 2005. The grazing prescription mainly occurred during vegetative growth of the larger perennial bunchgrasses. This permitted plants to begin regrowth from existing tillers almost immediately after grazing, particularly in 2005, when soil water content remained near field capacity through the grazing cycle (Rhodes 2006). If grazing had occurred later, when plants were in the boot to early flower stages, and removed apical and intercalary meristems, regrowth response would likely have been reduced and may have lowered yield in 2006. Grazing of perennial bunchgrasses in boot and flower stages requires growth initiation from axillary buds, which delays regrowth response (Briske and Richards 1995) and may reduce yield and tillering in subsequent growing seasons (Blaisdell et al. 1952; Ganskopp 1988; Britton et al. 1990).

Secondary Succession

The response of herbaceous vegetation after fire, whether grazed or not grazed, was comparable to results from other postfire (prescribed and wildfire) studies in big sagebrush systems. Herbaceous cover, standing crop, and annual yields in the Burn and burn–grazed treatments equaled or exceeded the unburned treatment by the second (2004) or third year (2005) after fire. These response times were similar to herbaceous recovery after fire in sagebrush steppe reported by Blaisdell

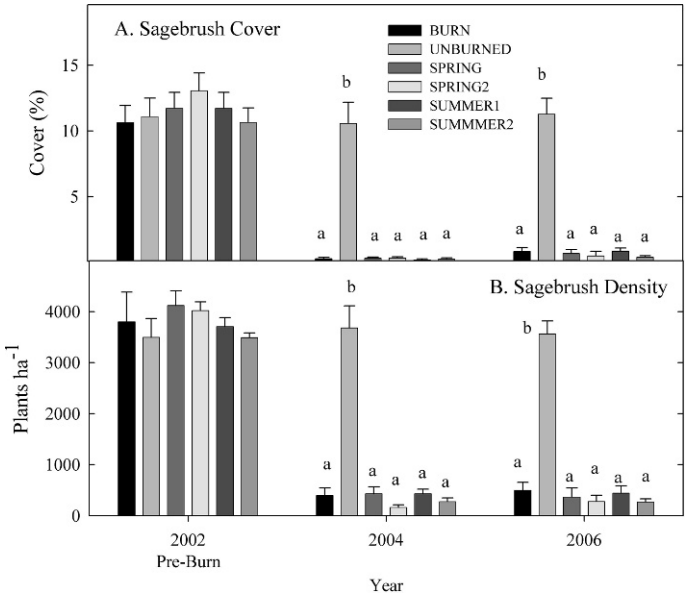

Figure 7. Wyoming big sagebrush **A,** canopy cover (%) and **B,** density (plants · ha^{-1}) for the burn–grazing treatments (Burn, Spring 1, Spring 2, Summer 1, Summer 2) and unburned treatment in Wyoming big sagebrush steppe, Northern Great Basin Experimental Range, Oregon, June 2002, 2004, 2006. Values represent means ± one standard error. Different lowercase letters indicate significant differences ($P < 0.05$) among the treatments within year.

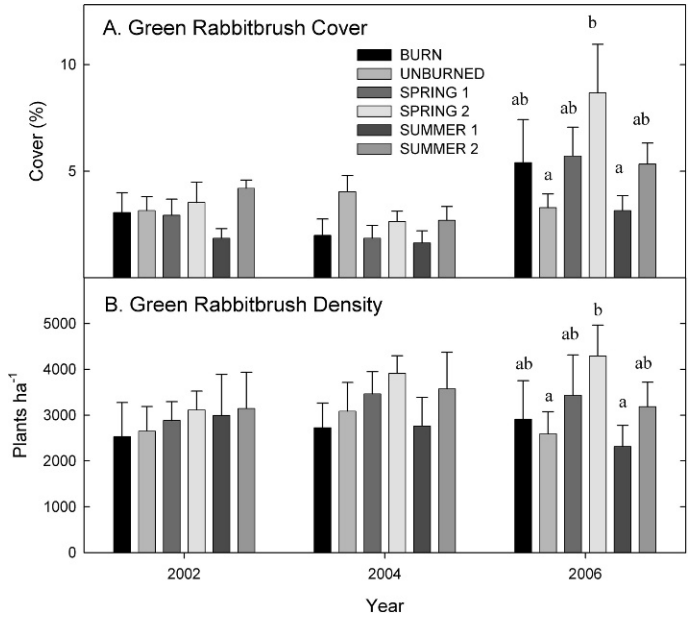

Figure 8. Green rabbitbrush **A,** canopy cover (%) and **B,** density among the burn–grazing treatments (Burn, Spring 1, Spring 2, Summer 1, Summer 2) and unburned treatment in Wyoming big sagebrush steppe, Northern Great Basin Experimental Range, Oregon, June 2002, 2004, 2006. Values represent means ± one standard error. Different letters indicate significant differences ($P < 0.05$) among the treatments within year.

(1953), Conrad and Poulton (1966), and Uresk et al. (1976). The increases in annual yield (perennial grasses and annual forbs) were likely influenced by a combination of sagebrush removal and favorable postburn growing conditions (e.g., above-average precipitation) between 2004 and 2006. Although soil water content did not differ between burned and unburned treatments (Rhodes 2006), the removal of Wyoming big sagebrush likely made more soil water available for herbaceous uptake. Inorganic nitrogen was more available after fire on the study site (Davies et al. 2007), which probably contributed to the rapid herbaceous response.

Another factor for the rapid and progressive herbaceous response was a lack of mortality among bunchgrass species, indicating a fire of low severity. Fire can negatively impact bunchgrasses by killing individuals and reducing basal cover, especially species with densely packed culms, such as Idaho fescue and Thurber's needlegrass (Conrad and Poulton 1966; Tisdale et al. 1969; Uresk et al. 1976; Wright and Bailey 1982; Britton et al. 1990). These were the most common perennial grasses on our study sites. However, neither species was reduced in density, and both species demonstrated a positive response by the second year after fire (Rhodes 2006; Davies et al. 2007; Davies and Bates 2008). Most reported negative effects to these species are a result of early season fires (May to July) and wildfires, which have more severe impacts on vegetation than late-season prescribed fires (Wright and Klemmedson 1965; Britton et al. 1990).

Cheatgrass and other exotic species are a major threat to maintaining Wyoming big sagebrush communities (Whisenant 1990; Young and Allen 1997; Rowland and Wisdom 2005). Our results demonstrated that burning can successfully stimulate herbaceous native species and not induce an increase of cheatgrass with or without grazing. There were likely two reasons for the lack of a cheatgrass response: The prefire community was largely composed of native perennials, and fire severity was low because there was limited mortality of perennial grasses. Bruce et al. (2007) and West and Yorks (2002) both reported increases in cheatgrass after fire, but found no differences in cheatgrass cover between grazed and ungrazed treatments.

The main exotic that increased and comprised the bulk of forb yield and composition after fire was pale alyssum (*Alyssum alyssoides* L.), an introduced Old World weed (Rhodes 2006). More than 90% of annual forb production was composed of pale alyssum. Information on the competitive abilities of alyssum is not available, although it likely interferes with native annual forbs because 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 (Bates et al. 2005).

Our results suggest that burning Wyoming big sagebrush communities may not increase the abundance or yield of perennial forbs. Other studies have found no increase in forb diversity (Fischer et al. 1996), frequency (Pyle and Crawford 1996), or abundance (Wrobleski and Kauffman 2003) after burning in Wyoming big sagebrush communities. The lack of perennial forb response may result from the high survival of perennial grasses, which recovered quickly after the fire, as well as the large increases in pale alyssum. Others have noted the potential for increasing forb production appears to be limited in Wyoming big sagebrush communities (Wright and Bailey 1982; Cronquist et al. 1994; Kolb and Sperry 1999).

The rate and level of Wyoming big sagebrush recovery after fires is dependent on several elements, including level of

mortality, seed pools, and prefire and postfire weather (Tisdale and Hironaka 1981; Wright and Bailey 1982). Literature, although limited, suggests that recovery of Wyoming sagebrush will exceed 30 yr (Harniss and Murray 1973; Wambolt et al. 2001). Wambolt and Payne (1986) measured only a 16% recovery of Wyoming big sagebrush cover 18 yr after burning in southwest Montana. In our study, surviving sagebrush were scattered throughout the burn and provided a potential seed source. Because of the short-term length of the study, it is premature to speculate on what effects grazing treatments will have on sagebrush recovery.

Green rabbitbrush cover was reduced 10-fold the first year after fire, returning to preburn levels by the second year after fire. Green rabbitbrush is a vigorous sprouter and often increases within a few years after fire (Blaisdell 1953; Young and Evans 1974; Wright and Bailey 1982). By the fourth year after the fire, there was some separation, beginning among the treatments for rabbitbrush cover and density.

Moss and other biological crust had not recovered to preburn levels by the fourth year after the fire. Recovery of mosses and biological crusts after fire varies, depending on species and plant community composition. Lichens and tall mosses had not recovered 10 yr after the fire on Wyoming big sagebrush sites in Idaho (Hilty et al. 2004). In our study, fire, rather than grazing, appears to have had the main impact on moss and biotic crust recovery; however, it is likely too early to evaluate the effects of grazing. Trampling by livestock has been shown to reduce biotic crusts and soil integrity thus increasing nutrient and soil loss and altering species composition (Belnap and Elderidge 2001; Fierer and Gabet 2002).

MANAGEMENT IMPLICATIONS

The primary goals of postfire 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 requiring grazing rest the first 2 yr after fire to encourage herbaceous recovery, as applied in the Spring 2 treatment, may not be necessary in all situations.

Nevertheless, the results and interpretations of this study must be considered under the conditions it was conducted. The trials were performed on a distinct big sagebrush site, with fires causing minimal, if any, mortality to perennial bunchgrasses; with 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 postfire recovery scenarios. Study plots were small and we managed to obtain uniform grazing use. However, livestock tend not to graze uniformly in large pastures in the Great Basin as distance to water and topography results in areas of high, moderate, and low use and nonuse (Ganskopp 2001; Holechek et al. 2004). Grazing after fire in larger pastures and for longer duration would likely have resulted in areas of differential use and levels of herbaceous recovery.

Our study has only provided a short-term herbaceous response to grazing after fire in sagebrush steppe. Results presented by West and Yorks (2002) indicate that longer-term monitoring is needed to evaluate postfire grazing. Their data indicated no differences in herbaceous cover among burn–ungrazed and burn–grazed areas the first 6 yr after fire. Between years 7 and 18 after fire, perennial grass cover in grazed areas decreased compared with ungrazed areas. Unfortunately, West and Yorks (2002) were unable to provide much information on the grazing regime. They judged that grazing was moderate; however, the lack of information on timing and duration make it difficult to evaluate grazing impacts.

In the mixed grass prairies of the central United States, Engle and Bidwell (2001) concluded that, because of variable vegetation responses to fire and grazing, the use of broadly applied rules are inappropriate for managing postfire plant communities. This viewpoint is appropriate for managing postfire recovery of vegetation in the sagebrush steppe. Management should not be hasty in disregarding past recommendations for grazing rest after fire in sagebrush steppe; however, mounting evidence also indicates that postfire grazing decisions can be applied more flexibly to meet vegetation recovery goals. For instance, the summer-grazing treatments provided the most robust outcome regarding herbaceous recovery, and our results were in agreement with recent postfire grazing (Bruce et al. 2007) and defoliation trials (Bunting et al. 1998). Moderate grazing use after perennial grass dormancy/seed shatter within the first two summers after fire should not reduce the recovery ability of herbaceous communities in sagebrush steppe. Postfire recovery of the herbaceous community with the Spring 1 grazing treatment was similar to the other treatments. However, this is the first study of spring grazing in sagebrush steppe after fire, and the trials only evaluated defoliation during vegetative and early boot stages of growth of the larger perennial bunchgrasses. At this point, grazing sagebrush steppe in the spring during the first 2 yr after fire should be applied cautiously until additional information becomes available.

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