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Effects of Targeted Grazing and Prescribed Burning on Community and Seed Dynamics of a Downy Brome (*Bromus tectorum*)–Dominated Landscape

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Downy brome (*Bromus tectorum* L.)—dominated communities can remain as stable states for long periods, even with frequent disturbance by grazing and fire. The objective of this study was to determine the effectiveness of using targeted cattle grazing and late-season prescribed burning, alone and in combination, to reduce *B. tectorum* seed bank input and seed bank density and thus alter aboveground community dynamics (species composition) on a *B. tectorum*–dominated landscape in northern Nevada. Cattle removed 80 to 90% of standing biomass in grazed plots in May of 2005 and 2006 when *B. tectorum* was in the boot (phenological) stage. Grazed and ungrazed plots were burned in October 2005 and 2006. The combined grazing–burning treatment was more effective than either treatment alone in reducing *B. tectorum* seed input and seed bank density, and in shifting species composition from a community dominated by *B. tectorum* to one composed of a suite of species, with *B. tectorum* as a component rather than a dominant. This study provides a meso-scale precursor for landscape-scale adaptive management using grazing and burning methodologies.

Nomenclature: Downy brome, *Bromus tectorum* L. BROTE.

Key words: Cheatgrass, litter, seed bank, seed input, seedbed ecology, landscape scale.

The Great Basin now has more than 6.8 million ha (17 million ac) dominated by downy brome (*Bromus tectorum* L.) and an additional 25 million ha with *B. tectorum* as a component species (Morrow and Stahlman 1984; Pellant and Hall 1994). Over 20% of former Great Basin sagebrush–grassland communities are infested with *B. tectorum* to levels that preclude reestablishment of native perennial species (Knapp 1996). This community degradation is due primarily to improper grazing by domestic livestock, the associated invasion of *B. tectorum*, and the resulting grass-fire cycle (Miller et al. 1994; Whisenant 1990; Young and Clements 2009). *Bromus tectorum* provides the fine fuel that facilitates frequent, large wildfires (D'Antonio and Vitousek 1992). Although historical fire frequencies in Great Basin sagebrush–grassland communities prior to *B. tectorum* invasion were 50 to 100 yr (Wright and Bailey 1982), they are now 2 to 15 yr (Whisenant 1990). This grass-fire cycle, in conjunction with plant traits such as early, prolific growth and high seed production, promote *B. tectorum* dominance (Melgoza and Nowak 1991; Rice 2005; Uresk et al. 1979).

Invasive species such as *B. tectorum* can have large propagule pools within litter and on the soil surface. Depending on plant densities and environmental conditions, individual *B. tectorum* plants can produce 10 to 6,000 seeds (Hulbert 1955; Young and Evans 1978). Seed bank densities of 2,400 to 8,300 seeds m^{-2} (216 to 747 seeds per ft^{-2}) have been reported for overgrazed sagebrush communities (Young and Evans 1975), and 4,800 to 19,000 seeds m^{-2} for unburned, *B. tectorum*–dominated communities in the Great Basin (Hempy-Mayer and Pyke 2008; Humphrey and Schupp 2001). After summer dispersal (late May to late June, depending on moisture conditions), most seeds germinate the following fall through spring; however, seeds can remain viable in the soil for up to 2 to 5 yr (Burgert et al. 1971; Mack and Pyke 1983; Smith et al. 2008). The majority (up to 90%) of seeds disperse a short distance from the parent plant by dropping to the soil surface and then being moved along

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Management Implications

Livestock grazing, the invasion of downy brome, and the resulting grass-fire cycle have played major roles in the conversion of sagebrush–grassland and other native plant communities to downy brome–dominated landscapes. Grazing and fire, if properly managed, can also play major roles in suppressing downy brome and changing plant community composition. This investigation was aimed at determining if targeted cattle grazing and prescribed burning, alone and in combination, could reduce downy brome reproductive potential, and thus its dominance in a degraded sagebrush–grassland community. In this study, we found that intensive cattle grazing in May, when downy brome was in the boot stage (just before inflorescence emergence from the culm), reduced seed input into the seed bank (Figures 1 and 2). Prescribed burning in October consumed much of the litter on the soil surface, killing or damaging many downy brome seeds suspended in the litter and reducing the number of favorable microsites for germination and establishment of surviving seeds in the soil. The integration of targeted grazing with prescribed burning was more effective than either treatment alone in reducing downy brome seed bank density and changing species composition from a community dominated by downy brome to one dominated by less flammable species such as *Sisymbrium altissimum* (Figures 1 and 3). Although *S. altissimum* is less flammable than downy brome the potential for fire spread is still present because of the tumbling nature of *S. altissimum.* Thus, our methodologies created a less fire-prone plant community, not a fireproof community. These findings are encouraging; the required stocking density for intensive grazing and the short temporal window for grazing during the boot stage will limit the use of targeted grazing to relatively small scales, i.e., about 42 ha during one growing season for a herd of 500 cow–calf pairs. And, managers must recognize that the effects of grazing and prescribed burning treatments are short-lived (1 to 2 yr); thus, treatments must be integrated with other management methods (herbicide or mechanical) and repeated to have the greatest impact on downy brome. These treatments could be used to create or maintain fuel-break strips and possibly to prepare patches of downy brome–dominated areas for revegetation. We have laid the groundwork for further studies at larger scales.

the surface via wind (Mack and Pyke 1983). The short rigid hairs on the awns and lemmas facilitate long-distance dispersal when attached to animal fur and human clothing (Pyke and Novak 1994). These dispersal methods allow *B. tectorum* to readily colonize disturbed patches and adjacent communities.

Bromus tectorum–dominated communities in the Great Basin are characterized by near-monotypic stands of *B. tectorum* with interspersed annual forbs such as tumble mustard (*Sisymbrium altissimum* L.) and clasping pepperweed (*Lepidium perfoliatum* L.), and remnant bunchgrasses such as Sandberg bluegrass (*Poa secunda* J. Presl). *Sisymbrium altissimum* and *L. perfoliatum* colonize sites after disturbance and modify the seed bed to allow for *B. tectorum* germination, whereas *P. secunda* tolerates disturbance (Hironaka and Tisdale 1963; Young et al. 1970). Litter deposited by *S. altissimum* and *L. perfoliatum* moderates temperature and moisture conditions on the soil surface, providing safe sites for *B. tectorum* germination (Facelli and Pickett 1991; Piemeisel 1951; Young et al. 1969). The two forb species can comprise 10% (wet year) to more than 40% (dry year) of a *B. tectorum*–dominated community, whereas *P. secunda* remains a small component even under heavy grazing and frequent burning (Hironaka and Tisdale 1963; Young et al. 1970).

Vegetation manipulation methods such as targeted grazing and prescribed burning have the potential to reduce *B. tectorum* dominance by altering seed and aboveground community dynamics. Intensive sheep grazing (McAdoo et al. 2007; Mosley and Roselle 2006) and cattle grazing (Sternberg et al. 2003) at the boot stage can reduce seed production, biomass, density, and cover of annual grasses. Grazing, however, does not significantly alter site characteristics (litter cover and depth) that facilitate *B. tectorum* establishment, because it only removes standing biomass. Prescribed burning has the potential to alter *B. tectorum* site characteristics by removing or reducing the litter bed (Humphrey and Schupp 2001). Fire can also kill many of the seeds in the litter and on the soil surface; however, this reduction in seed bank density may last for only 1 yr (Evans and Young 1984).

The objective of this study was to determine the effectiveness of using targeted cattle grazing and late-season prescribed burning alone, and in combination, to reduce *B. tectorum* seed input and seed bank density, and alter aboveground community dynamics (species composition) on a *B. tectorum*–dominated landscape in northern Nevada.

Materials and Methods

Site Description. The study site is located in northwestern Nevada, 20 km (12 mi) southeast of McDermitt (41°51′52.92″N, 117°39′17.85″W), within the Quinn River Management Area of the Bureau of Land Management Winnemucca Field Office. It is on a 5% slope with a western aspect at 1,400 m (4,592 ft) elevation. Average annual precipitation is 228 mm (9.0 in), most of which falls as snow from November through March. Mean maximum and minimum temperatures are 17 and −1 C (63 and 30 F), respectively. The site has 50 to 60% *B. tectorum* cover. Other primary species include *L. perfoliatum*, *S. altissimum*, and *P. secunda*. Secondary species consist of annual and biennial forbs, including Scotch thistle (*Onopordum acanthium* L.), bur buttercup [*Ceratocephala testiculata* (Crantz) Roth], blue mustard [*Chorispora tenella* (Pall.) DC.], desert alyssum (*Alyssum desertorum* Stapf), filaree [*Erodium cicutarium* (L.) L'Her], and prickly lettuce (*Lactuca serriola* L.); the perennial grass, bulbous bluegrass (*Poa bulbosa* L.); and the annual grass, sixweeks fescue [*Vulpia octoflora* (Walter) Rydb.]. The *B. tectorum*–dominated site is part of a 19,830-ha grazing allotment that

Table 1. Mean values (± SE) for flame length and rate of spread for treatments in 2005 and 2006.

	2005				2006			
Attributes	GB[a]	GNB	NGB	NGNB	GB	GNB	NGB	NGNB
Flame length (m)	0.25 ± 0.1	—[b]	2.3 ± 0.2	—[b]	0.0	—[b]	0.5 ± 0.3	—[b]
Rate of spread (m min^{-1})	7 ± 6	—[b]	7 ± 4	—[b]	0.0	—[b]	7 ± 6	—[b]

[a] Abbreviations: GB, graze and burn; GNB, graze and no-burn; NGB, no-graze and burn; NGNB, no-graze and no-burn.

[b] No burn treatment; no data collected.

is divided into 15 pastures grazed in a rest–rotation–deferment system, where pastures are used early (March 1 to May 15), late (May 15 to August 31), deferred (July 1 to August 31), or fall–winter (October 1 to February 28), or receive complete rest in alternating years (USDI BLM 1998). About 1,500 cow–calf pairs are divided into four distinct herds, each of which is generally grazed in separate pastures throughout the grazing season. Historically, herbaceous forage utilization estimates have ranged between 20 and 40% for the pastures. The site has burned in wildfires in 1972, 1985, 1994, and 1996.

Soils are characteristic of the McConnel series (sandy-skeletal, mixed, mesic Xeric Haplocambids). These are deep soils formed with mixed rock particles and components of loess and volcanic ash over lacustrine deposits or gravelly alluvium fans extending into the Quinn River Valley (USDA NRCS 1997). These soils correspond to Loamy, Claypan, and Droughty Loam ecological sites in the 200- to 350-mm precipitation zone (USDA NRCS 1997).

Treatments and Experimental Design. Four grazing–burning treatments were arranged in a two by two factorial design in a block, and replicated three times; all replicates were located within the McConnel soil series. Treatment plots were 60 by 60 m. Shred lines, mowed to 4 to 8 cm (1.6 to 3.1 in) high and 10 m wide, were placed between treatments to reduce the potential of fire spread between treatments. The southern edge of each block had a 35-m-wide *B. tectorum* "wick" to carry fires into the treatment plots.

The four treatments included: graze and no-burn (GNB), graze and burn (GB), no-graze and burn (NGB), and no-graze and no-burn (NGNB). These treatments were designed to assess not only seed and aboveground community dynamics but also the resulting fire behavior (Diamond et al. 2009). The GB and GNB treatments were intensively grazed (equivalent of 83 cow–calf pairs ha^{-1}) during the boot stage of *B. tectorum* (just before inflorescence emergence from the culm) in early May 2005 and 2006. The plots were grazed to 80 to 90% removal of aboveground biomass and a stubble height of $<$ 10 cm over a 32- to 40-h period. Cool temperatures and frequent precipitation promoted regrowth and additional germination of *B. tectorum*, so intensive grazing (same duration and stocking density) was repeated on GB and GNB treatments in late May to maintain 80 to 90% removal of aboveground biomass. Although the initial study design called for peak fire season (July–August) burns, Hurricane Katrina in 2005 and an active fire season in 2006 diverted fire management resources. Thus, the October burns, after peak fire season in 2005 and 2006, were implemented during the optimum time period for prescribed burning of sagebrush–grassland communities in the Great Basin (Bunting et al. 1987). The NGB treatment was burned in mid-October 2005 and 2006. The GB treatment was also burned in mid-October 2005, but did not have enough fuel (biomass and continuity) to carry a fire more than 5 m into the treatment plots in mid-October 2006 (Diamond et al. 2009). The GB and NGB treatments were located at the southern end of all three blocks. The ignition point for all prescribed burns was a 35-m-wide *B. tectorum* wick, which allowed fires to reach peak behavior (flame length and rate of spread) before contacting the interface of the two burn treatments. Rate of spread was consistent across treatments; however, - flame length was greater in the NGB treatment than in the GB treatment (Table 1).

Seed Dynamics. Effects of grazing and fire on the seed dynamics of the four primary species, *B. tectorum*, *P. secunda*, *L. perfoliatum*, and *S. altissimum*, were evaluated in two ways: seed bank density and seed input. We estimated seed bank density and composition for each of the treatments by collecting soil cores (5 cm in depth, 2.5 cm in diam) and associated surface litter at 40 points in a five-by-eight grid of sampling points 2.5 m apart within each treatment plot. In 2005, a single soil core and associated litter was collected at each of the 40 points; however, in 2006, five soil cores and associated litter (subsamples) were collected at each of the 40 points. The subsamples were then mixed, and a composite soil–litter sample (one-fifth of the volume) was used to evaluate the seed bank density. We repeated this sampling in each of the treatments three times per year: post-graze (late May), peak biomass (late June), and post-burn (mid-October). After soil–litter samples were stored in a cold room set to 3 to 4 C for 3 mo to meet dormancy requirements, each soil–litter sample was placed on top of 4.5 cm of sand in a 10 by 10 by 10–cm (width by length by height) container. Soil–litter samples were spread evenly across the sand surface. Containers were placed in a greenhouse with a 12-h light period and a 12-h dark period, and a high temperature of 27 C and a low temperature of 15 C. After a 2-mo growing period, individuals of each species were identified, counted, and removed. The soil–litter samples were then dried in the greenhouse for 1 mo, and each soil–litter sample was mixed and placed back on the sand surface as before. The greenhouse study was then repeated. Some seeds that did not germinate in the first growing period germinated in the second growing period, allowing for a more complete estimation of the number of viable seeds per unit area. Seed bank data were analyzed in a three-way factorial (fire by grazing by year plus period). This is a split-split-plot design with whole plots in blocks. We used mixed-model ANOVAs to examine the effects of grazing, burning, and the combined effect of year and the period of collection on the seed bank. We used Fisher's Protected LSD ($P \leq 0.05$) to evaluate differences among treatment means (SAS Institute 2005).

Seed input was measured by collecting seed rain beginning in late May (post-graze) and ending mid-July (just prior to the originally scheduled burn during peak fire season) in 2006. Seeds were collected using 10 sample points along three randomly placed 30-m transects in each treatment plot. Each sample point consisted of a 10-cm-diam funnel buried to 1 cm above the soil surface to only allow seed entrance from above (methods modified from Chabrerie and Alard 2005). By only allowing seed entrance vertically, we only measured phase I dispersal and avoided the difficulty of measuring phase II dispersal (Chambers and MacMahon 1994). The funnel exit was sealed with cotton to allow water, but no solids, to pass through. The funnel was filled with fine gravel, which entrapped and incorporated the seeds over time. At the termination of the collection period, samples were stored in a cold room set to 3 to 4 C for 3 mo to meet dormancy requirements. Seeds from each sample were then sorted by species and placed on saturated filter paper in a 5 by 10 by 2.5–cm (width by length by height) germination container. A 12-h light period and a 12-h dark period, at high and low temperatures of 27 and 15 C, respectively, were used in a germination chamber. Germination was evaluated for grasses with emergence of the radicle and coleoptile, and for forbs with the emergence of the radicle and the cotyledon. Seed input was not measured for *S. altissimum* because dispersal for this species does not occur until fall, after sampling was discontinued (Young et al. 1970). The effects of intensive grazing and prescribed burning on seed input were evaluated in a two-way factorial (grazing by burning). This is a split-split-plot design with whole plots in blocks. We used mixed-model ANOVAs and Fisher's Protected LSD test ($P \leq 0.05$) to examine the effects of grazing and burning on seed input (SAS Institute 2005).

Aboveground Community Dynamics. The effects of grazing and fire on aboveground community composition were evaluated with cover, litter depth, and biomass production. We evaluated percentage of cover and litter depth measurements using 10 sample points alternating along three permanent 30-m transects in each treatment plot. Cover (live plant canopy by species, litter, and rock and soil surface) was measured in a 0.5 by 0.5–m quadrat at each sampling point. Litter depth was measured to the nearest millimeter when encountered in the cover survey. To measure biomass, we clipped the vegetation in 10 0.5 by 0.5–m quadrats alternating along a 30-m transect. Vegetation was clipped at the soil surface, separated by species, and dried at 60 C for 48 h. Two transects were randomly placed within each of the treatments in all three blocks. Biomass samples were collected three times per year: pregraze (late April), postgraze (late May), and at peak biomass (late June). Relative species composition for the four grazing–burning treatment combinations was determined each year (at peak biomass) by dividing the biomass for each species by the total biomass. Community composition was analyzed in a three-way factorial (fire by grazing by year plus period). This is a split-split-plot design with whole plots in blocks. We used mixed-model ANOVAs to examine the effects of grazing, burning, and the combined effect of year and the period of collection on community dynamics. We used Fisher's Protected LSD ($P \leq 0.05$) to evaluate differences among treatment means (SAS Institute 2005).

Results

Seed Dynamics. *Bromus tectorum* seed bank density varied significantly ($F_{15,2528} = 8.68$; $P < 0.001$) across treatments within sampling period, i.e. postgraze (late May), peak biomass (late June), and postburn (mid-October), ranging from 66 to 4,278 seeds m^{-2} (Figure 1). Postgraze 2005, the GB and GNB treatments had less than half the seed bank density of the NGB and NGNB treatments. At peak biomass 2005, after most of the seeds had dispersed, seed bank densities increased in all four grazing–burning treatments, but densities in the GB and GNB treatments remained significantly lower than in the NGB and NGNB treatments. Following burning in 2005, seed bank densities in the GB and NGB treatments were one one-hundreth the seed bank density in the GNB treatment, which was significantly lower than in the NGNB treatment. By postgraze 2006, after most of the seeds in the seed bank had germinated, seed bank densities were low in all four grazing–burning treatments, but remained significantly lower in the two burn treatments than in the two no-burn treatments. By peak biomass 2006, following seed dispersal, seed bank densities increased in all four treatments, with densities significantly higher in the

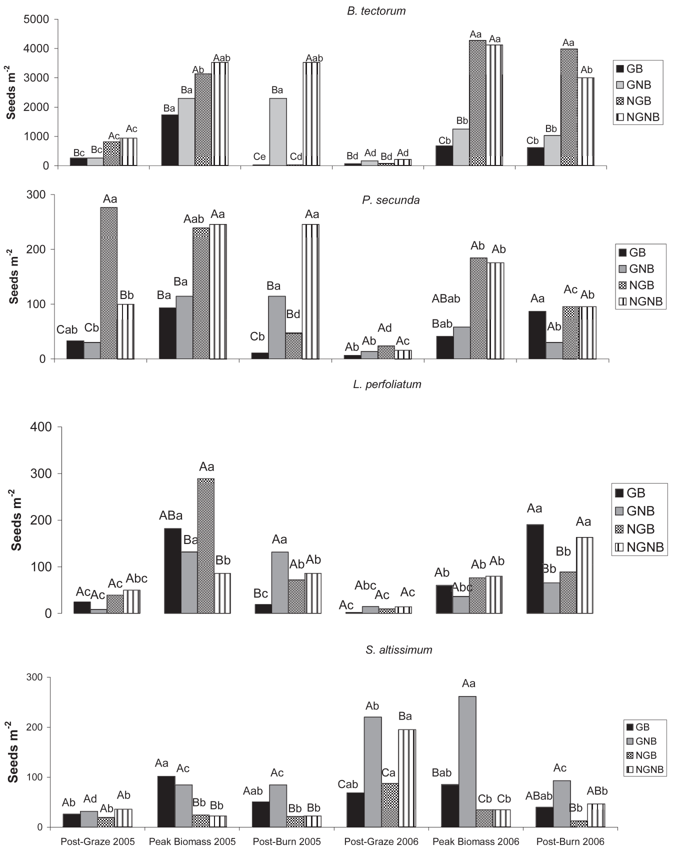

Figure 1. Seed density for *Bromus tectorum*, *Poa secunda*, *Lepidium perfoliatum*, and *Sisymbrium altissimum* for four treatments: graze and burn (GB), graze and no-burn (GNB), no-graze and burn (NGB) and a no-graze and no-burn treatment (NGNB), and six periods: postgraze (May 2005 and 2006), peak biomass (July 2005 and 2006), and postburn (October 2005 and 2006). Capital letters indicate mean comparisons across treatments within time period, and lowercase letters indicate mean comparisons across time periods within treatment. Means with different letters are significantly different ($P < 0.05$).

NGB and NGNB treatments than the density in the GNB treatment, which was also significantly higher than in the GB treatment. This trend held through the last sampling period after burning in 2006. *Bromus tectorum* seed bank density also varied significantly ($F_{5,2528} = 13.57$; $P < 0.001$) across sampling time periods within treatment. Seed bank densities were lowest in the GB and NGB treatments after burning in 2005; within 1 yr, they increased by 4-fold and 20-fold, respectively, after burning in 2006. Seed bank densities were lowest in the GNB treatment after grazing in 2005 and 2006. Since the NGNB treatment was not disturbed by grazing or burning, seed bank densities remained high during most sampling periods, except for postgraze 2005 and 2006, when densities were lowest after germination of seeds in the seed bank.

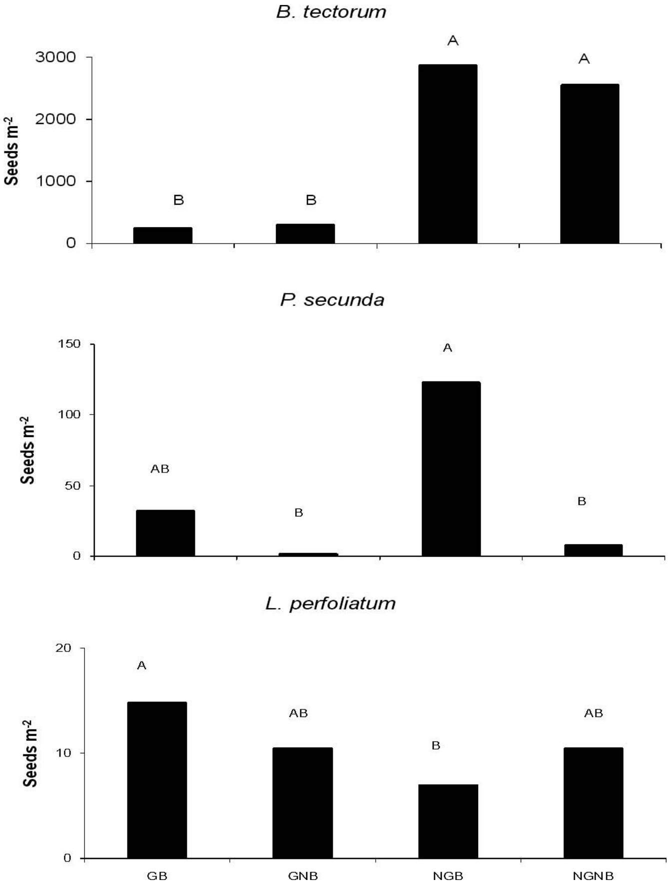

Figure 2. *Bromus tectorum, Poa secunda* and *Lepidium perfoliatum* seed input in 2006 for four treatments: graze and burn in 2005 and graze 2006 (GB), graze in 2005 and 2006 and no-burn (GNB), no-graze and burn in 2005 (NGB), and a no-graze and no-burn control (NGNB). Means with different letters are significantly different ($P < 0.05$).

Poa secunda seed bank densities ranged from 6 to 276 seeds m^{-2}, and differed across treatments ($F_{15,2528} = 9.39$; $P < 0.001$) within sampling period and across time periods within treatment ($F_{5,2528} = 30.61$; $P < 0.001$) (Figure 1). The effects of grazing and burning on *P. secunda* seed bank densities were similar to those for *B. tectorum*, with the GB and GNB treatments generally having significantly lower seed bank densities than the NGB and NGNB treatments at the postgraze 2005 and peak biomass 2005 and 2006 sampling periods, and the GB and NGB treatments having lower seed bank densities than the GNB and NGNB treatments at the postburn 2005 sampling period. In addition, *P. secunda* seed bank densities were low in all four grazing–burning treatments by the postgraze 2006 sampling period. There were no significant differences in seed bank densities among the four treatments after burning in 2006.

Lepidium perfoliatum seed bank densities ranged from 2 to 289 seeds m^{-2}, and varied significantly across treatments within time period ($F_{15,2528} = 8.68$; $P < 0.001$) and across

Table 2. Mean biomass (kg ha^{-1}) for *Bromus tectorum* (BROTE), *Sisymbrium altissimum* (SSYAL), *Lepidium perfoliatum* (LEPPE), *Poa secunda* (POASE), all other forbs combined (other forbs). and all other grasses combined (other grasses). These data were collected for three consecutive years at peak biomass (July) in four treatments.

Treatment	Year	BROTE[a]	SSYAL	LEPPE	POASE	Other forbs	Other grasses	Total
GB	2005	340 Ab[b]	32 Ab	160 Aa	5 Bb	11 Ab	2 Ab	550 Ab
	2006	34 Bb	5 Ba	15 Ba	1 Ba	8 Ab	0 Aa	63 Cc
	2007	15 Bb	33 Ab	6 Ca	48 Aa	15 Aab	7 Aa	125 Bb
GNB	2005	378 Ab	49 Aab	64 Ab	5 Ab	13 Ab	3 Ab	511 Ab
	2006	34 Bb	5 Ba	15 Ba	2 Aa	8 Ab	0 Aa	63 Cc
	2007	80 Bab	43 Aa	10 Ba	2 Ac	6 Ab	11 Aa	154 Bab
NGB	2005	896 Aa	65 Aa	108 Ab	49 Aa	57 Aa	46 Aa	1,221 Aa
	2006	101 Bb	3 Ca	6 Ba	2 Ca	17 Ba	2 Ba	131 Cb
	2007	85 Bab	36 Bb	7 Ba	16 Bb	28 Ba	4 Ba	177 Bab
NGNB	2005	952 Aa	54 Aab	177 Aa	46 Aa	21 Aab	11 Aa	1,261 Aa
	2006	578 Ba	13 Ca	9 Ba	2 Ba	8 Bb	5 Ba	616 Ba
	2007	146 Ca	23 Bb	19 Ba	0 Bc	15 Aab	0 Ba	202 Ca

[a] Abbreviations: BROTE, *Bromus tectorum*; SSYAL, *Sisymbrium altissimum*; LEPPE, *Lepidium perfoliatum*; POASE, *Poa secunda*; GB, graze and burn; GNB, graze and no-burn; NGB, no-graze and burn; NGNB, no-graze and no-burn.

[b] Capital letters indicate comparisons within treatment across years, and lower case letters indicate comparisons within year across treatments. Means with different letters are significantly different ($P < 0.05$).

time periods within treatment ($F_{5,2528} = 60.1$; $P < 0.001$) (Figure 1). Densities were lowest (and not significantly different) for all four grazing–burning treatments at the postgraze 2005 and 2006 sampling periods after seeds had germinated in the seed bank. By peak biomass 2005, following the dispersal of most *L. perfoliatum* seeds, seed bank densities increased in all treatments and were highest in the NGB treatment. Following burning in 2005, seed bank densities were significantly lower in the GB treatment than in the other treatments. It appears that seed dispersal extended over a longer period in 2006, with seed bank densities increasing in the four grazing–burning treatment combinations at peak biomass 2006, and further increasing after burning in 2006.

Sisymbrium altissimum seed bank densities ranged from 19 to 261 seeds m^{-2}, and varied significantly ($F_{15,\ 2528} = 7.41$; $P < 0.001$) across treatments within time periods and across time periods within treatment ($F_{5,2528} = 44.69$; $P < 0.001$) (Figure 1). Seed bank densities were low and indistinguishable in all four grazing–burning treatment combinations at the postgraze 2005 sampling period after seeds had germinated in the seed bank. Seed bank densities increased in the GB and GNB treatments and remained unchanged in the NGB and NGNB treatments at the peak biomass 2005 and postburn 2005 sampling periods. Following seed dispersal from tumbling *S. altissimum* plants in the fall and winter, seed bank densities increased in all four treatments (with significant increases in the GNB, NGB, and NGNB treatments) by postgraze 2006. Seed bank density remained highest in the GNB treatment for the peak biomass and postburn sampling periods in 2006.

Seed input for *B. tectorum*, *P. secunda*, and *L. perfoliatum*, extrapolated from seeds collected in funnel traps from late May to mid-July 2006, varied across the four grazing-burning treatment combinations (Figure 2). *Bromus tectorum* seed input ranged from 250 to 2,870 seeds m^{-2}, and was significantly reduced ($F_{3,6} = 63.95$; $P < 0.001$) by grazing in May 2006, with GB and GNB treatments having one-tenth the input of NGB and NGNB treatments. *Poa secunda* seed input was much lower than that of *B. tectorum*, ranging from 2 to 123 seeds m^{-2}. The NGB treatment had at least four times greater seed input ($F_{3,6} = 0.45$; $P = 0.76$) than not only the GB and GNB treatments, but also the NGNB treatment, which was never grazed or burned. *Lepidium perfoliatum* seed input was even lower than that for *P. secunda*, ranging from 7 to 15 seeds m^{-2}. Recent grazing in May 2006 did not reduce ($F_{3,6} = 0.54$; $P = 0.67$) the seed input of this forb as it did for *B. tectorum* and *P. secunda*. In fact, the NGB treatment had the lowest seed input.

Aboveground Community Dynamics. Species biomass varied significantly across years and treatments (*B. tectorum* [$F_{3,452} = 29.51$; $P < 0.001$], *P. secunda* [$F_{3,452} = 7.29$; $P = 0.02$], *S. altissimum* [$F_{3,452} = 11.41$; $P < 0.001$], and *L. perfoliatum* [$F_{3,452} = 7.80$; $P < 0.001$]) (Table 2). These differences in species biomass resulted in changes in community composition from 2005 to 2007 (Figure 3). In the GB treatment, *B. tectorum* composition decreased from > 50 to $< 10\%$, *P. secunda* increased from < 5 to $> 50\%$, *S. altissimum* increased from 5 to $> 20\%$, *L. perfoliatum* decreased from 20 to 5%, and other forbs and grasses

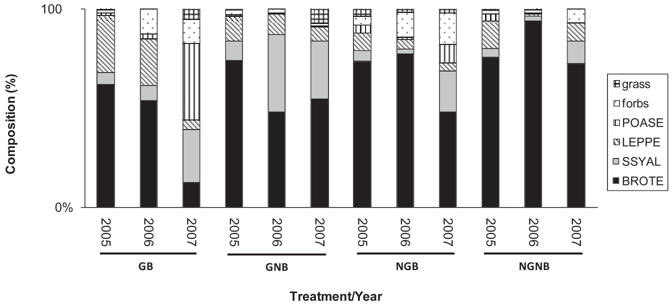

Figure 3. Community composition based on proportion of total biomass for *Bromus tectorum* (BROTE), *Sisymbrium altissimum* (SSYAL), *Lepidium perfoliatum* (LEPPE), *Poa secunda* (POASE), all other forbs combined (forbs) and all other grasses combined (grass). These data were collected for three consecutive years at peak biomass in four treatments: graze and burn (GB), graze and no-burn (GNB), no-graze and burn (NGB), and a no-graze and no-burn control (NGNB).

increased from < 2 to > 15%. In the GNB treatment, *B. tectorum* decreased from > 60 to < 50%, *P. secunda* and *L. perfoliatum* remained at 10%, *S. altissimum* increased from 10 to > 20%, and other forbs and grasses increased from < 2 to > 10%. In the NGB treatment, *B. tectorum* composition decreased from 60 to < 50%, *P. secunda* increased from 2 to 10%, *S. altissimum* increased from 5 to > 15%, *L. perfoliatum* decreased from 5 to 2%, and other forbs and grasses increased from < 2 to > 10%. Species composition in the NGNB treatment did not vary markedly throughout the study. *Bromus tectorum* accounted for 60 to 90% of the composition, *P. secunda* for 1 to 2%, *S. altissimum* for 2 to 10%, *L. perfoliatum* for 1 to 10%, and other forbs and grasses for 1 to 5%.

Soil and litter dynamics are presented here because of their influence on annual plant establishment and performance. There was a significant treatment effect of grazing and burning on bare soil cover ($F_{3,6} = 24.42$; $P < 0.001$) (Table 3). In 2005, the grazed treatments (GB and GNB) had twice the soil cover of the nongrazed treatments (NGB and NGNB). By 2006, the soil cover in the GB treatment was three times that of the GNB and NGB treatments and 15 times that of the NGNB treatment. In 2007, soil cover in the GB treatment was not significantly different from the NGB treatment, but it was two and nine times greater than in the GNB and NGNB treatments, respectively.

Grazing and burning also had a significant effect on litter cover across treatments ($F_{3,6} = 6.09$; $P < 0.029$) in 2006 and 2007 (Table 3). In 2006, litter cover in the GNB treatment was at least two times greater than in the other treatments, which did not differ from one another. In 2007, the nonburned treatments (GNB and NGNB) had almost twice the litter cover observed in the burned (GB and NGB) treatments.

Table 3. Mean values (± SE) for litter cover, litter depth, and bare soil cover for treatments in 2005, 2006, and 2007.[a]

	2005				2006				2007			
Attribute	GB	GNB	NGB	NGNB	GB	GNB	NGB	NGNB	GB	GNB	NGB	NGNB
Litter cover (%)	10 ± 3.7	17 ± 3.7	10 ± 3.7	20 ± 5	18 ± 3.7	30 ± 3.4	9 ± 3.5	12 ± 3.4	27 ± 3.2	46 ± 3.3	29 ± 3.9	50 ± 4.4
Litter depth (cm)	1 ± 0.1	1 ± 0.3	2 ± 0.3	2 ± 0.5	0.8 ± 0.1	1.5 ± 0.4	0.6 ± 0.2	2.5 ± 0.4	0.4 ± 0.1	1.4 ± 0.1	0.5 ± 0.1	2.8 ± 0.1
Soil cover (%)	31 ± 4.4	42 ± 4.4	15 ± 4.4	14 ±4.4	45 ± 4.2	12 ± 4.1	17 ± 4.1	3 ± 4.1	45 ± 4.2	19 ± 4.2	37 ± 4.2	5 ± 4.3

[a] Abbreviations: GB, graze and burn; GNB, graze and no-burn; NGB, no-graze and burn; NGNB, no-graze and no-burn.

Grazing and burning also had a significant effect on litter depth across treatments and years ($F_{6,940} = 119.72$; $P < 0.001$) (Table 3). Litter depth was lowest in the GB treatment in 2005. In 2006, grazing (GNB) and burning (NGB) alone, and in combination (GB), reduced litter depth to about one-half that of the control treatment (NGNB). Litter depth was significantly greater in the control treatment (NGNB) than the burning treatment (NGB), which was significantly greater than the grazing (GNB) and combination (GB) treatments (Table 3).

Discussion

Grazing and fire, and their interaction, have the potential to drastically alter plant communities, as observed in the decline of sagebrush–grasslands (Miller et al. 1994; Peters and Bunting 1994; Whisenant 1990; Young and Clements 2009). Any recovery of plant communities in the northern Great Basin requires management of these disturbances (Evans and Young 1984). Intensive grazing has the potential to reduce *B. tectorum* dominance via the removal of biomass (fuel for frequent fires) and the suppression of reproductive potential (Daubenmire 1940; Mack and Pyke 1984). Prescribed burning also has the potential to suppress *B. tectorum* by killing or damaging seeds in the litter and modifying microsites for germination and establishment via litter removal (Evans and Young 1984; Humphrey and Schupp 2001). The integration of intensive grazing and prescribed burning can have a greater impact on *B. tectorum* seed and aboveground community dynamics than either treatment alone (Young and Clements 2009).

The GNB treatment reduced *B. tectorum* seed bank density during most sampling periods in 2005 and 2006 (Figure 1). The reduction of seed density following intensive grazing in May 2005 was likely due to cattle hoof action and environmental conditions. Trampling has the potential to compress and redistribute litter, increasing seed–soil contact for *B. tectorum* seeds suspended in the litter (Allen et al. 1995). Trampling along with cool temperatures and frequent precipitation between the first (early May) and second (late May) grazing events promoted germination. Seed bank density was low in all four grazing–burning treatment combinations at the postgraze sampling period in May 2006. Germination of most of the seed in the seed banks in all treatments was promoted by favorable moisture conditions in fall 2005 and spring 2006 prior to grazing in May 2006. In a seed bank carryover study in western Utah, Smith et al. (2008) observed that most of the *B. tectorum* seed bank (96%) can germinate during the first fall and spring after seed dispersal. Grazing at the boot stage reduced seed input into the seed bank, as reflected in lower seed bank densities at peak biomass sampling periods in late June 2005 and 2006 (Figures 1 and 2).

Two years of consecutive grazing also altered the seed dynamics of *P. secunda*, *L. perfoliatum*, and *S. altissimum*. Although an order of magnitude lower, *P. secunda* seed input and seed bank density for the GNB treatment essentially followed the same pattern as for *B. tectorum* (Figures 1 and 2). Both species flower and set seed at approximately the same time (Blaisdell 1958; Pyke and Novak 1994); therefore, *P. secunda* is also susceptible to having flower heads removed or trampled during intensive cattle grazing in early and late May, reducing potential seed input into the seed bank. Hoof action may have also increased seed–soil contact for *P. secunda* seeds, enhancing germination. The palatability of *L. perfoliatum* and *S. altissimum* is low for cattle, with some limited use when plants are young (Dittberner and Olson 1983); thus, these species were avoided when they were in the flowering stage during grazing events in May 2005 and 2006. Although some of these annual forbs were trampled during grazing events, most plants flowered and set seeds in the GNB treatment. The small, smooth, ovate seeds of *L. perfoliatum* (2 mm long by 2 mm diam) and *S. altissimum* (1 mm long by 0.8 mm diam) allow for good seed–soil contact without trampling (Evans and Young 1970; Young et al. 1970). However, redistribution of litter by hoof action reduced litter depth and exposed small patches of bare soil, creating sites more favorable to both species (Young et al. 1970). *Lepidium perfoliatum* and *S. altissimum* germination is much higher on bare soil than under litter in their native ranges in Russia (Volodina 1992; Young and Evans 1975). Seed input of *S. altissimum* was likely composed of primary dispersal from standing plants within treatments as well as secondary dispersal from plants that tumbled onto the treatment plots from the GB and NGB treatments and adjacent untreated areas (Kostivkovsky and Young 2000).

The suppression of *B. tectorum* seed bank density and seed input by two consecutive years of grazing (GNB treatment) led to changes in the community composition (Figure 3). The resultant community was composed of approximately 50% *B. tectorum*, 30 to 40% *S. altissimum,* 8 to 10% *L. perfoliatum,* 5% *P. secunda*, and a small percentage of other grasses and forbs (*Ceratocephala testiculata, Chorispora tenella, Alyssum desertorum*, *Erodium cicutarium*, *Lactua serriola*, *Poa bulbosa*, and *Vulpia octoflora*). Daubenmire (1940) observed an increase in *S. altissimum* on intensively grazed sites in a bunchgrass prairie in southeastern Washington. Grazing not only directly suppressed *B. tectorum*, but fragmented the litter bed via hoof action. The increase in *S. altissimum* following grazing is short-lived because even though fragmented, remaining litter will provide safe sites for subsequent *B. tectorum* establishment. However, the persistent seed bank of *S. altissimum* allows for reestablishment following the next disturbance (Rickard 1985). Grazing alone can only alter community composition, seed input, and seed bank densities for a very narrow window of time. Thus, this grazing method should be used as a step in an integrated management approach.

Prescribed burning in 2005 (NGB treatment) significantly reduced *B. tectorum* seed bank density (Figure 1). By burning in October (after seed shatter), fire has the potential to kill or damage seeds suspended in the litter bed (Thill et al. 1984; Young and Evans 1975). However, following a late-season burn, *B. tectorum* can rapidly reestablish dominance on a site via increased seed production from plants that develop from seeds protected in the soil (Daubenmire 1975). Seed production can increase from 10 to 250 seeds plant^{-1} prior to a burn, to 960 to 6,000 seeds plant^{-1}after a burn, due to lower plant densities and greater resource availability (Young and Evans 1978). Thus, within 1 yr, *B. tectorum* seed bank density in the NGB treatment had recovered to preburn conditions (Figure 1). A similar trend was reported by Humphrey and Schupp (2001) in the West Desert of Utah, where an initial drop in seed bank density the first year after burning was followed by a quick recovery the following year. Hassan and West (1986) documented a doubling of the *B. tectorum* seed bank density 1 yr after a fire in a sagebrush community in Central Utah.

As with the grazing treatment, *P. secunda* and the annual forbs, *L. perfoliatum* and *S. altissimum*, responded differently to the NGB treatment in terms of seed dynamics (Figures 1 and 2). Burning in October reduced the seed bank density of *P. secunda* in 2005 but not in 2006. Fire effects on the seed bank density of this grass species are not well documented, but fire may kill some seeds in the upper soil layers. Champlin (1982), using a burning chamber in a mountain big sagebrush community in eastern Oregon, found that *P. secunda* seedling emergence (from seeds in the top 1 to 2 cm of the soil) was significantly reduced by cool (104 C) and hot (416 C) prescribed burns. The first prescribed burn in our study, in October 2005, had a greater fuel load and continuity, and thus was hotter than the second prescribed burn in October 2006 (Diamond et al. 2009). After a fire, both *L. perfoliatum* and *S. altissimum* establish from soil-stored seeds and those dispersed into the site postfire (Young and Evans 1981). The impact of fire on the seed bank densities of these two species is lacking, but their tiny seeds, particularly those of *S. altissimum*, can easily fall into fire-safe microsites such as soil crevices (Young and Evans 1981). Fire is likely to kill some seed, but the overall effect to seed bank densities of these two species is probably negligible compared to the effect on the larger, more elongate seeds (florets) of *B. tectorum*, which have a greater tendency to remain in litter or on the soil surface (Chambers and MacMahon 1994).

Two consecutive years of late-season prescribed burns (NGB treatment) also resulted in initial changes in *B. tectorum* community composition (Figure 3). The decrease in *B. tectorum* was likely due to removal of much of the litter bed and soil seed bank via fire, thus reducing the numbers of seeds and of potential safe sites for germination (Evans and Young 1970). Prescribed burning altered soil surface characteristics (litter cover and depth, and amount of bare soil), and resulted in an increase in *S. altissimum* (Table 3). Annual forbs such as *S. altissimum* add to the litter layer, which facilitates *B. tectorum* establishment and recovery following a fire (Evans and Young 1984). Once *B. tectorum* becomes established under the conditions provided by *S. altissimum,* the latter is readily out-competed for nutrients and water (Daubenmire 1940; Young and Evans 1978). *Poa secunda* responded positively to the prescribed burns. Wright and Klemmedson (1965) noted that *P. secunda* basal cover increased twofold the first year after a fire in a sagebrush–grassland community in southern Idaho. Daubenmire (1975) observed that *P. secunda* competed more successfully than other native perennials with *B. tectorum* as a result of increased tillering following the reduction of litter and improved insulation caused by fire, but he noted that postfire gains lasted only a few years, after which *B. tectorum* resumed its prefire dominance. Young and Evans (1978) also described a similar response after a fire in northern Nevada, where *P. secunda* initially increased after a fire, but quickly decreased by 2 yr postfire, indicating that this prescribed fire method is a step in an integrated management approach.

The GB treatment resulted in reduced *B. tectorum* seed input and community dominance, as with the GNB treatment, and reduced seed bank density, as with the NGB treatment (Figures 1–3). The magnitude of these changes, however, was greater for the GB treatment. Lower representation of *B. tectorum* in the community was due to a reduction in the seed input via grazing, and the removal of the litter bed and associated seeds via burning. The GB treatment shifted a *B. tectorum*–dominated community with high seed inputs, high seed bank densities, and a deep and contiguous litter bed to a *P. secunda* and *S. altissimum*–dominated community with low *B. tectorum* seed input, a greatly reduced *B. tectorum* seed bank density, and islands of litter in a matrix of bare soil.

After using intensive and repeated clipping treatments during the boot stage to reduce *B. tectorum* seed input and seed bank densities in sagebrush-steppe communities in eastern Oregon, Hempy-Mayer and Pyke (2008) questioned the potential of livestock to remove *B. tectorum* competition in preparation for the successful reestablishment of native plants through artificial seeding. They indicated that four questions should be investigated: (1) whether livestock are able to achieve equal or greater seed reductions using the defoliation parameters in their study (clipping plants short at the boot stage, and again 2 wk later); (2) what the range of environmental conditions would be for this treatment to be effective; (3) whether livestock would be practical for larger-sized projects; and (4) whether defoliation effectiveness could be improved by increasing the defoliation intensity, repeating the defoliation for at least 2 yr, using an integrated weed management approach with other control methods such as herbicide application or prescribed burning, or some combination of these measures.

Although our study did not specifically address the potential of using cattle to prepare a *B. tectorum*–dominated community for native plant seeding, it did address some aspects of the questions above. After 2 yr of targeted grazing, seed bank densities in our study (1,032 seeds m^{-2} for GNB treatment and 616 seeds m^{-2} for GB treatment) were still above a threshold of 330 *B. tectorum* seeds m^{-2}, below which reseeding success increases due to decreased competition (Hempy-Mayer and Pyke 2008).

Our treatment plots, 0.36 ha in size, do not equate to a large-scale project. However, based upon our grazing treatment parameters (biomass production of 1,503 kg ha^{-1}, stocking density of 83 cow–calf pairs ha^{-1}, and 80 to 90% biomass utilization), we can estimate that a herd comprising of 500 cow–calf pairs could intensively graze about 42 ha of *B. tectorum*–dominated rangeland during the growing season (grazed two times during boot/soft dough stage over a 1-mo period) if fencing and water requirements can be met.

Given the spatial and temporal limits of this intensive grazing treatment, most land managers would apply it at a fairly small scale, i.e., to prepare patches for seeding or to create or maintain fuel break strips. By grazing for two consecutive years, we were able to reduce *B. tectorum* seed bank densities further than by grazing for just 1 yr. And, we demonstrated that *B. tectorum* suppression was more effective if integrated with prescribed burning (Figures 1–3) Thus, our study addressed some of the questions posed by Hempy-Mayer and Pyke (2008); however, further work is required before targeted cattle grazing (and other integrated treatments) can be effectively used to shift the community and seed dynamics of *B. tectorum*–dominated landscapes, especially at large scales (> 10 ha). However, we have demonstrated the feasibility of these grazing and burning methods for changing community dynamics, seed input, and seed bank densities at a meso scale. This meso-scale approach provides a baseline for designing landscape scale *B. tectorum* adaptive management grazing and burning methodologies.

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