Weed Science 2008 56:469–476

Restoring Western Juniper- (*Juniperus occidentalis*) Infested Rangeland after Prescribed Fire

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Restoring range sites dominated by western juniper is central to maintaining healthy functioning shrub–steppe ecosystems. On sites without adequate species composition to respond favorably to juniper controlled by fire, revegetation is necessary. We tested the following two hypotheses related to restoration after juniper control: (1) higher seeding rates would translate into higher density of seeded species, and (2) a rich seeding mixture would provide higher density and biomass than monocultures. Western juniper control was done by cutting 25% of the trees in 2002, allowing cut trees to dry for one year, followed by a broadcast fire applied in October 2003 which killed the remaining live juniper trees. Seeding treatments were applied in 2003 and included seeding six native species in monocultures, seeding a mixture of all six species at four rates (16.8, 22.4, 28.0, or 33.6 kg ha^{-1} of pure live seeds), and a nonseeded control. Treatments were applied on a Sagebrush/bunchgrass and Snowberry/fescue site. We found that bluebunch wheatgrass, Idaho fescue, big bluegrass, and western yarrow density ranged from 450 to 700 plants m^{-2}, which was over six-fold that of the control in 2004 at both sites. Only arrowleaf balsamroot did not establish successfully. The density of big bluegrass nearly doubled from 2004 to 2005. The highest plant density resulted from the highest seeding rate. The highest biomass production was combination seeding at 22.4 kg ha^{-1} on the Sagebrush/bunchgrass site and 33.6 kg ha^{-1} on the Snowberry/fescue site. Seeding a combination of species resulted in a moderate to high density of plants and optimized plant diversity and richness over seeding monocultures.

Nomenclature: Arrowleaf balsamroot, *Balsamorhiza sagittata* (Pursh) Nutt.; bluebunch wheatgrass, *Pseudoroegneria spicata* (Pursh) A. Löve; Idaho fescue, *Festuca idahoensis* Elmer; western juniper, *Juniperus occidentalis* Hook.; big bluegrass, *Poa ampla* Merr.; western yarrow, *Achillea millefolium* L.

Key words: Juniper management, prescribed fire, reseeding, revegetation.

The expansion of western juniper during the past 130 yr causes considerable concern because woodlands are replacing shrub–steppe and deciduous plant communities (Miller et al. 2000). The geographic range of western juniper has increased by 95% since 1870 to about 4 million ha in central and eastern Oregon, northeastern California, southwestern Idaho, and northwestern Nevada (Miller et al. 2005). The negative impacts of invasion by western juniper include increased soil erosion (Miller et al. 2005), reduced forage production (Bates et al. 2005; Vaitkus and Eddleman 1987), altered wildlife habitat (Leckenby et al. 1971; Miller et al. 2005; Noson et al. 2006; Schaefer et al. 2003), and changes in plant community composition (Bates et al. 2000; Miller et al. 2000). Land managers are currently planning and implementing control measures for western juniper throughout the four-state region.

Previous research has focused on understanding the response of desired vegetation after control of western juniper (Bates et al. 2000, 2005; Eddleman 2002). The level and rate of plant community response varies in response to posttreatment weather conditions, management, grazing history, site potential, seedbanks, and plant composition prior to treatment (Miller et al. 2005). In several studies, exotic annual grasses (primarily downy brome, *Bromus tectorum* L.) dominated the site after control (Vaitkus and Eddleman 1987; Young et al. 1985). Eddleman (2002) and Bates et al. (2005) estimated that 1 to 3 perennial bunchgrass plants m^{-2} are sufficient to allow native community recovery following western juniper control. Restoration is necessary for sites that lack adequate desired species composition to respond favorably to juniper controlled by fire.

Revegetation of weed dominated rangeland with nonnative species has been somewhat successful (Jacobs et al. 1999; Sheley et al. 2001; Young et al. 1985), whereas restoring weed infested rangeland with native species has largely been unsuccessful. In most cases, restoration with native plants is not included in juniper management because of the high cost and risk of failure (Jacobs et al. 1999). Failures occur because of poor germination and emergence (Rose 1998). In most cases, environmental conditions do not coincide with the ecological requirements of individual species selected for establishment. For example, Wirth and Pyke (2003) found that only 8% of the seeds of woolypod milkvetch (*Astragalus purshii* Dougl. ex Hook.) emerged, whereas 38% of two *Crepis* species emerged across various site preparation treatments in a sagebrush-grassland habitat.

Three factors that contribute to the successful restoration of herbaceous plant communities after western juniper control are: (1) the degree to which the seeded species are adapted to the environment (Miller et al. 2005); (2) the number of seeds that reach a safe site (Sheley et al. 2005); and (3) the degree to which current year's environmental conditions favor germination and establishment (Sheley and Half 2006). Intuitively, species abundant in the plant community prior to invasion by western juniper could offer some guidance as to species choice. However, drastic alterations in plant communities might have changed the system enough to make establishing these species difficult (Jones 2003). In any case, seeding species mixtures that represent a diversity of functional characteristics can convey some invasion resistance to the resulting plant community (Pokorny et al. 2005).

One method for enhancing seedling establishment can be increasing seeding rates to increase the probability that seeds reach a safe site. While restoring rangeland dominated by spotted knapweed (*Centaurea maculosa* Lam.), seeding rates higher than 500 seeds m^{-2} yielded greater wheatgrass biomass than the nonseeded control with or without tillage or glyphosate (Sheley et al. 2005). In a similar system, Sheley and Half (2006) found native forb density was greatest using

DOI: 10.1614/WS-07-131.1

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the highest seeding rates. Without a priori knowledge of species germination and establishment characteristics or stable weather patterns, seeding a mixture of species can provide greater probabilities for consistent establishment. Seed mixtures can be selected so that they possess a variety of requirements for germination and emergence so at least one or two species traits match the current year's conditions (Sheley and Half 2006).

Little is known about species choice, seeding rates, and the merits of using a rich seed mixture during restoration of western juniper-dominated rangeland. Our objectives were to: (1) evaluate potential species for seeding in dry (Sagebrush/bunchgrass) or wet (Snowberry/fescue) sites dominated by western juniper that was controlled using a cutting and prescribed fire combination, (2) determine if increasing the seeding rate would increase desired species establishment, and (3) determine if a mixture of species would yield greater establishment than seeding a monoculture. We hypothesized that the highest density and biomass of seeded species would occur at the highest seeding rate and that seeding a rich mixture would provide densities and biomass equal to or greater than species seeded as monocultures, regardless of site.

Methods

Study Sites. The study sites were located within the Juniper Creek watershed on South Mountain, southwest Idaho (42°39′50.6″N, 116°51′31″W, 1927). Elevation at the sites was 1,650 m. The study was conducted on two plant associations; Western snowberry–Mountain big sagebrush/Idaho fescue–Columbia needlegrass [*Symphoricarpus occidentalis* Hook.–*Artemisia tridentata* Nutt. ssp. *vaseyana* (Rydb.) Beetle/*Festuca idahoensis* Elmer–*Achnatherum nelsonii* (Scribn.) Barkworth ssp. *nelsonii*] and mountain big sagebrush/Letterman's needlegrass–bluebunch wheatgrass [*Artemisia tridentata* Nutt. ssp. *vaseyana* (Rydb.) Beetle/*Achnatherum lettermanii* (Vasey) Barkworth, *Pseudoroegneria spicata* (Pursh) A. Löve ssp. *spicata*]. These associations are representative of the main community types found between 1,525 and 2,135 m being invaded by juniper. The Western snowberry–Mountain big sagebrush/Idaho fescue–Columbia needlegrass (Snowberry/fescue) site lies on a north-facing aspect, and the mountain big sagebrush/bluebunch wheatgrass–Letterman's needlegrass (Sagebrush/bunchgrass) lies on a west-facing aspect. Both associations were dominated by postsettlement (< 100 yr old) western juniper woodlands. Studies by Miller et al. (2000, 2005) of similar plant communities in eastern Oregon indicated that on both our study sites juniper encroachment had largely eliminated the shrub layer and depleted the understory on our sites. In the Snowberry/fescue site, western juniper, shrub, and herbaceous canopy cover averaged 68, 2, and 8%, respectively. Western juniper density on the snowberry/fescue site was 460 mature trees ha^{-1}. In the Sagebrush/bunchgrass site, western juniper, shrub, and herbaceous canopy cover averaged 47, 1, and 7%, respectively. Western juniper density on the sagebrush/bunchgrass site was 400 mature trees ha^{-1}. Pre- and posttreatment vegetation (trees, shrubs, herbaceous) descriptions were obtained in summer 2002. On each site, four 50-m transects were established with transects spaced 15 m apart. Western juniper and shrub cover were estimated by line intercept along the 50-m transects. Densities of mature

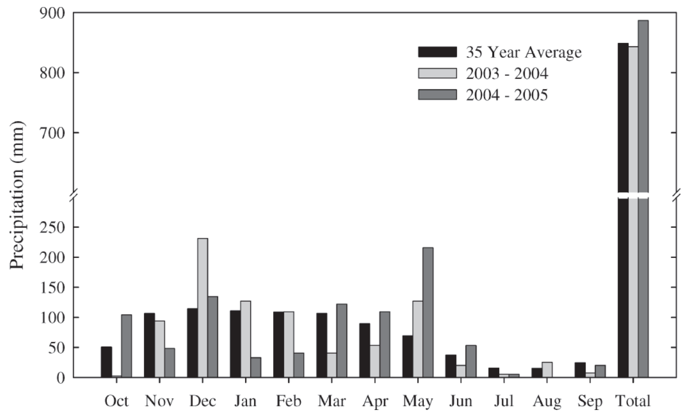

Figure 1. Precipitation 12.5 km north of the study sites on South Mountain, ID.

western juniper were estimated by counting all rooted individuals along four, 6- by 50-m belt transects. Densities of shrubs and juvenile junipers (< 2 m height) were estimated by counting all rooted individuals along four, 2 by 50 m belt transects. Understory canopy cover (by species) and herbaceous perennial densities (by species) were sampled inside 0.2 m^{-2} frames (0.4 by 0.5 m). Frames were placed every 2 m along transect lines.

Soils were described to the subgroup level on each site. Both soils were classified as Pachic Argixerolls and exceeded 1 m in depth. The Snowberry/fescue site had a deeper A horizon (A1, 0 to 10 cm; A2, 10 to 30 cm) than the Sagebrush/bunchgrass site (0 to 6 cm deep). Soil pH of the A horizon was 6.7 in the Snowberry/fescue site and was 7.4 in the Sagebrush/bunchgrass site.

Climate is typical of the northern Great Basin with cold, wet winters and warm, dry summers. Precipitation occurs mostly in winter and early spring. Annual precipitation (October 1 to September 30) at the NRCS SNOTEL site on South Mountain (12.5 km north of the study, 1,980 m elevation) has averaged 850 mm the past 35 yr (1971 to 2005; Figure 1). Precipitation at the SNOTEL site likely overestimates what was received at our study area, which is 330 m lower in elevation. The precipitation data is presented to indicate precipitation trends during the study period. Precipitation was about average during the 2 yr posttreatment (2003 to 2005), although distribution appeared to be different.

Pretreatment Western Juniper Control Using Fire. A quarter of the juniper trees were cut in October 2002 to provide ladder fuels to kill remaining uncut juniper. The prescribed fire was conducted in mid-October 2003. All remaining trees were killed by the fire treatment. The fire was judged to be severe in the Snowberry/fescue site because more than 90% of the perennial bunchgrasses were killed. In the Sagebrush/bunchgrass site the fire was judged to be of moderate severity because less than 30% of the perennial bunchgrass was killed. Mortality estimates were derived from pre- and posttreatment site measurements of bunchgrass density. The differences in perennial grass mortality were likely a result of fuel continuity and loads. In the Snowberry/fescue site the ground was covered with juniper needle litter, in addition to downed trees, and soil temperature (2 cm deep) ranged from 135 to 650 C (average: 339 ± 62 C). In the

Sagebrush/bunchgrass site, areas between trees were primarily bare ground, and soil temperature did not exceed 79 C.

Experimental Design and Procedures. On each site, treatments included seeding six native species in monoculture at four rates, seeding a mixture of all six species at four rates, and a not-treated control (7 species/species combinations × 4 seeding rates + 1 control = 29 treatments). Native grasses were bluebunch wheatgrass, Idaho fescue, and big bluegrass. The native forbs were western yarrow, arrowleaf balsamroot, and wild blue flax (*Linum perenne* var *lewisii* (Pursh) Eat. and Wright). All species, aside from blue flax, were present on each site prior to western juniper control. Seeds were purchased from Granite Seed, Loveland, CO. Seeding rates were 16.8, 22.4, 28.0, or 33.6 kg ha^{-1} of pure live seeds. To compare species, we used seed weight because seed weight represents the total amount of carbohydrates available for germination and establishment of that species (Fenner and Thompsen 2005). Seeds were broadcast on the soil surface within 2 by 2 m plots in October 2003. The mixture included equal proportions based on weight of all six species. Treatments were replicated four times at both sites and placed in a randomized complete block design.

Sampling. Plots were sampled in July 2004 and 2005. In 2004, density of species was counted in three randomly placed 20 by 50-cm frames in each plot. Density of tillers was counted for grasses, whereas the number of individuals was counted for forb species. Densities were used to provide an initial indication of seedling establishment without disrupting the study by destructive sampling. In 2005, frames were rerandomized and density of each species was counted. In addition, each frame was clipped to ground level to estimate biomass. Plants were separated by species, dried (60 C for 48 hr), and weighed.

Richness was the number of species occurring in each plot. To provide a measure of the character of the community in each plot that takes into account abundance patterns, we calculated Simpson's diversity index using:

$$D = \frac{1}{\sum_{i=1}^{S} p_i^2} \qquad [1]$$

where s was the total number of species (i.e., richness) and the proportion, p_i for the ith species, was based on that species density (Magurran 1988).

Data Analysis. Data for the seeded species were analyzed individually, but data from naturally occurring species were combined into four groups: perennial grasses, annual grasses, perennial forbs, and annual forbs. Data from plots seeded with the combination of species represent their combined density or biomass. Data were tested and met conditions for homogeneity of variances. Analysis of variance was conducted as a split-split-plot in time using Proc Mixed (SAS 2006). Rep (site) was used as the error term for site. Species by rate by rep (site) was used as the error term for species, rate, species by rate, and species and rate interactions within site. Year by rep (site) was used as the error term for testing year and year by site. The residual error was used for other interactions with year. Because the control could not include seeding rates, data from control plots are presented in the same graphs along with the standard error of the mean. The P values from *F*-tests are presented and individual means were compared using Tukey's Honestly Significant Difference (HSD) test at the 5% level of confidence when P values were significant at the 5% level (Peterson 1985). Data presented are averaged over factors that were not significant or did not interact.

Table 1. P values from the ANOVA on the effects of site, species, seeding rate, and year on density and biomass of seeded species.

Source	Seeded Density	Seeded Biomass[a]
Site	0.060	0.936
Species	0.001	0.001
Rate	0.001	0.431
Rate × site	0.957	0.028
Species × rate	0.185	0.929
Species × site	0.529	0.001
Species × rate × site	0.549	0.163
Year	0.001	
Rate × year	0.067	
Site × year	0.239	
Species × year	0.001	
Rate × site × year	0.841	
Species × rate × year	0.131	
Species × site × year	0.020	

[a] Biomass data were only collected in 2005.

Results

Seeded Species. *Density.* The effect of seeded species on their density depended upon the site and year after seeding (Table 1). At the Sagebrush/bunchgrass site, Idaho fescue and big bluegrass produced about twice the tillers than did bluebunch wheatgrass in 2004 (Figure 2). By 2005, all three seeded grasses had similar densities and those densities were higher in 2005 than in 2004. At the Snowberry/fescue site, grasses responded in a similar pattern as at the Sagebrush/bunchgrass site, except big bluegrass nearly tripled in density in 2005. This response by big bluegrass accounted for the site interaction. Among forbs, western yarrow density was higher where seeded than that of the nonseeded control. Although some blue flax established and maintained presence in seeded plots, the density was not significantly higher than that of the nonseeded control either year. The density of the seeded species in plots where a combination of species were seeded essentially mimicked the pattern of grasses. Arrowleaf balsamroot density was near zero and similar to that of the control in both years.

The density of seeded species also depended upon seed rate, regardless of species, year or site (Table 1). Seeding at 16.8 kg ha^{-1} produced the lowest density of seeded species (404 plants m^{-2}; SE = 52, HSD = 102). Seeding at 22.4 or 28.0 kg ha^{-1} produced 542 and 559 plants m^{-2}, respectively. The highest seeding rate, 33.6 kg ha^{-1}, produced the highest density of seeded species, which was 708 plants m^{-2}.

Biomass. Bluebunch wheatgrass and Idaho fescue produced about 200 and 70 g m^{-2}, respectively, but did not differ between sites (Figure 3). Big bluegrass yielded about 140 g m^{-2} on the Sagebrush/bunchgrass site and 450 g m^{-2} on the Snowberry/fescue site. Among the forbs, arrowleaf balsamroot biomass did not differ from that of the

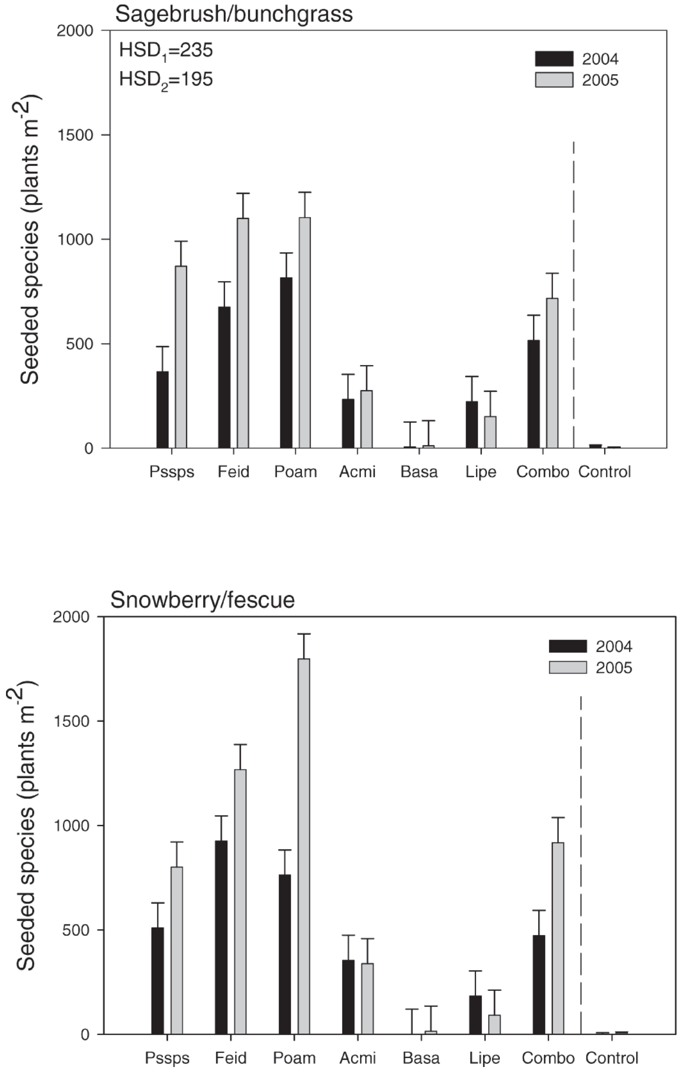

Figure 2. Interaction of seeding treatments, year, and site on seeded species density. Native grasses were bluebunch wheatgrass (Pssps), Idaho fescue (Feid), and big bluegrass (Poam). The native forbs were western yarrow (Acmi), arrowleaf balsamroot (Basa), and Lewis blue flax (Lipe). The control was nonseeded and the combination (Combo) included all species in equal proportions. HSD_1 is used for comparing site within species and year. HSD_2 is used for comparing years within species and site. Bars indicate 1 standard error (SE) of the mean. Controls were not included in the mixed analysis, but their means and SE are presented for ease of interpretation. HSD = Tukey's Honestly Significant Difference.

control. Blue flax produced just over 100 g m^{-2} more than the control. The highest producing forb was western yarrow, which produced over 450 and 250 g m^{-2} on the Sagebrush/bunchgrass and Snowberry/fescue sites, respectively. The plots seeded with a combination of species produced as much seeded species biomass as any other treatment, regardless of site.

The effect of seeding rate on seeded species biomass depended upon site (Table 1). On the Sagebrush/bunchgrass site, seeding 22.4 kg ha^{-1} yielded the highest biomass (Figure 4). On the Snowberry/fescue site, seeding 33.6 kg ha^{-1} yielded the highest biomass.

Naturally Occurring Species. *Density.* The density of nonseeded perennial grass tillers was affected by species and year (Table 2). In 2004, perennial grass tillers were less than 16 m^{-2} regardless of the species seeded (Figure 5). Naturally

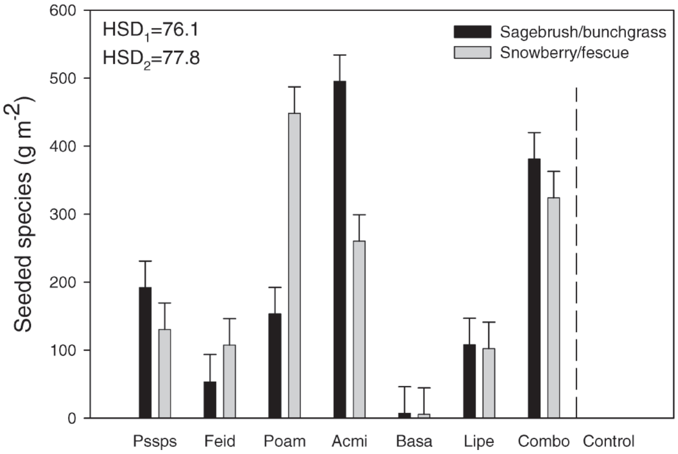

Figure 3. Interaction of seeding treatments and site on seeded species biomass. Means are averaged across years. Native grasses were bluebunch wheatgrass (Pssps), Idaho fescue (Feid), and big bluegrass (Poam). The native forbs were western yarrow (Acmi), arrowleaf balsamroot (Basa), and Lewis blue flax (Lipe). The control was nonseeded and the combination (Combo) included all species in equal proportions. HSD_1 is used for comparing species within site. HSD_2 is used for comparing site within species. Bars indicate 1 standard error (SE) of the mean. Controls were not included in the mixed analysis, but their means and SE are presented for ease of interpretation. HSD = Tukey's Honestly Significant Difference.

occurring grass density was highest where arrowleaf balsamroot was seeded in 2005. Seeding Idaho fescue appeared to favor naturally occurring perennial grass density, but not as much as seeding arrowleaf balsamroot. Seeding other species did not seem to affect naturally occurring grass tillers, all of which were relatively low in 2005 (below 20 tillers m^{-2}). There was no downy brome in 2004. Downy brome was present in 2005, but not in significant numbers.

The effect of sowing on perennial forbs density depended upon the species, site, and year (Table 2). Naturally occurring perennial forb density ranged between 6 and 35 plants m^{-2} (SE = 8.1; HSD = 32) in all plots in 2004. In 2005, seeding arrowleaf balsamroot increased perennial forb density to 60 plants m^{-2} over all other treatments at the Snowberry/fescue site.

Biomass. Among the naturally occurring species, only the biomass of annual forbs was influenced by any seeding treatment (Table 2). In this case, seeding rate affected annual forb biomass at the Sagebrush/bunchgrass site, but not at the Snowberry/fescue site (Figure 6). At the Sagebrush site, the two lowest seeding rates (16.8 and 22.4 kg ha^{-1}) produced about the same annual forb biomass, which ranged from 12 to 15 g m^{-2}. Seeding at 28 kg ha^{-1} slightly increased annual forbs biomass over seeding at 22.4 kg ha^{-1}. Increasing the seeding rate to 33.6 kg ha^{-1} decreased annual forb biomass below those where plots were seed at 22.4 kg ha^{-1}. It appears that all plots seeded had lower annual forb biomass than the nonseeded controls.

Richness and Diversity. The influence of species seeded on plant richness depended upon year (Table 3). In 2004 all plots except those seeded with a combination of species had nearly the same richness (Figure 7). Seeding a combination of species increased the richness from an average of 4 species to about 7.5 species the first year after seeding. In 2005, species richness increased to 5 or 6 in all plots, except where the

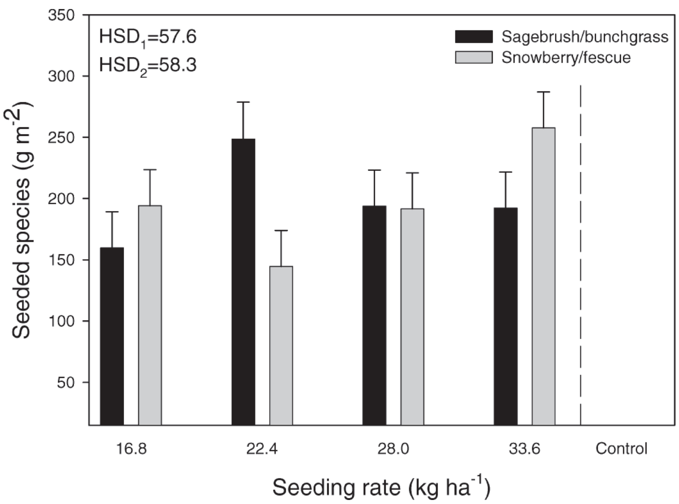

Figure 4. Interaction of seeding rate and site on seeded species biomass. Means are averaged across species and years. HSD_1 is used for comparing site within rate. HSD_2 is used for comparing rate within site. Bars indicate 1 standard error (SE) of the mean. Controls were not included in the mixed analysis, but their means and SE are presented for ease of interpretation. HSD = Tukey's Honestly Significant Difference.

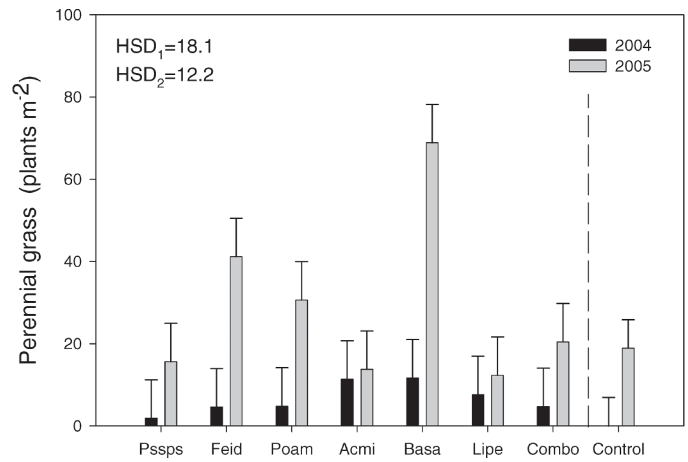

Figure 5. Effect of seeding treatments and year on the number of tillers from perennial grasses that were not seeded. Means are averaged across rates. Native grasses were bluebunch wheatgrass (Pssps), Idaho fescue (Feid), and big bluegrass (Poam). The native forbs were western yarrow (Acmi), arrowleaf balsamroot (Basa), and Lewis blue flax (Lipe). The control was nonseeded and the combination (Combo) included all species in equal proportions. HSD_1 is used for comparing species within year. HSD_2 is used for comparing year within species. Bars indicate 1 standard error (SE) of the mean. Controls were not included in the mixed analysis, but their means and SE are presented for ease of interpretation. HSD = Tukey's Honestly Significant Difference.

combination of species was seeded. Richness was about 7 in plots seeded with a combination of species that year.

Plant diversity was influenced by species, site and year (Table 3). At the Sagebrush/bunchgrass site, seeding any grass, western yarrow, or blue flax had a diversity index just above 1 in 2004 (Figure 8). Areas seeded to arrowleaf balsamroot had a diversity of about 2.5 the first year after seeding. Seeding a combination of species produced the highest diversity in 2004. By 2005, seeding big bluegrass or western yarrow produced the least plant diversity, whereas all other species and the combination of species produced an index of at least 2.5. The diversity index in the nonseeded control was about 2.7 at the Sagebrush/bunchgrass site. At the Snowberry/fescue site, species diversity followed a similar pattern as at the Sagebrush/bunchgrass site with a few exceptions. Diversity of big bluegrass, western yarrow, bluebunch wheatgrass, and Idaho fescue seeded treatments did not change from 2004 to 2005. Another important response was that in 2005 the combination of species had lower diversity than seeding arrowleaf balsamroot alone, which was not the case at the Sagebrush/bunchgrass site.

Discussion

In this study, all seeded species, except arrowleaf balsamroot, established at levels sufficient for successful restoration. Seeding rate did not have a large impact on seeding success. Re-establishing displaced grasses and forbs after control of western juniper is essential to recovering shrub–grassland communities in these degraded systems (Miller et al. 2005). In areas where the abundance of desired plants growing in association with western juniper is inadequate to provide natural recovery or the recovery rate is unacceptably slow, restoration with native species might be necessary to meet land management objectives (Eddleman 2002; Miller et al. 2005). Successful establishment of native plant communities requires that species be well-adapted to the site, which might have been altered by juniper invasion (Miller et al. 2005) or by fire (Bates et al. 2006). All the grasses seeded in this study, bluebunch wheatgrass, Idaho fescue, and big bluegrass, were present on site prior to treatment and established well. They established especially well on the Snowberry site north aspect,

Table 2. P values from ANOVA on the effects of site, species, seeding rate, and year on naturally occuring species that were not seeded. Acronyms are as follows: PG = perennial grass; AG = annual grass; PF = perennial forbs; AF = annual forbs.

	Density				Biomass			
Source	PG	AG	PF	AF	PG	AG	PF	AF
Site	0.013	0.202	0.001	0.005	0.057	0.372	0.148	0.774
Species	0.020	0.211	0.002	0.001	0.581	0.360	0.279	0.001
Rate	0.234	0.368	0.758	0.585	0.455	0.245	0.967	0.636
Rate × site	0.557	0.442	0.633	0.640	0.315	0.439	0.249	0.032
Species × rate	0.458	0.833	0.585	0.603	0.602	0.747	0.385	0.834
Species × site	0.694	0.126	0.001	0.429	0.469	0.170	0.148	0.451
Species × rate × site	0.830	0.794	0.353	0.118	0.669	0.650	0.633	0.106
Year	0.001	0.103	0.001	0.001				
Rate × year	0.196	0.368	0.781	0.459				
Site × year	0.001	0.202	0.001	0.512				
Species × year	0.028	0.211	0.001	0.001				
Rate × site × year	0.582	0.794	0.629	0.400				
Species × rate × year	0.717	0.833	0.614	0.637				
Species × site × year	0.440	0.126	0.001	0.565				

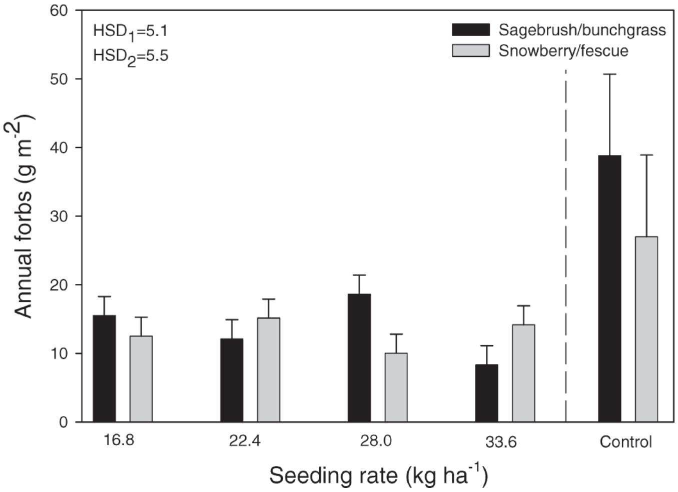

Figure 6. Interaction of seeding rate by site on annual forb biomass. Means are averaged across seeding rates and years. HSD_1 is used for comparing rate within site. HSD_2 is used for comparing site within rate. Bars indicate 1 standard error (SE) of the mean. Controls were not included in the mixed analysis, but their means and SE are presented for ease of interpretation. HSD = Tukey's Honestly Significant Difference.

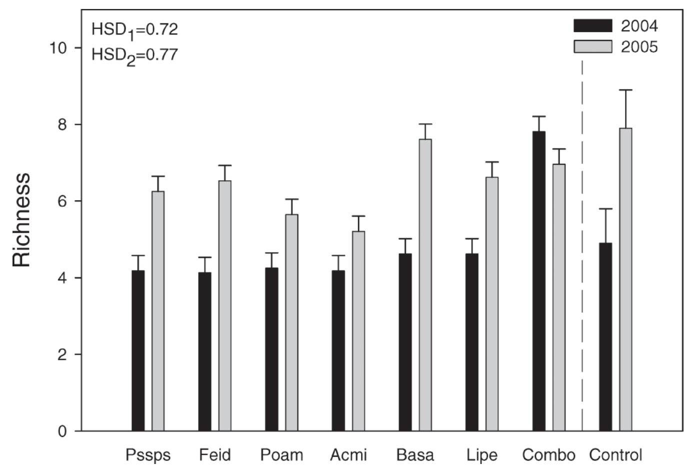

Figure 7. Interaction of seeding treatments and years on species richness. Native grasses were bluebunch wheatgrass (Pssps), Idaho fescue (Feid), and big bluegrass (Poam). The native forbs were western yarrow (Acmi), arrowleaf balsamroot (Basa), and Lewis blue flax (Lipe). The control was nonseeded and the combination (Combo) included all species in equal proportions. HSD_1 is used for comparing year within species. HSD_2 is used for comparing species within year. Bars indicate 1 standard error (SE) of the mean. Controls were not included in the mixed analysis, but their means and SE are presented for ease of interpretation. HSD = Tukey's Honestly Significant Difference.

which is not surprising because soil moisture is essential to germination and emergence. Among the forbs, western yarrow established well and blue flax was present, but not arrowleaf balsamroot. Arrowleaf balsamroot requires a 3 mo stratification period (Young and Evans 1979), and it is likely that the germination requirements of this species were not met during the study.

Disturbances, such as fire, create safe sites for seeds from which they can germinate and emerge (Sheley and Krueger-Mangold 2003). The number of safe sites relative to the number of seeds available determines the likelihood that a seed reaches a safe site and ultimately establishes (Sheley et al. 2005). Increasing the seeding rate has enhanced seedling establishment of intermediate wheatgrass [*Elytrigia intermedia* (Host) Nevski] because more seeds were available to reach limited safe sites (Sheley et al. 2005). We accepted our hypothesis that the highest density of seeded species would occur at the highest seeding rate. This suggests that enough safe sites were available and the establishment was limited by the availability of seeds (Harper 1977). The results are consistent with those of Sheley and Half (2006) and Velagala et al. (1997) when restoring plant communities dominated by spotted knapweed.

Table 3. P values from the ANOVA on the effects of site, species, seeding rate, and year on richness and diversity.

Source	Richness	Diversity
Site	0.001	0.120
Species	0.001	0.001
Rate	0.548	0.003
Rate × site	0.403	0.500
Species × rate	0.324	0.139
Species × site	0.001	0.001
Species × rate × site	0.732	0.368
Year	0.001	0.002
Rate × year	0.877	0.344
Site × year	0.220	0.200
Species × year	0.001	0.001
Rate × site × year	0.307	0.223
Species × rate × year	0.743	0.245
Species × site × year	0.457	0.001

Interestingly, the biomass of seeded species responded somewhat differently to seeding rate. There appeared to be an optimum seeding rate for maximizing biomass production. On the Sagebrush/bunchgrass site, seeding at 22.4 kg ha^{-1} yielded the highest biomass, whereas seeding at 33.6 kg ha^{-1} (the highest rate) yielded the highest biomass on the Snowberry/fescue site. On the Snowberry/fescue site, plants were probably able to capture large amount of resources even at high plant densities. In cropping systems, seeding rate are often developed along production gradients (Klein and Lyon 2004). Developing seeding rate recommendations for restoring herbaceous plant communities after removing western juniper will probably require a similar process. In any case, it appears that the higher the site productivity, the higher the seeding rate to maximize biomass response.

Our control plots allowed assessment of the potential for natural vegetation recovery without seeding, which occurs on many sites with a desired understory of species growing in association with western juniper (Miller et al. 2005). It appears that natural recovery will occur, but the rate might be very slow, especially at the Sagebrush/bunchgrass site. By 2005, the density of seeded species was three to 10 times greater than the nonseeded controls. And in most cases, seeded species reduced the naturally occurring species. Seeding was effective at speeding the successional process to an herbaceous–perennial stage and increasing biomass production relative to controls.

Weather patterns of arid rangelands are highly variable, especially within the high elevation sagebrush biome (Passey et al. 1982). The frequency and seasonal distribution of precipitation and temperature play a major role in the availability of water within soil profiles, and thus strongly influence plant composition (Bates et al. 2006). We accepted our hypothesis that seeding a rich mixture would provide establishment at a density equal to or greater than the average densities of all species seeded as monocultures, regardless of site characteristics. We believe that using a rich seed mixture, rather than a single species, will enhance the likelihood of

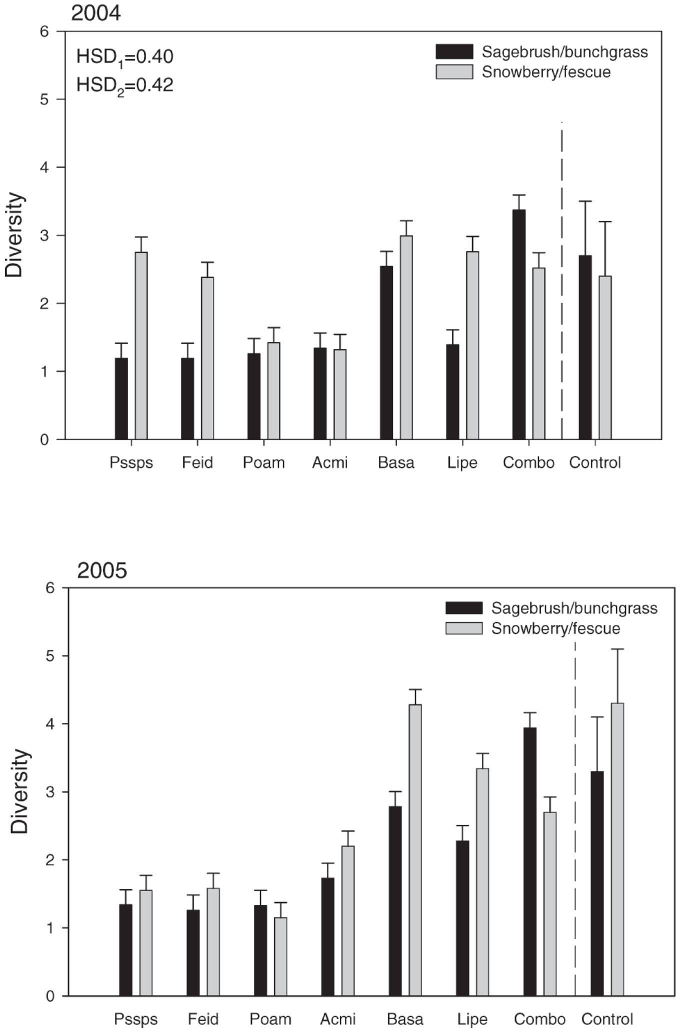

Figure 8. Interaction of seeding treatments, year, and sites on Simpson's plant diversity index. Native grasses were bluebunch wheatgrass (Pssps), Idaho fescue (Feid), and big bluegrass (Poam). The native forbs were western yarrow (Acmi), arrowleaf balsamroot (Basa), and Lewis blue flax (Lipe). The control was nonseeded and the combination (Combo) included all species in equal proportions. HSD_1 is used for comparing year within species and site. HSD_2 is used for comparing species and site within year. Bars indicate 1 standard error (SE) of the mean. Controls were not included in the mixed analysis, but their means and SE are presented for ease of interpretation.

establishment in various and unpredictable environments because the group possesses a variety of traits that can match conditions that vary from site to site and year to year. Similarly, in a greenhouse study, Sheley and Half (2006) found that seeding a mixture of forbs produced greater densities than seeding species individually. A well-designed mixture could provide the niche occupation necessary to minimize invasion by weeds (Dukes 2001; Pokorny et al. 2005).

Ecologists emphasize the importance of species richness in maintaining ecosystem function, productivity, and sustainability (Chapin et al. 1997; Hooper and Vitousek 1997; McNaughton 1977; Naeem 1998; Tilman and Knops 1997). Working in a Minnesota grassland, Tilman et al. (1996) determined that plant productivity and resource utilization improved as species richness increased. When manipulating microbial communities, Naeem and Li (1997) observed higher stability in biomass and density measures when more than one species per functional group was present. Frank and McNaughton (1991) compared the response of eight grasslands in Yellowstone National Park to drought and found greater stability in communities with higher plant diversity. In our study, plots seeded with native grasses or western yarrow had the lowest diversity indices, all of which were below 2 in 2005. These were the species that also had the greatest establishment. This indicates that high establishment affected the abundance of other species rather than eliminating species altogether. However, seeding the combination of species provided high establishment of seeded species and as high a species richness and diversity as any other treatment. It is possible that having fewer seeds of species representing various functional groups allows some degree of niche separation (Carpinelli et al. 2004; Pokorny et al. 2005).

Implications for Practice. Successfully restoring desired grasses and forbs after controlling western juniper using fire requires knowledge of appropriate species, combinations of species, and seeding rates. We found bluebunch wheatgrass, Idaho fescue, big bluegrass, and western yarrow established well in the Sagebrush/bunchgrass and Snowberry/fescue sites after western juniper was controlled using a tree cutting–fire combination. The mixture of all species provided excellent establishment of all seeded species, as well as optimum diversity and richness. We also found that seeding rates at the 33.6 kg ha^{-1} provided maximum establishment, but seeding rate should be less on Sagebrush/bunchgrass sites to favor biomass production. In cases where species are lacking, a rich mixture of species adapted to a site should be seeded.

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Received July 30, 2007, and approved October 19, 2007.