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Restoring Native Plants to Crested Wheatgrass Stands

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Abstract

Crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) is a nonindigenous grass introduced to North America for improving degraded rangelands. It is often criticized for forming nearly monotypic stands. Our objective was to determine the feasibility of restoring native plant species to crested wheatgrass-dominated rangeland. We investigated methods for suppressing crested wheatgrass followed by revegetation with a mix of native species. We tested five suppression treatments: undisturbed, low rate of glyphosate (0.25× recommended rate), high rate of glyphosate (recommended rate), 1-pass mechanical (disked once), and 2-pass mechanical (disked twice). Procedures were repeated in two trials in separate years. We sampled density and canopy cover of crested wheatgrass and density of seeded species for three (trial 1) and two (trial 2) years. Mechanical treatments increased crested wheatgrass density by 30–50%, whereas most other treatments were similar to the undisturbed (6.8 plants/m^2). Crested wheatgrass cover decreased in mechanical and full herbicide treatments in trial 1 and was variable across treatments in trial 2. Seeded species density in all treatments (29 plants/m^2) was greater than in the undisturbed treatment (18 plants/m^2) 1 year after seeding in trial 1 and was similar across treatments (26 plants/m^2) in trial 2. By the end of the study, though, all treatments resulted in similar seeded species density (<5 plants/m^2). Results suggest suppression treatments were not effective and therefore did not improve restoration of native species in crested wheatgrass stands. Native species establishment may require subsequent management to favor persistence of native species and retard crested wheatgrass.

Key words: ***Agropyron cristatum*, disturbance, rangeland restoration, revegetation, succession.**

Introduction

Rangelands throughout western North America changed dramatically during the late 1800s and early 1900s. Increased fire suppression, introduction and expansion of nonindigenous species, cultivation, and overgrazing by livestock led to a decrease in species diversity and richness and widespread degradation of the land (D'Antonio & Vitousek 1992). Revegetation is an important component in restoration of degraded rangelands. Attempts to establish nonindigenous species such as crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.), Siberian wheatgrass (*Agropyron fragile* (Roth) P. Candargy) and Russian wildrye (*Psathyrostachys juncea* (Fisch.) Nevski) were successful relative to similar establishment efforts of native species (Monsen 2004). Consequently, nonindigenous species dominate past rangeland revegetation projects.

Crested wheatgrass was widely introduced to the Great Plains and Intermountain regions of North America to improve condition of degraded rangelands (Pellant & Lysne 2005). It proved to be a successful revegetation species due to its superior ease of establishment, strong competitive ability, and grazing tolerance (Monsen 2004). Once established, crested wheatgrass can quickly dominate the seedbank and hinder recruitment and growth of native species (Marlette & Anderson 1986; Henderson & Naeth 2005), thereby forming nearly monotypic stands. Crested wheatgrass is also reported to resist invasion by nonindigenous forbs and annual grasses (Berube & Myers 1982; D'Antonio & Vitousek 1992; Sheley et al. 2008). It has therefore been proposed as a bridge species for converting annual grass-infested rangeland to a perennial-dominated system, followed by reinsertion of species native to the pre-disturbance plant community (Cox & Anderson 2004).

Nevertheless, debate continues over the use of nonindigenous species due to their ability to reduce diversity within a plant community. Because plant community diversity is positively correlated with ecosystem functioning (Kinzig et al. 2002), federal agencies are now promoting the use of native species for rangeland revegetation to maintain and restore functioning ecosystems with appropriate habitat for wildlife species such as the Greater Sage-grouse (*Centrocercus urophasianus*) and pygmy rabbit (*Brachylagus idahoensis*)

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(USDI USFWS 2001; USDI BLM 2005; USDA USFS 2008). The ongoing development of more effective methods for increasing native species diversity remains a major focus of rangeland restoration research.

Our objective was to determine the feasibility of restoring native plant species to crested wheatgrass-dominated rangeland. We applied various treatments (mechanical and chemical) aimed at suppressing crested wheatgrass followed by revegetation with a mix of native grasses, forbs, and shrubs. We hypothesized that (1) treatments would decrease crested wheatgrass density and cover; and (2) treatments and revegetation would interact to increase native species density.

Methods

The study site was located about 80 km south of Burns, Oregon, on the Malheur National Wildlife Refuge. Elevation of the site is 1,400 m and mean annual precipitation is 290 mm. Weather observations were taken from the P-Ranch Station located near Frenchglen, Oregon, approximately 24 km from the study site (WRCC 2007). Soils consist of a complex of loamy, mixed, frigid, shallow Xeric Haplodurids and fine-loamy, mixed, frigid Xeric Argidurids. This site was drill seeded with a mixture of crested wheatgrass and desert wheatgrass (*Agropyron desertorum* (Fisch. ex Link) Schult.) by the Bureau of Land Management in 1981 following a wildfire. It was dominated by crested wheatgrass with cheatgrass (*Bromus tectorum* L.) and *Alyssum* spp. occurring infrequently. Based on soils and composition of adjacent plant communities, native vegetation would have likely consisted of Wyoming big sagebrush (*Artemisia tridentata* Nutt. spp. *wyomingensis* Beetle & Young), bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) A. Löve), Sandberg's bluegrass (*Poa secunda* J. Presl), Thurber needlegrass (*Achnatherum thurberianum* (Piper) Barkworth), bottlebrush squirreltail (*Elymus elymoides* (Raf.) Swezey), and Indian ricegrass (*Stipa hymenoides* (Roem. & Schult.) Barkworth).

A randomized block, split–split-plot design was used to test effects of the following treatments: (1) undisturbed (no treatment applied), hereafter referred to as UD; (2) low rate of glyphosate (0.25× recommended rate), hereafter referred to as low rate herbicide (LH); (3) recommended rate of glyphosate, hereafter referred to as high rate herbicide (HH); (4) 1-pass with a tractor-mounted 4.2-m off-set disk with 50-cm disks, hereafter referred to as 1-pass mechanical (1M); and (5) two passes with the aforementioned disk, hereafter referred to as 2-pass mechanical (2M). The quarter rate herbicide and 1-pass mechanical treatments were included to test whether native species could be established with a minimal level of crested wheatgrass suppression, thereby decreasing expense of restoration.

These five main plots (UD, LH, HH,1M, and 2M) were split into a seeded and nonseeded subplot, 30 × 70-m (0.2 ha). Nonseeded split-plots were included to simulate the outcome of suppression treatments if revegetation failed. Treatments were replicated in five blocks with a 30-m buffer between blocks. The study was replicated in two trials.

Herbicide treatments were applied on 12 July 2005 for trial 1 and on 3–8 May 2006 for trial 2. These dates corresponded to the phenological stages of late heading and boot for trials 1 and 2, respectively. For the high herbicide treatment, glyphosate (Roundup Pro) was applied at the recommended rate for rangelands of 4.8 L/ha. For the low herbicide treatment, glyphosate was applied at 1.2 L/ha. Glyphosate was applied using an ATV-mounted boom sprayer that was calibrated for the appropriate rate and delivered 95 L/ha of water as a carrier. Mechanical treatments were applied on 17–18 October 2005 (trial 1) and 15 May 2006 (trial 2). These dates corresponded to the phenological stages of senescence and boot, respectively. The difference between trials 1 and 2 in phenological stages when treatments were applied was not intended, but was instead due to logistical complications. However, the variation in timings allowed us to make some observations about efficacy of treatments across the growing season.

Seeded species were separated into large- and small-seed mixes to ensure the most appropriate seed placement in and on the soil (Table 1). Large- and small-seed mixes were put into a cool-season and fluffy seed box, respectively. Alternating drops were used from the cool-season and fluffy boxes; the cool-season box fed the seeding disks, and the fluffy box dropped seeds onto the soil surface where they were rolled over by Brillion wheels. Plots were seeded as a fall dormant seeding using a modified Truax Rough Rider no-till drill on 31 October–1 November 2005 (trial 1) and 30–31 October 2006 (trial 2).

Density and foliar cover of crested wheatgrass and other existing perennial vegetation and density of seeded species were sampled for 3 years (2006, 2007, and 2008) and 2 years (2007 and 2008) for trials 1 and 2, respectively. Five 18-m transects were established in each subplot, 10 m apart and perpendicular to the seeded rows. Density and canopy cover were estimated in ten 0.25-m^2 frames placed every 2 m along each transect. Density included counting every individual within the sampling frame, while cover was estimated according to Daubenmire cover classes (Daubenmire 1959). It was difficult to distinguish seedlings of bluebunch wheatgrass, Indian ricegrass, and bottlebrush squirreltail; therefore, these were grouped into seeded perennial grasses. The other seeded species could be identified and were recorded individually. Sampling occurred on 19–28 June 2006 (trial 1 only), 4–15 June 2007, and 10–23 June 2008 (trials 1 and 2).

A mixed effect model split–split plot analysis was used for comparing trial 1 plots over 3 growing years and trial 2 plots over 2 growing years (PROC MIXED SAS Institute 2003). Trials 1 and 2 were analyzed separately. Split-plots included seeding level (seeded vs. nonseeded) and year. Fixed effects in these analyses included treatment, year, and seeding level while block was a random effect. When a significant p value (≤ 0.05) was found, means were separated using Tukey's Honestly Significant Difference (HSD) test (Ramsey & Schafer 2002). Residuals for all models were checked for model fit, normality and variance homogeneity. Because individual seeded species occurred too infrequently for independent analysis, densities were summed across species (i.e. seeded

Table 1. List of seeded species, seed mix, seeding rates, and cultivar (where appropriate).

Species	*Seed Mix*	*Seeding Rate (kg Pure Live Seed/hectare)*	*Cultivar*
Wyoming big sagebrush (*Artemisia tridentata* spp. *Wyomingensis*)	S	0.22	
Fourwing saltbush (*Atriplex canescens*)	L	1.1	
White-stemmed rabbitbrush (*Chrysothamnus nauseosus* spp. *Albicaulis*)	S	0.28	
Lewis flax (*Linum lewisii*)	L	0.84	Appar
Western yarrow (*Achillea millefolium*)	S	0.22	Eagle mountain
Munro globemallow (*Sphaeralcea munroana*)	L	0.56	
Bluebunch wheatgrass (*Pseudoroegneria spicata*)	L	3.4	Anatone
Sandberg's bluegrass (*Poa sandbergii*)	S	0.84	Mountain home
Squirrel tail (*Elymus elymoides* spp. *elymoides*)	L	2.0	Toe Jam Creek
Indian ricegrass (*hymenoides*)	L	2.0	Nezpar

L, large-seeded; S, small-seeded.

species included grasses, forbs, and shrubs) for final analysis. Existing perennial vegetation other than crested wheatgrass occurred too infrequently for analysis. Seeded species density in unseeded plots was zero; therefore, those means are not included in results.

Results

Crested Wheatgrass Suppression

Density. Treatment and year interacted to affect crested wheatgrass density ($p < 0.01$; Fig. 1) in trial 1. In 2006, all treatments resulted in similar crested wheatgrass density. Except in the UD treatment, which remained constant at 6.7 ± 0.3 plants/m^2, crested wheatgrass density increased from 2006 to 2007. By 2007, the 2M treatment increased crested wheatgrass density to 14.3 ± 1.5 plants/m^2, which was higher than any other treatment. In addition, the 1M (8.5 ± 0.8 plants/m^2) treatment was higher in density than the HH (7.2 ± 0.5 plants/m^2) and UD treatments. The density of crested wheatgrass in 2008 was similar to that of 2007 for each treatment. Three years post-treatment, the mechanical treatments resulted in increased crested wheatgrass density compared to undisturbed plots.

In trial 2, the main effect of treatment influenced crested wheatgrass density ($p = 0.01$). All treatments increased crested wheatgrass density over that of the UD treatment (7.0 ± 0.4 plants/m^2). Similar to trial 1, the highest density was found in the 2M treatment (11.7 ± 0.7 plants/m^2) followed by HH (10.5 ± 1.2 plants/m^2), 1M (9.2 ± 0.3 plants/m^2), and LH (8.3 ± 0.4 plants/m^2).

Cover. In trial 1, treatment and year interacted to affect crested wheatgrass cover ($p < 0.01$; Fig. 2). Except for the 2M treatment, cover decreased from 2006 to 2008. In 2006, the 2M treatment showed the lowest crested wheatgrass cover compared to all other treatments at $9.9 \pm 1.3\%$, and it increased in 2007 and 2008 to $12.6 \pm 1.9\%$ and $14.8 \pm 2.1\%$, respectively. By 2008, crested wheatgrass cover was lowest in the 1M treatment ($11.1 \pm 1.4\%$) and highest in the 2M ($14.8 \pm 2.1\%$) and UD ($14.1 \pm 1.2\%$) treatments.

The main effect of year influenced crested wheatgrass cover in trial 2 ($p < 0.01$). Cover was $11.3 \pm 0.6\%$ in 2007 and increased to $15.1 \pm 0.8\%$ in 2008. Crested wheatgrass cover was also influenced by an interaction between treatment and seeding level ($p = 0.05$; Fig. 3). In the LH treatment, seeded plots ($14.8 \pm 1.4\%$) resulted in lower crested wheatgrass cover than the unseeded plots ($18.4 \pm 1.5\%$). In contrast, the UD treatment resulted in lower crested wheatgrass cover in unseeded plots ($14.3 \pm 1.6\%$) as compared to the seeded plots ($17.8 \pm 2.2\%$). Seeding level had no apparent influence in the HH, 2M and 1M treatments.

Seeded Species Establishment

Year interacted with treatment in trial 1 to affect seeded species density ($p < 0.01$; Fig. 4). The highest seeding density of 43.9 ± 2.6 plants/m^2 occurred in the 2M treatment in 2006. Except for the UD treatment which saw no change in seedling density (18.2 ± 4.3 plants/m^2), seedling density decreased from 25 to 67% between 2006 and 2007. By 2008, all treatments experienced an 88–98% decrease in seeded species density, and all treatments resulted in similar densities.

The main effect of year influenced seeded species density in trial 2 ($p < 0.01$). Density decreased from 2007 to 2008 from 26.1 ± 1.5 plants/m^2 to 1.0 ± 0.2 plant/m^2, respectively, which was about a 95% reduction in seeded species density. Treatment had no affect on seeded species density in trial 2 ($p = 0.68$).

Discussion

Crested wheatgrass density increased with suppression treatments, especially mechanical treatments. These findings led us to reject our hypothesis that treatments would decrease crested wheatgrass density. We believe increased density was a product of disks breaking up large tussocks of crested wheatgrass, which created several smaller plants that were able to survive and colonize available safe sites. Other studies have shown that mechanical disturbance may not reduce crested wheatgrass (Houston 1957; Wilson & Gerry 1995). Houston (1957) found that crested wheatgrass density had recovered to pretreatment levels and forage production had increased 2 years

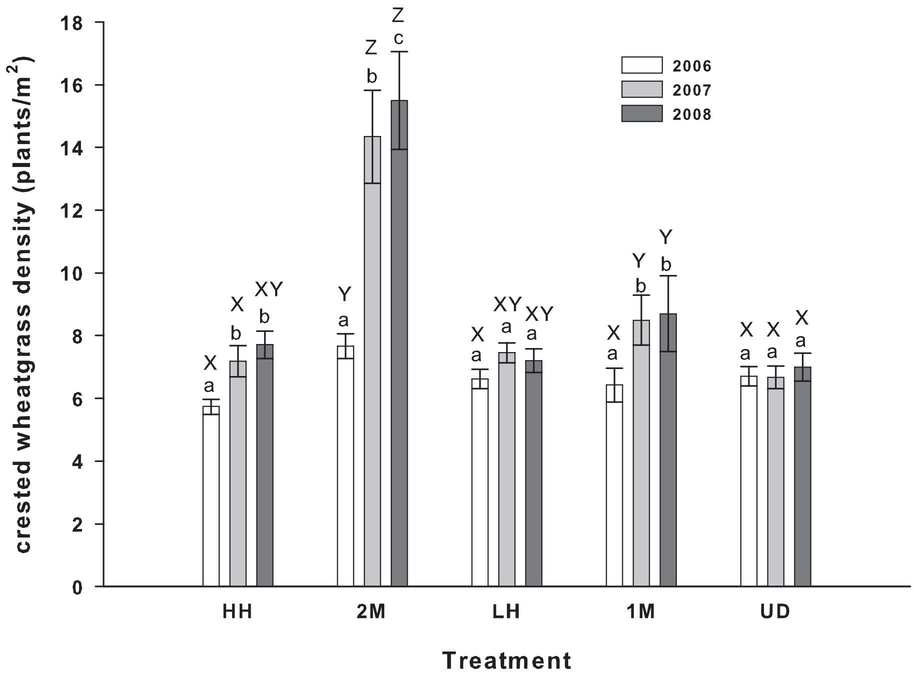

Figure 1. Crested wheatgrass density (plants/m^2) as affected by treatment and year in trial 1. Lowercase letters separate means within a treatment across years (HSD = 1.1). Uppercase letters separate means across treatments within 1 year (HSD = 1.5). Error bars equal ± 1.0 SE. HH, high rate herbicide; 2M, 2-pass mechanical; LH, low rate herbicide; 1M, 1-pass mechanical; UD, undisturbed.

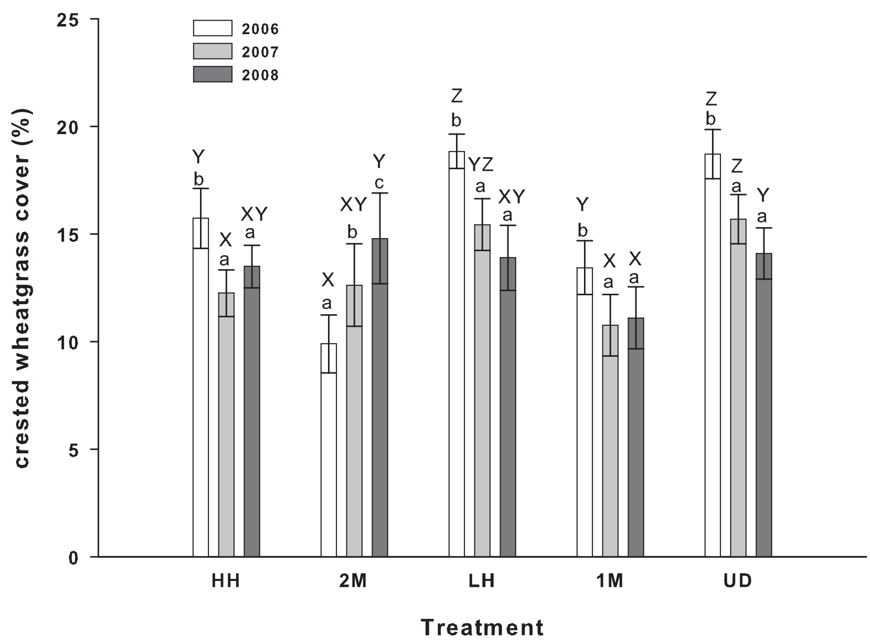

Figure 2. Crested wheatgrass cover (%) as affected by treatment and year in trial 1. Lowercase letters separate means within a treatment across years (HSD = 2.1). Uppercase letters separate means across treatments within 1 year (HSD = 2.8). Error bars equal ± 1.0 SE. See Figure 1 for explanation of treatment codes.

after double-disking. A vigorous tilling treatment that initially created 100% bare ground did not reduce crested wheatgrass 1 year later (Wilson & Gerry 1995). It is difficult to explain the increase in crested wheatgrass density in the herbicide treated plots, but herbicide applications can cause a decrease in intraspecific competition and increased per capita seed production in crested wheatgrass (Ambrose & Wilson 2003). In addition, Hansen (2007) found that crested wheatgrass treated

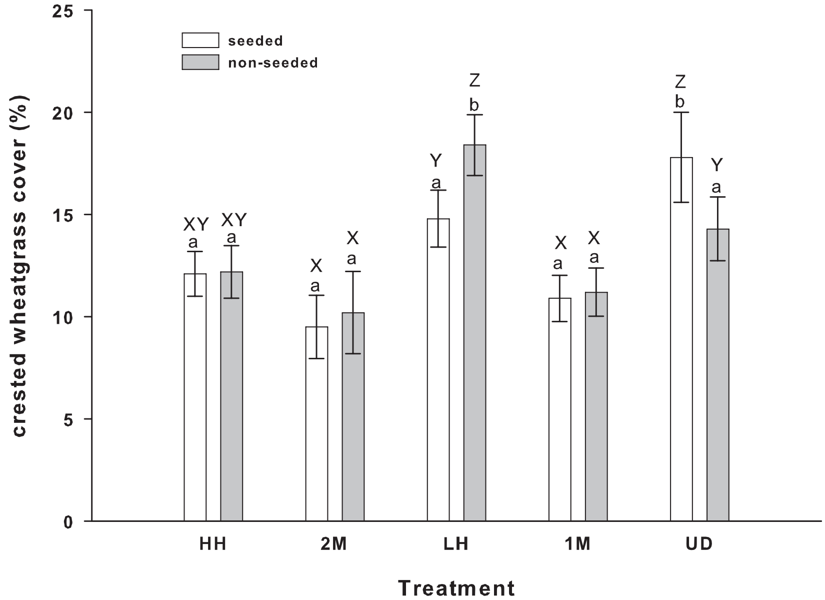

Figure 3. Crested wheatgrass cover (%) as affected by treatment and seeding level in trial 2. Lowercase letters separate means within a treatment across seeding level (HSD = 2.3). Uppercase letters separate means across treatments within a seeding level (HSD = 2.8). Error bars equal ± 1.0 SE. See Figure 1 for explanation of treatment codes.

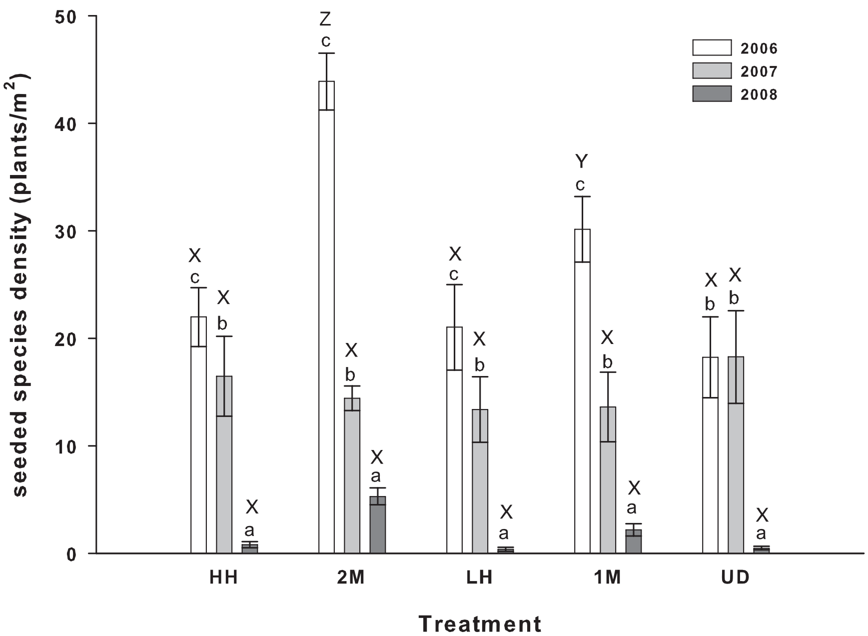

Figure 4. Seeded species density (plants/m^2) as affected by treatment and year in trial 1. Lowercase letters separate means within a treatment across years (HSD = 4.9). Uppercase letters separate means across treatments within a year (HSD = 5.0). Error bars equal ± 1.0 SE. See Figure 1 for explanation of treatment codes.

with a one-time glyphosate application led to an increase in tiller and seed production.

Crested wheatgrass cover initially decreased in most treatments compared to the UD treatment. We therefore partially accepted our hypothesis that treatments would decrease crested wheatgrass cover. A study by Lodge (1960) indicated that compared to mowing in the fall and burning in the spring and fall, only double-disking in the fall reduced crested wheatgrass cover. The decrease in cover in our study may have been adequate to temporarily increase safe sites for establishment of native species, even though treatments did not decrease crested wheatgrass density. Although evidence suggests that double-disking crested wheatgrass may stimulate plant growth in the long term (Houston 1957), our objective was to reduce the competitive ability of crested wheatgrass such that desired species were more likely to establish. We believe multiple treatments will be necessary to improve and prolong the reduction in crested wheatgrass and increase the window of opportunity in which seeded native species can establish (Ambrose & Wilson 2003; Wilson & Pärtel 2003; Hansen & Wilson 2006).

With few exceptions, herbicide treatments were ineffective. Glyphosate is a nonselective herbicide that stunts or kills an entire plant after contact (Monsanto Company 2004). The effectiveness of the herbicide depends on the quantity and timing of application and the phenological stage of the plant. In our study, herbicide applications may have been ineffective at controlling crested wheatgrass due to the timing in which the herbicides were applied, especially during trial 1. Applying glyphosate at the late heading stage in trial 1 probably reduced its effectiveness compared to an earlier application. Crested wheatgrass suppression appeared to improve in trial 2 when spraying was carried out at a more appropriate time (boot stage), but cover still remained relatively high compared to some other studies. For example, applying glyphosate to crested wheatgrass in late winter in Utah, decreased cover from 12 to 4% in the first year (Cox & Anderson 2004). Bakker et al. (1997) reduced crested wheatgrass cover from about 45% to about 10% with applications of glyphosate in May. It should be noted, though, that in both those studies crested wheatgrass cover increased to pre-treatment levels by the next year (Cox & Anderson 2004) or to near pre-treatment levels later in the same year (Bakker et al. 1997). We may have seen improved results from an even earlier application in the spring or late winter. Alternatively, repeated applications throughout a season and across multiple years (Wilson & Pärtel 2003), or a combination of mechanical and chemical treatments over time might be required to achieve better suppression.

Our results suggest that after 3 (trial 1) and 2 years (trial 2), treatments did not decrease crested wheatgrass nor did they improve the establishment of native species over that of the undisturbed control, and we partially rejected our second hypothesis regarding treatments and revegetation interacting to increase native species density. No native species were found in unseeded plots (data not shown), so revegetation did initially increase native species density. In spite of high initial densities, seedling densities decreased over the course of the study, and most of the seedlings that emerged the first year did not truly establish and persist until the end of the study (Hyder et al. 1971; Ries & Svejcar 1991). As crested wheatgrass density increased and greater niche overlap occurred between crested wheatgrass and 2- and 3-year-old individuals of the seeded species, competition may have become more intense resulting in mortality of seeded species.

High initial establishment of seeded species followed by declining persistence could also be attributed to annual variation in amount and timing of precipitation. MacDougall et al. (2008) concluded that the outcome of efforts to establish natives in crested wheatgrass stands in Saskatchewan, Canada, was climate-mediated, and that multiple seed additions were required to take advantage of windows of recruitment during certain years. Higher than normal precipitation occurred in November and December 2005 (200– 300% of normal) and in April 2006 (200% of normal) (WRCC 2007). We speculate that more seeds were able to establish in their initial growing year due to an adequate amount of moisture in the soil, especially in trial 1. Although we can only speculate about why there was such a large decrease in seeded species density between the first and second growing years, we suspect it was due to a combination of stressful climatic factors and an increase in competition from crested wheatgrass. Seedling mortality is not uncommon in revegetation projects. Some studies report perennial seedling mortality rates of 80% or more (Thomas & Dale 1975; Hawthorne & Cavers 1976; Bishop et al. 1978; Silvertown & Dickie 1981; Jessop & Anderson 2007).

In spite of seedling densities decreasing over the course of the study, final densities of seeded native species in the 2-pass mechanical treatment (about 5 plants/m^2) were comparable to crested wheatgrass densities in the undisturbed plots. Maintenance of such densities on semiarid rangeland would likely be acceptable to most land managers and restoration practitioners. For example, 2.7–5.4 plants/m^2 is rated as fair to good grass establishment for a 280–330 mm precipitation zone in the Intermountain Region (Vallentine 1989). Furthermore, maintenance of such densities would increase the level of plant community diversity, which is positively correlated with ecosystem functioning (Kinzig et al. 2002).

Most of the seeded species that emerged were perennial grasses and Lewis flax. Very few shrubs emerged. Grasses and forbs are typically easier to establish than shrubs. Cox and Anderson (2004) noted native grass emergence was two to five times greater than for shrubs. When studying seedling establishment of native grasses, forbs, and shrubs in sagebrush steppe, Chambers (2000) found grasses and forbs displayed the highest emergence. Some shrubs are episodic in establishment (Harrington & Hodgkinson 1986), and perhaps conditions in our study were not favorable for their germination or establishment.

Successional management has been proposed and tested as a framework for developing restoration strategies in rangeland (Sheley et al. 1996; Sheley & Krueger-Mangold 2003; Krueger-Mangold et al. 2006; Sheley et al. 2006; Pokorny & Mangold 2009). First outlined by Pickett et al. (1987), successional management is based on the three primary causes of succession: site availability, species availability, and species performance. Previous attempts to reintroduce native species into crested wheatgrass stands suggest that (1) crested wheatgrass plants and propagules must be destroyed or severely damaged, which addresses site availability and (2) deliberate introduction of native species is required, which addresses species availability (Bakker et al. 1997; Cox & Anderson 2004; MacDougall et al. 2008). In this study bare ground in undisturbed and treated plots averaged about 20% (Fansler 2007), so we believe there was adequate site availability for native species to initially establish (Williams 1992; Aguilera & Lauenroth 1993; Bard et al. 2004). We also feel we provided sufficient propagule availability through reseeding to establish native species. However, our methods did not include any management action to address species performance, and except for the 2-pass mechanical treatment in trial 1, our results would probably be less than satisfactory for a land manager whose objective is to restore native plant diversity to a site. Follow-up management to address species performance, especially between the first and second year after seeding, may be required to encourage persistence of seeded native species.

Conclusion

Restoration of crested wheatgrass stands into more diverse plant communities that meet multiple land-use objectives has been proposed. Land managers, however, are reluctant to invest in revegetation projects with a high probability of failure. This study suggested that strategies to increase native plant diversity in crested wheatgrass stands need to address all three causes of succession (site availability, species availability, species performance) and not only site availability and species availability. Furthermore, treatments to suppress crested wheatgrass need to be applied at the most opportune time and may need to be repeated prior to introducing native species. Subsequent management that favors the persistence of native species and retards crested wheatgrass, such as properly timed grazing (Pellant & Lysne 2005) or repeated wick applications of herbicide (Bakker et al. 2003), is critical. Otherwise, attempts to control crested wheatgrass and establish native species will lead to failure and lost investments. Treatments that address species performance should be considered in future research projects. Our study was replicated through time at one site, and we acknowledge that results may differ from one site to the next.

Implications for Practice

- Restoring native plants to crested wheatgrass-dominated rangeland requires suppression of crested wheatgrass, reintroduction of native plants, and follow-up management to ensure persistence of seeded native species.
- Suppression of crested wheatgrass may require multiple techniques and multiple years of treatment prior to reintroduction of native plants.
- Techniques used to suppress crested wheatgrass need to be applied at the most opportune time and may have to be repeated over time to achieve desired outcomes.

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