

# Landscape-Scale Rehabilitation of Medusahead (*Taeniatherum caput-medusae*)-Dominated Sagebrush Steppe

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Producers facing infestations of invasive annual grasses regularly voice the need for practical revegetation strategies that can be applied across broad landscapes. Our objective was to determine the potential for scaling up the single-entry approach for revegetating medusahead-infested rangeland to broader, more heterogeneous landscape-scale revegetation of winter annual grass–infested rangeland. We hypothesized, when applied on a highly variable landscape scale, the combination of imazapic and seeding would provide highest abundance of perennial grasses and lowest amount of annual grasses. Treatments included a control, seeding of crested wheatgrass ('Hycrest') and Sandberg's bluegrass, spraying (60 g ai ha<sup>-1</sup> imazapic), and a simultaneously applied combination of spraying and seeding. The HyCrest and Sandberg's bluegrass seeding rates were 19 and 3.4 kg ha<sup>-1</sup>, respectively. The treatments were applied to large plots (1.4 to 8 ha) and replicated five times, with each replication located in different watersheds throughout southeastern Oregon. This study shows that the single-entry approach can be scaled up to larger landscapes, but variation within establishment areas will likely be high. This procedure should reduce the costs over multientry treatment applications and make revegetating annual grass–infested rangeland across landscapes more affordable.

**Nomenclature:** Imazapic; medusahead, *Taeniatherum caput-medusae* (L.) Nevski; crested wheatgrass, *Agropyron cristatum* (L.) Gaertn. × *Agropyron desertorum* Gaertn. 'Hycrest'; Sandberg's bluegrass, *Poa secunda* J.S. Presl.

**Key words:** Invasive annual grasses, medusahead, cheatgrass, restoration, rangeland, one-pass system.

Winter annual grasses, such as medusahead [*Taeniatherum caput-medusae* (L.) Nevski], have invaded millions of hectares of rangeland throughout western North America; they continue to spread at an alarming rate (Davies and Johnson 2008; Young 1992). These invasive grasses displace desirable perennial grasses, reduce livestock forage, and accumulate large fuel loads that foster frequent fires (Davies 2011; Davies and Svejcar 2008; Hironaka 1961; Miller 1996). Medusahead has major negative effects on ecosystem function by reducing plant and animal diversity, reducing suitable wildlife habitat, accelerating erosion, and altering nutrient cycles, hydrologic cycles, and energy flow (Davies 2011; Davies and Svejcar 2008; Olson 1999). Rehabilitation of rangeland

dominated by winter annual grasses is essential to recovering the ecological goods and services once provided by functioning healthy ecosystems (Sheley et al. 1996).

Effective management of medusahead-infested rangeland has been elusive because responses to management are highly variable. Several studies have shown the effectiveness of imazapic for controlling medusahead (Monaco et al. 2005; Sheley et al. 2007). Monaco et al. (2005) found that applying 140 g ai ha<sup>-1</sup> (0.12 lb ai ac<sup>-1</sup>) provided better medusahead control than 70 g ai ha<sup>-1</sup> (0.06 lb ai ac<sup>-1</sup>) and that a fall application was most efficacious. Similarly, Sheley et al. (2007) found rates from 35 g ai ha<sup>-1</sup> (0.03 lb ai ac<sup>-1</sup>) to 210 g ai ha<sup>-1</sup> (0.19 lb ai ac<sup>-1</sup>) can be effective in controlling medusahead, but variation in plant responses and longevity of the control is highly variable. For any long-term benefits, periodic and frequent herbicide applications must be applied, and costs probably prohibit the sustainability of this approach (Sheley et al. 2011). On medusahead-infested rangeland devoid of perennial grasses, revegetation aimed at filling niches with desired species is a critical objective of ecologically based invasive plant management (Sheley and Carpinelli 2005). Davies (2008) demonstrated that perennial grasses were the critical

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## Management Implications

Managing invasive annual grass infestations on a large scale remains a major impediment for successful rangeland restoration. The high cost of treatments and low percentage of success often keep managers from initiating management plans where large-scale infestations are present. In this experiment, we utilized a single-entry treatment of herbicide application and seeding on landscape-scale plots of medusahead- and cheatgrass-infested rangeland. We were interested in determining whether this method would provide acceptable levels of control for the invasive grasses and establishment of desired species. Our results suggest that the one-pass system might be a suitable method for restoring invasive annual grass infestations and lower the cost of treatment by completing an herbicide application and seeding in a single entry into the field.

functional group to preventing medusahead re-establishment. Revegetation can be successful on small plots in some cases, especially if a prescribed burn is applied before seeding and an herbicide application (Davies 2010). However, establishing desired species in annual grass-dominated areas has proven very difficult (Milton, 2004; Rafferty and Young 2002), and revegetation of medusahead-infested rangeland is often unsuccessful (Monaco et al. 2005; Sheley et al. 2007; Young 1992). The need for practical revegetation strategies for annual grass-dominated rangeland that can be applied across broad landscapes is substantial, but more options are available than in the past.

We tested the potential for using the single-entry approach (simultaneous application of herbicide and seed with one entry) developed for other invasive weed-infested systems (Sheley et al. 2012) for revegetating medusahead-infested rangeland in an attempt to create a more practical approach to revegetating rangeland (Sheley 2007; Sheley et al. 2001). In this early work to manage medusahead, treatments included three seeding rates (none, and 13.2 (11.8) or 25.0 kg ha<sup>-1</sup> (22.3 lb ac<sup>-1</sup>) of an even mixture of all species), two herbicide applications (with and without 52 g ai ha<sup>-1</sup> (0.05 lb ai ac<sup>-1</sup>) imazapic), and two burning regimes (burned, not-burned) applied mid-October 2006 on two sites. This experiment was designed to minimize variability and maximize our ability to detect statistical differences. In that study, we found that simultaneous application of imazapic and seeding provided some establishment of desired species where they were absent. However, little is known about the effectiveness of this system applied across landscape-scale management units.

Conservation management practices are highly variable because of spatial heterogeneity that occurs across complicated rangeland landscapes (Bestelmeyer et al. 2012). Scaling up management programs on the basis of small-plot experimentation may be misleading because the research does not account for natural variation across landscapes (Kreuter et al. 2005). To make wise decisions,

managers need information about how a management program based on small-scale localized plots is actually manifested across highly heterogeneous management units.

Our objective was to determine the potential for using the single-entry approach on more heterogeneous landscape-scale acreage for revegetating medusahead-infested rangeland. We hypothesized that even when applied on a highly variable landscape scale, the combination of imazapic and seeding would provide the highest abundance of desired perennial grasses and the lowest amount of invasive annual grasses.

## Materials and Methods

This study was conducted on five sites from 2008 through 2011 along the southeastern Oregon–Idaho border in Malheur County, OR (Jordan Valley). The specific study area is located within the Owyhee High Plateau Major Land Resource Area (MLRA-25) and occurs within the Owyhee Ecological Province (Anderson et al. 1998) (42.9769°N, -117.0347°W). Elevation ranges from about 1,200 to 1,500 m across the five study sites. Rainfall occurs in the spring and sporadically in summer, and precipitation occurs mainly as snow in the winter. Precipitation was relatively higher compared with the mean during the spring of 2009 and 2011 (Figure 1a). During the 3 yr of the study, the average air temperature for May through June at the Jordan Valley Soil Climate Analysis Network site (Natural Resource Conservation Service National Water and Climate Center) was relatively close to historic mean temperatures (Figure 1b). Two sagebrush alliances typically are found within the study area: 1) *Artemisia tridentata* Nutt. var. *wyomingensis* Beetle & Young,–*Pseudoroegneria spicata* (Pursh) A. Love and 2) *A. tridentata*–*Chrysothamnus viscidiflorus* (Hook.) Nutt.–*P. spicata*. However, medusahead, cheatgrass (*Bromus tectorum* L.), or both were the dominant herbaceous understory at each site, with *P. spicata*, *Elymus elymoides* (Raf.) Swezey, and Sandberg's bluegrass (*Poa secunda* J.S. Presl) as subordinate species. Soils were variable across the study area and included Aridisols and Mollisols and are generally well drained, clayey or loamy, and shallow or moderately deep.

**Procedures and Experimental Design.** We used a single-entry (one-pass) restoration strategy to enhance the success of establishing desired species and reduce the costs associated with multi-entry strategies (Sheley et al. 2001). Treatments included (1) single-entry herbicide and seeding, (2) herbicide only, (3) seeding only, and (4) no-herbicide/nonseeded control. This large-scale study was arranged in a randomized block design and replicated across five different sites throughout the Jordan Valley area; the treatments were not replicated at the sites. Sites were replicates for this experiment. Plot sizes varied at each site

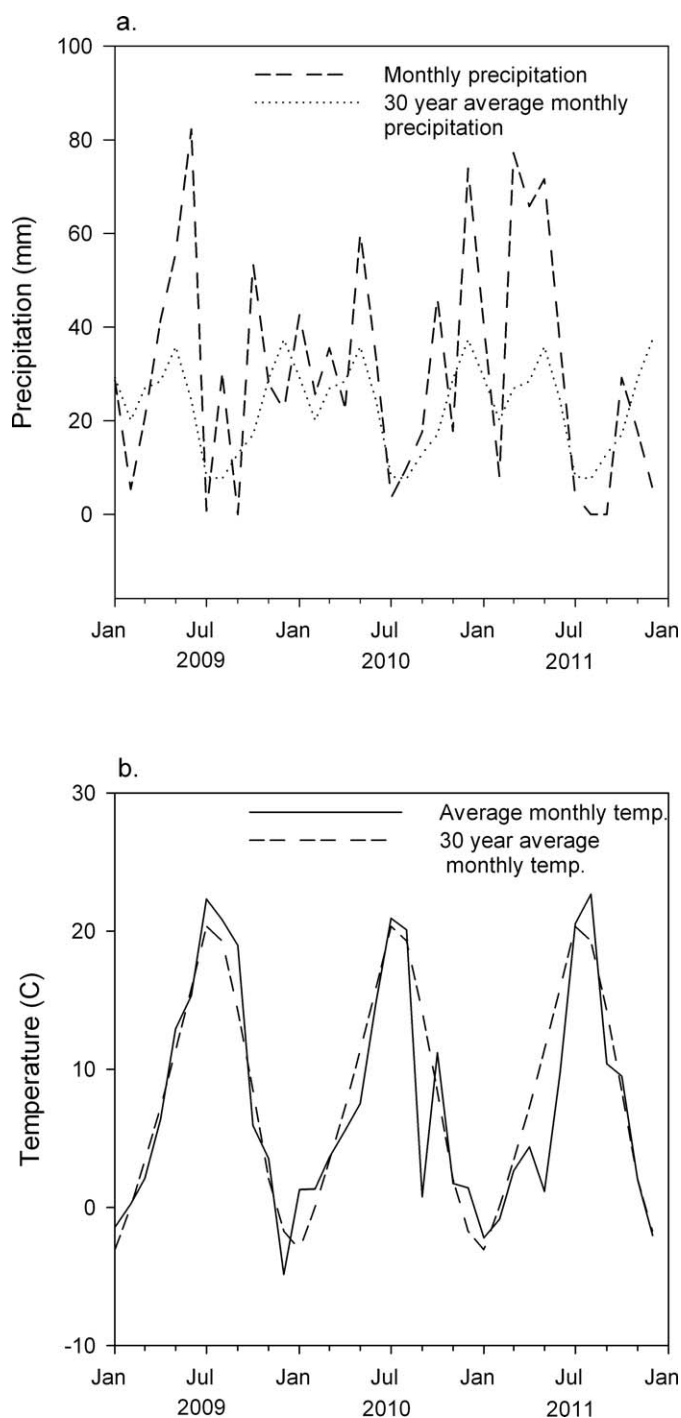


Figure 1. (a) Total precipitation for each season during the study period collected from a centralized weather station in Jordan Valley. (b) Average air temperatures for each season during the study period collected from a centralized weather station in Jordan Valley. The dashed lines represent the mean values for each season over the previous 18 yr that data were collected.

but were a minimum of 1.4 ha to nearly 8 ha. The seed mixture included: 1) crested wheatgrass [*Agropyron cristatum* (L.) Gaertn. × *Agropyron desertorum* Gaertn. 'Hycrest'], which is an improved cultivar of crested wheatgrass that was developed from a hybrid between *A. cristatum* and *A. desertorum*, and 2) Sandberg's bluegrass. The crested wheatgrass and Sandberg's bluegrass seeding rates were 19 and 3.4 kg ha<sup>-1</sup> (16.9 and 3.03 lb ac<sup>-1</sup>), respectively. Treatments were implemented mid-November 2008 (fall dormant) using a no-till rangeland drill. Grasses were seeded to a depth of 4 mm and packed with a pipe pulled directly over each drill row. Seedling establishment was unsuccessful in 2008. Early winter season drought in 2008 to 2009 is thought to have been the primary reason for poor establishment; consequently, these treatments were repeated in mid-November of 2009 at each of the five sites. Additionally, seeding rate for crested wheatgrass was increased to 24.6 kg ha<sup>-1</sup> (21.9 lb ac<sup>-1</sup>) in 2009. In plots designated to receive herbicide, imazapic (Panoramic 2SL, Alligare LLC, 13 N 8th Street, Opelika, AL) was applied at a rate of 60 g ai ha<sup>-1</sup> (0.05 lb ai ac<sup>-1</sup>). The herbicide application occurred in the same entry as seeding using a front-mounted spray applicator calibrated to deliver a total volume of 234 L ha<sup>-1</sup> (25 gal ac<sup>-1</sup>).

Sampling occurred in mid-July 2010 and 2011. Density was sampled by counting the number of annual grass and perennial grass tillers in 20 randomly located 0.25-m<sup>-2</sup> (2.7 ft<sup>-2</sup>) frames in each plot. In addition to counting density in 2010 and 2011, each frame was clipped to ground level to estimate biomass. Plants were separated by species, dried (60°C [140°F] for 48 h), and weighed.

**Data Analysis.** A generalized, linear, mixed model was implemented using SAS Proc Glimmix with either the Poisson or Negative Binomial distribution used to model the responses (SAS 2009). Year, treatment, and the interaction were considered fixed effects, and rep and rep by treatment were the random effects. When the year by treatment effect was not significant, Tukey's adjustment was used for making comparisons among the treatment main effect means. When the year by treatment effect was significant, comparisons among treatments within years were made using the Bonferroni adjustment for multiplicity.

## Results

**Perennial Grasses. Crested Wheatgrass.** ANOVA indicated no treatment affected crested wheatgrass density using multiple comparisons, but the individual treatment comparison indicated that those plots sprayed and seeded had higher density than the control ( $P < 0.001$ ). The sprayed and seeded plots had 41 plants m<sup>-2</sup>, with only 0.38 plants m<sup>-2</sup> where no treatment was applied. However, crested wheatgrass biomass was higher than all

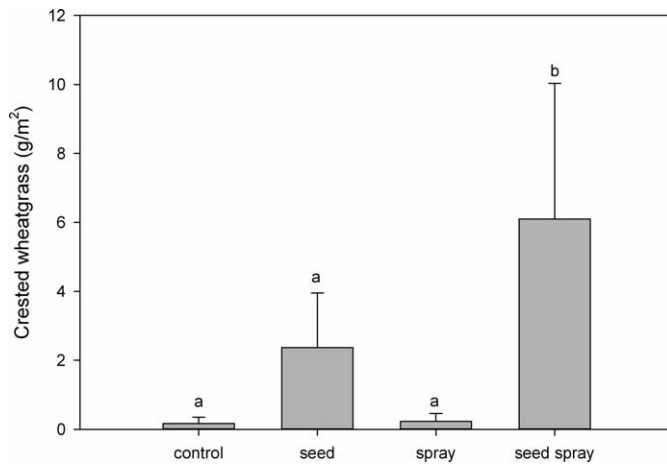


Figure 2. Effects of treatments on crested wheatgrass biomass in 2010 and 2011 combined.

other treatments where spray and seed was applied simultaneously (Figure 2).

**Sandberg's Bluegrass.** Across years, tiller density of Sandberg's bluegrass was higher after the spray and seed combination was applied than in the control and where seeded with the herbicide, but it was not higher than spraying alone ( $P = 0.005$ ; Figure 3a). Sandberg's bluegrass biomass was affected by treatments, but the effect depended on the year of sampling ( $P = 0.031$ ). In 2010, there was no response to any treatment, but spraying and spraying plus seeding more than doubled Sandberg's bluegrass biomass in 2011 (Figure 3b).

**Associated Grasses.** No treatment or treatment combinations produced any detectable effects on the associated perennial grass, primarily *P. spicata* and *E. elymoides* density ( $P = 0.25$ ) or biomass ( $P = 0.36$ ).

**Annual Grasses. Medusahead.** The effects of treatments on medusahead density ( $P = 0.002$ ) and biomass ( $P < 0.001$ ) depended on year, and these parameters followed a similar pattern (Figure 4a). In 2010, medusahead was reduced to nearly zero after the spray or spray plus seeding treatments. By 2011, only the spray plus seeding combination continued to control medusahead, which was lower than all other treatments at that time (Figure 4b).

**Forbs.** No treatment or treatment combination affected perennial forbs, a mix of many species, but primarily *Achillea millefolium* L., *Phlox* sp., and *Crepis* sp. ( $P > 0.35$ ). However, seeding had a temporary effect on annual forb density ( $P = 0.056$ ) and biomass ( $P = 0.016$ ; Figures 5a and 5b). Annual forbs were also a mix of many different species but were primarily nonnative, such as *Sisymbrium* sp. and *Lactuca* sp. Annual forb density and biomass nearly tripled over other treatments where plots

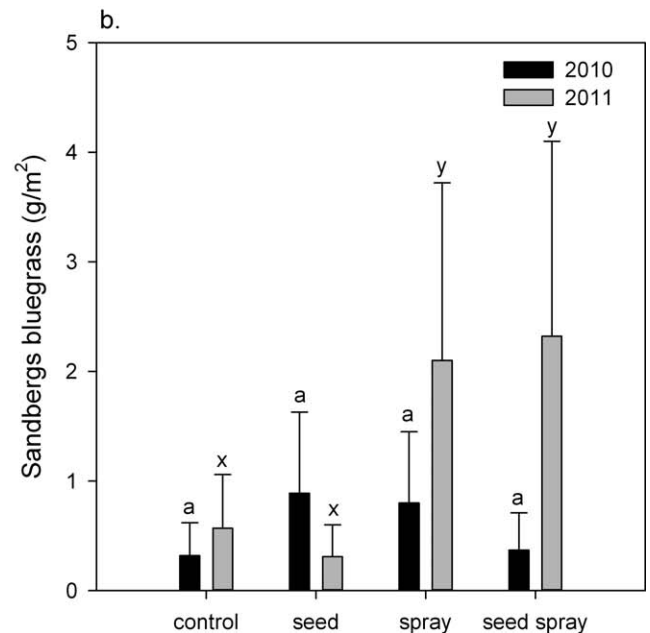
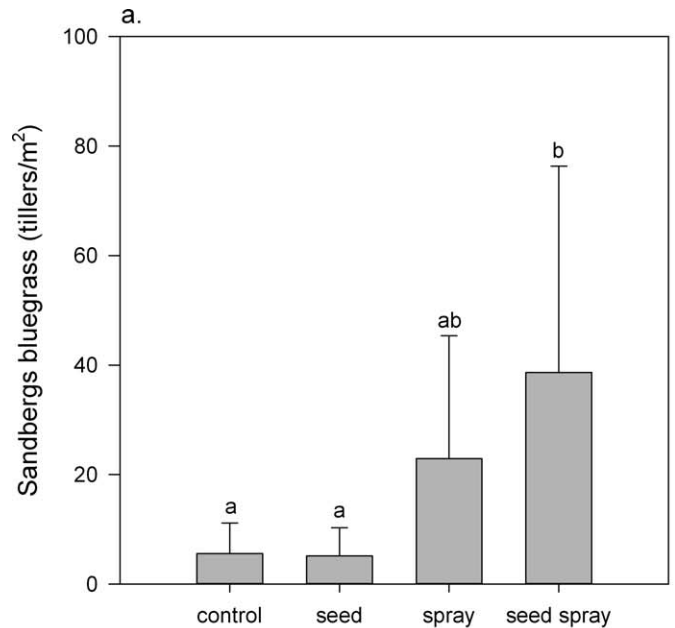


Figure 3. Effects of (a) treatments on Sandberg's bluegrass tillers in 2010 and 2011 combined and (b) the interaction of years on Sandberg's bluegrass biomass by treatment.



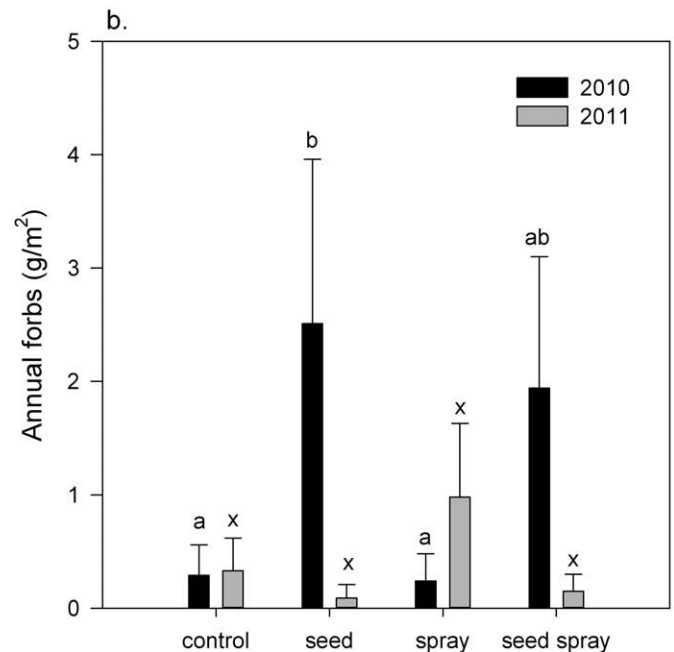
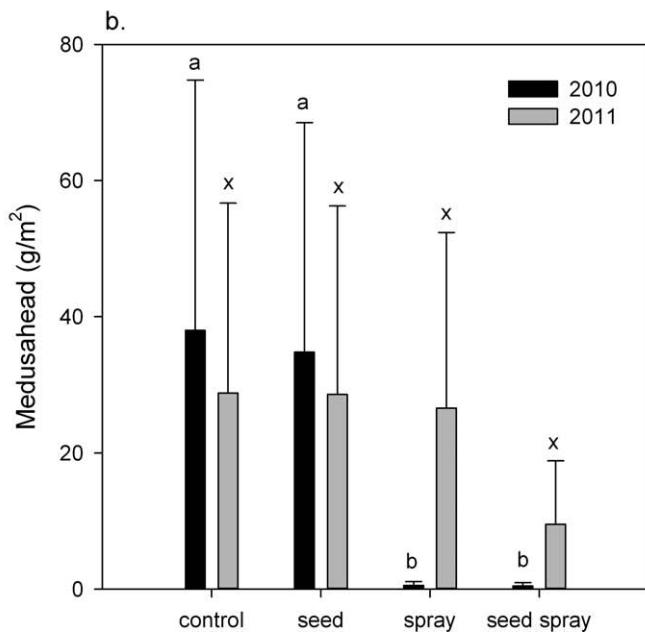
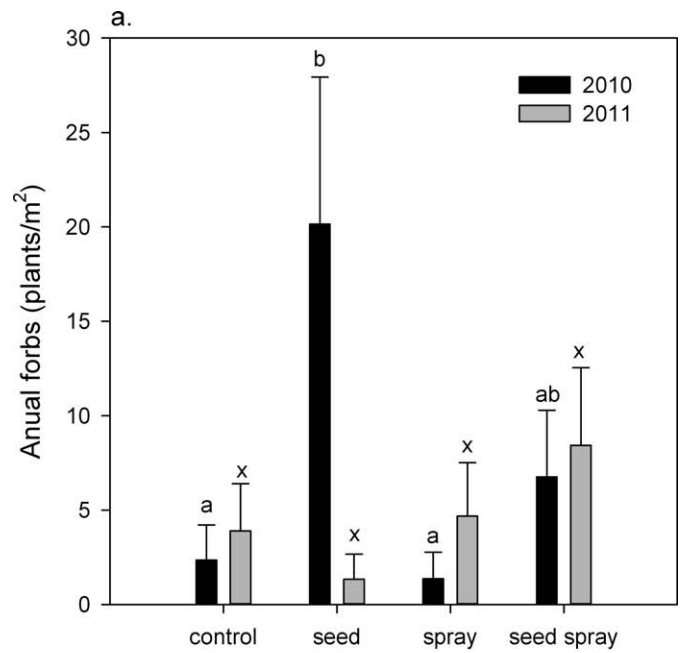
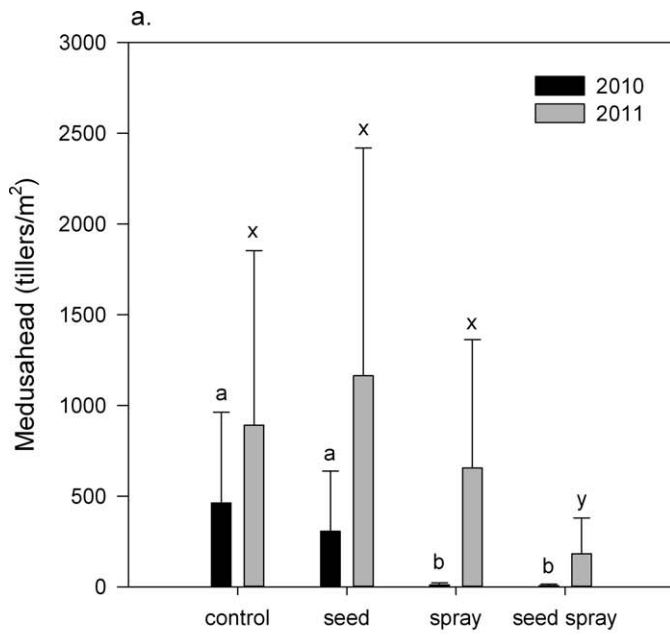


Figure 4. Effects of treatments in each year on medusahead (a) tillers and (b) biomass.

were seeded in 2010, and annual forb biomass was higher in plots that were seeded and sprayed than in the control.

### Discussion

Providing viable and cost-effective options for managing medusahead has been identified as a critical need by ranchers in southeastern Oregon (Johnson et al. 2011). It is

Figure 5. Effects of treatments in each year on forb (a) number of plants and (b) biomass.

increasingly clear that revegetation is central to recovering the effects associated with medusahead invasion, especially in areas devoid of desired grasses (Davies and Svejcar 2008; Sheley et al. 2007). The aim of revegetation is to create invasion resistance within the plant community by

maximizing niche occupancy and biomass production (Borman et al. 1991; Davies 2008; James et al. 2008). Thoughtful but complex integrated annual grass management strategies combining herbicides, fire, and seeding have been shown to create a diverse plant community that resists future invasions (Johnson and Davies 2012; Sheley et al. 2007). However, complex revegetation is costly, and the likelihood of failure is so high that managers are often directed to aim efforts toward situations with potentially greater success, such as prevention or applying herbicides in areas where some residual desired species would be released from competition after medusahead control (Davies and Johnson 2008; Davies and Sheley 2011). After more than a century of invasion, large monocultures of medusahead dominate millions of hectares across the western United States and will likely continue to increase until a practical and successful revegetation strategy is developed.

Some of the expense and difficulty associated with revegetation of medusahead-infested rangeland arises when complex strategies require multiple entries into the management unit and repeated attempts at revegetation after failure (Sheley et al. 2012). In traditional revegetation processes where medusahead infestations occur, the area is burned in the fall to remove litter and create access to the soil surface, then sprayed with imazapic, and seeded before the onset of severely cold temperatures. Each application is usually conducted independently. To lower the expense associated with this multi-entry approach, Sheley et al. (2001) and Sheley (2007) found that the combination of spraying an herbicide and seeding in a late-fall, dormant, single-entry application successfully established several wheatgrass species in knapweed infestations. Sheley et al. (2012) tested the single-entry approach for revegetating medusahead-infested rangeland using small plots. In that study, we found that the simultaneous application of imazapic and seeding provided establishment of desired species where they were absent. However, the evidence was only partially supportive because establishment depended on the site and its environmental conditions. In that study, data supported other investigations, suggesting imazapic combined with seeding can be an effective strategy for revegetating medusahead-infested rangeland, but reemphasizes the difficulty in predicting the conditions under which desired vegetation can be successfully established (Davies 2010; Sheley et al. 2005).

Variation in establishment of desired species using the single-entry approach occurs widely among sites (Sheley et al. 2012). Variation across landscape is a ubiquitous feature of rangeland that must be considered in large-scale rangeland management (Bestelmyer et al. 2011). In this study, we found evidence to support the hypothesis even when applied on a highly variable landscape scale, the combination of imazapic and seeding would provide the highest abundance of perennial grasses and the lowest

amount of annual grasses. The two seeded species used in this large-scale study had the highest density and biomass in areas that received a simultaneous combination of imazapic and seeding, and prolonged medusahead control was highest after this treatment combination. It should be clearly noted that spring conditions during this study were wetter than average, and these results might not reflect those for dryer years.

The current focus of landscape-scale management often assumes the landscape is relatively homogeneous, which is clearly not the case on complex rangeland (Brown et al. 2002; Washington-Allen et al. 2006). In addition to our hypotheses, it was also reasonable to expect that the standard errors of the mean responses would be large, reflecting the variation caused by heterogeneous landscapes. In our small-plot study, standard errors ranged from 20% to 10% of the mean (Sheley et al. 2012). In this study, standard errors ranged from 50% to the size of the mean across all responses. Spatial heterogeneity likely elicits variable responses across landscapes and increases the variance, similar to that across sites (Fulendorf and Smeins 1998; Turner and Chapin 2005). In spite of high variances, the simultaneously applied combination of imazapic and seeding provided the greatest abundance of perennial grasses and the lowest amount of annual grasses. However, managers should expect that large-scale application of this single-entry revegetation approach will create a diversity of densities of desired species across heterogeneous landscapes.

Revegetating medusahead plant-dominated rangeland is central to managing invasive species. The current multi-entry approach is too expensive because of the high cost of application and low probability of success. Common multientry approaches often include a fall herbicide application, followed by burning or disking the following spring and a separate seeding operation in the spring or fall after disking. In small plots, Sheley et al. (2012) developed a single-entry program that simultaneously applied imazapic with a fall-dormant seeding to enhance the establishment of desired species in areas dominated by annual grasses. However, the results of that study raised concern over the procedure's effectiveness across heterogeneous landscapes. This study shows that the single-entry approach can be scaled up to larger landscapes, but variation within the establishment area will likely be high. We were encouraged by enduring medusahead control and perennial grasses biomass increases evident after two seasons posttreatment. This trend indicates longer term control of medusahead. As with all rangeland management, it is critical that producers practice adaptive management and continue to monitor sites after applying treatments. Ultimately, this procedure should reduce the costs of multientry treatment applications and make revegetating annual grass-infested rangeland across landscapes more affordable. The obvious implication is that any time a less

expensive, more effective alternative is available, producers are more likely to initiate management of medusahead before infestations take over healthy rangeland.

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