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Seedling growth and competition of a late-seral, native perennial grass and two early-seral, native forbs in the presence of two densities of the invasive annual grass *Bromus tectorum* L.

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ABSTRACT

The invasive, annual cheatgrass (*Bromus tectorum* L.) has invaded millions of hectares of the North American sagebrush steppe biome resulting in significant lost productivity, revenue and ecosystem function. Efforts to reestablish native perennials in highly infested sites and convert sites back to native dominance have been largely unsuccessful due to cheatgrass' competitive attributes and high stand densities. Seeding early-seral natives with characteristics advantageous for site colonization and stabilization has been seen as a possible means to transition between cheatgrass dominance and desired native plant diversity. We conducted greenhouse trials to compare competitive ability of two native, early-seral forbs, curlycup gumweed [*Grindelia squarrosa* (Pursh) Dunal] and hoary tansyaster [*Machaeranthera canescens* (Pursh) A. Gray], and one late-seral perennial grass, bluebunch wheatgrass [*Pseudoroegneria spicata* (Pursh) Á. Löve], when planted among low- and high-densities of cheatgrass during the critical seedling stage of growth. We also tested if curlycup gumweed, a species under investigation for germplasm release, had any negative effects on bluebunch wheatgrass. Over 12 weeks, cheatgrass grew faster and produced more biomass than the natives. Further, low- and high-densities of cheatgrass significantly reduced plant volume and aboveground biomass of all three natives. Of the natives, only bluebunch wheatgrass caused any notable reduction in cheatgrass growth. Curlycup gumweed did not affect bluebunch volume or biomass to any extent further than a same-species competitor. Our results indicate that the two early-seral forbs tested were not effective at out-competing cheatgrass, and their value in capturing cheatgrass infested sites may be limited. Finally, we found no suppressive effect from curlycup gumweed on bluebunch wheatgrass during the first 12 weeks of growth.

INTRODUCTION

Cheatgrass (*Bromus tectorum* L.) is a major concern among land owners and land managers in western states because of its invasiveness and the negative impacts it creates on the landscape. Millions of hectares are already invaded by cheatgrass, and much of that has been converted to cheatgrass dominated rangeland (Knapp, 1996; Mack, 1981; Stewart and Hull, 1949). At the turn of the last century approximately five million hectares of overgrazed rangeland in Idaho and Utah were covered by almost pure stands of cheatgrass (FICMNEW, 1997). Still millions more are at risk of being invaded and have a high probability of converting to cheatgrass domination (Stewart and Hull, 1949; Weltz et al., 2014). Cheatgrass conversion provides copious amounts of fine fuel creating perfect conditions for recurring wildfires (Brooks et al., 2004). This has led to a

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decrease in the natural fire cycle frequency interval in the sagebrush steppe ecosystem from every 500 to 100 years to every 1 to 5 years in some cases (Whisenant, 1990; Brooks and Pyke, 2001). Cheatgrass invasion further degrades wildlife habitat by reducing available forage as well as excluding native forbs (Knapp, 1996; Stewart and Hull, 1949; Young and Evans, 1978). Sagebrush obligates such as Sage Grouse (*Centrocercus urophasianus* Bonaparte) are particularly at risk as cheatgrass has significant effects on multiple facets of their lives including reducing nesting cover, decreasing forb and sagebrush food sources and reducing native insect populations (USDI FWS, 2015). The total cost to land managers and taxpayers to stave off cheatgrass dominance is staggering (Knapp, 1996).

Cheatgrass succeeds in invading Great Basin landscapes by exploiting key physiological and morphological traits. First, cheatgrass uses more water early in the season than natives by initiating root and shoot growth at lower temperatures (Arredondo et al., 1998; James et al., 2011; Knapp, 1996; Melgoza and Nowak, 1991; Norton et al., 2007). Second, cheatgrass is able to grow in extremely high densities ranging from around 10 plants/m^2 to 10,000 plants/m^2 (Young and Evans, 1978). Once cheatgrass has become established in a location, it is exceedingly difficult to convert a site back to its original state without major inputs.

Despite cheatgrass' advantages in disturbed sites, native plants have been shown to have the capacity to be effective at resisting invasive annual grass presence and building ecological resilience to invasion under non-disturbed conditions (Abella et al., 2011; Allen and Meyer, 2014; Chambers et al., 2007; Phillips and Leger, 2015; Row and Leger, 2011). Mature native perennials in areas in high ecological condition can be effective competitors against cheatgrass invasion, however, competition at the seedling stage is a crucial barrier to meaningful restoration (Allen and Meyer, 2014; Booth et al., 2003; Chambers et al., 2007). Further investigation is needed to determine which native species, if any, can effectively compete against cheatgrass during the establishment stage. One group that shows potential are the ruderal, or early-seral native weeds.

Early-seral natives have evolved to capture a site following disturbance and to facilitate transition to a climax community, yet this important group is often overlooked by plant materials developers and by restoration practitioners (Jones and Johnson, 1998; Ogle et al., 2014; Shaw et al., 2005). Following disturbance, semi-arid western plant communities often respond initially with a flush of early successional annuals or short-lived perennials (Koniak and Everett, 1982; Ott et al., 2003), that colonize the site, and convert soil resources (Busby, 2011; Stube, 2012). One role of early-seral species that may be of high importance is the plant's ability to form associations with, and increase soil populations of, arbuscular mycorrhizal fungi (AMF) which are needed by the later-seral occupants. Over time, longer-lived, late-seral species reestablish from surviving root systems, soil seed banks, or from seed dispersal from adjacent sites. Common restoration practices however tend to skip the early-seral step and attempt to establish mid- to late-successional communities directly after disturbance (Jones and Johnson, 1998; Ogle et al., 2014).

Ruderal and early successional species, especially annuals and short-lived perennials on the other hand, occupy a similar niche to many of the region's exotic grass invaders. Those species with similar ecological functions and attributes should be better equipped to resist potential invaders (Emery, 2007). Stube (2012) similarly asserts that native early-seral species that have traits in common with cheatgrass could potentially compete with cheatgrass if used at competitive seeding rates in restoration efforts and may alter site characteristics in ways that promote succession of the native plant community. For example, studies have indicated that early-seral natives can reduce red brome (*Bromus rubens* L.) establishment and biomass more than late-seral natives (Abella et al., 2011). Likewise, Leger et al., (2013) found the early successional native forb bristly fiddleneck (*Amsinckia tessellata* A. Gray) significantly reduced cheatgrass biomass and seed production, and Prasser and Hild (2016) showed that native annuals reduced halogeton [*Halogeton glomeratus* (M. Bieb.) C.A. Mey.] biomass more than did longer lived perennials. Thus, it may be of benefit to include site-adapted, early-seral species that have evolved with disturbance in restoration seed mixes to promote full site conversion and resiliency (Herron, 2013; Stube, 2012; Leger, 2008; Uselman et al., 2015).

Including certain early-seral species in a seed mix may come with a cost. While in nature it is clear that plant succession from early to late-seral species occurs over long spans of time, it is unknown if early-seral species might have an impact on initial establishment of plants typically associated with a climax community. There may be a threshold at which early-seral natives become “too weedy” to the detriment of conservation objectives. It needs to be determined if early-seral natives might have a negative effect on the establishment late-seral species included in a seed mixture.

While most early-seral work for the western U.S. to date has been conducted on native annuals, few are well-suited for commercial seed production. Many such as foothill deervetch (*Lotus humistratus* Greene), bigbract verbena (*Verbena bracteata* Cav. ex Lag. & Rodr.) and sixweeks fescue [*Vulpia octoflora* (Walter) Rydb.] (Barak et al., 2015; Herron et al., 2013) are low-statured or prostrate in growth habit and poorly suited for large-scale seed production. Still others may be limited in the quantity of seed produced making them economically unsustainable and prohibitively costly for most restoration practices. Early-seral species that serve the same function, while having better seed production attributes, would be beneficial.

Figure 1. Hoary tansyaster (*Machaeranthera canescens*) is a common colonizer of disturbed sites in semi-arid rangelands of the Intermountain West. Photo by Derek Tilley.

NRCS Aberdeen Plant Materials Center (IDPMC) is currently working with two short-lived perennials that may fill the same niche. Amethyst Germplasm hoary tansyaster [*Machaeranthera canescens* (Pursh) A. Gray] (Figure 1) was released by IDPMC in 2016 for inclusion in rangeland seedings in the Great Basin (Tilley, 2016). Similarly, curlycup gumweed [*Grindelia squarrosa* (Pursh) Dunal] (Figure 2) is currently under investigation for potential selected class germplasm release (Tilley and Pickett, 2019a). Both species are adapted to disturbed areas in semi-arid portions of the Great Basin (Welsh, 2003; Whitson et al., 1996) in sites receiving 10 to 20 inches mean annual precipitation (Cronquist et al., 1994; Tilley et al., 2010; Tilley and Pickett 2016). Both species appear to hold onto disturbed sites such as roadsides and gravel pits, but quickly disappear from established climax plant communities (pers obs.). Hoary tansyaster is common in early successional plant communities but is less common in highly disturbed sites. Barak et al. (2015) found a close relative, tansyleaf tansyaster (*M. tanacetifolia* [Kunth] Nees) a potentially valuable species for restoration of cheatgrass invaded rangelands. Because it doesn't have seed dormancy issues, hoary tansyaster has been observed to germinate from late summer and fall rains (pers. obs.), a beneficial trait as it allows the species to compete directly with cheatgrass, another early germinator (Barak et al., 2015; Parkinson et al., 2013). Parkinson et al. (2013) found biomass of hoary tansyaster was not reduced after 12 weeks of growing in the presence of the native grasses, bottlebrush squirreltail and Sandberg bluegrass compared to growing alone. However, cheatgrass at an effective density of 100 plants/m^2 significantly reduced total biomass and shoot relative growth rate of hoary tansyaster but not root growth rate. They attribute that to the tap-rooted morphology of hoary tansyaster which is different and not overlapping with cheatgrass.

Figure 2. Curlycup gumweed (*Grindelia squarrosa*) is being investigated by IDPMC for potential germplasm release for use in conservation and pollinator plantings in the Great Basin. Photo by Derek Tilley.

In this experiment, we compared seedling growth of two early-seral forbs, curlycup gumweed and hoary tansyaster, and the late-seral perennial grass, bluebunch wheatgrass, in the presence of cheatgrass at two densities. Our goals were to determine if the early-seral species had any suppressive effects on cheatgrass, and if early-seral species were more effective at suppressing cheatgrass growth than a late-seral grass. We also wanted to determine if curlycup gumweed had any negative impacts on bluebunch wheatgrass germination or growth. Bluebunch wheatgrass is a very common late-seral species and is the most widely seeded species in Great Basin restoration and conservation projects making up 27% of the total seed purchased by the Bureau of Land Management (BLM) from 2010-2015 (Roller, 2016). It is often the dominant grass species in 220 to 350 mm precipitation areas of the sagebrush steppe ecosystem (Welsh et al., 2003; Ogle et al., 2010). Because it is often among the most desired climax species targeted for restoration, we need to better understand the impact of including early-seral "weedy" natives in seed mixes (Parkinson et al., 2013). Due to curlycup gumweed's previous designation by some as a weed (Whitson et al., 1996; Stubbendieck et al., 1994) we decided to evaluate any potential ill-effects caused by its inclusion in restoration seed mixes.

MATERIALS AND METHODS

We evaluated growth characteristics of curlycup gumweed, hoary tansyaster and bluebunch wheatgrass in the presence of cheatgrass at two densities. Young and Evans (1978) and Hull and Pechanec (1947) found cheatgrass densities in highly degraded sites exceeding 900/ft^2 with an estimated average density of over 550 cheatgrass plants/ft^2. For our experiment we used modest densities of 32 plants/ft^2 (low-density) and 130 plants/ft^2 (high-density). We also included low- and high-density treatments of native species (minus hoary tansyaster) to compare the degree of competition imposed by cheatgrass to the same level of intraspecific competition of the focus species, even though such densities are unlikely in nature or currently recommended in restoration seedings. To test whether an early-seral native might have detrimental effects on climax species in a seed mixture, we also evaluated the growth of bluebunch wheatgrass in low- and high-density combinations of curlycup gumweed and compared it to bluebunch growth in the same densities of cheatgrass and a bluebunch wheatgrass control. We planted 8 to 12- 655 cc (40 ci) conetainers (hereafter referred to as pots) of each treatment expecting some losses. In total we evaluated 18 treatments with 6 to 10 replications depending on the number of pots successfully established (Table 1). Treatments are hereafter designated by first letter of focus species followed by the first letter of the competitor. The number 4 preceding the competitor is used to describe plants/pot in high-density treatments.

Table 1. Competition treatments investigated. G=curlycup gumweed, M=hoary tansyaster, P=bluebunch wheatgrass, B=cheatgrass. Low-density treatments were planted at a density of 350 plants/m^2 and high-density treatments were planted at 1400 plants/m^2.

Alone		Low-Density		High-Density	
Treatment	Replications	Treatment	Replications	Treatment	Replications
G	6	G-B	6	G4B	10
M	6	M-B	8	M4B	10
P	6	P-B	10	P4B	8
B	6	B-B	8	P4G	6
		P-G	8	P4P	9
		P-P	8	G4G	6
		G-G	6		
		M-M	7		

Bluebunch wheatgrass seed was of Anatone Germplasm produced in 2016, and hoary tansyaster was of Amethyst Germplasm produced in 2017. For curlycup gumweed we used a blend of seed collected from 25 locations throughout the Great Basin in 2018. Cheatgrass seed was collected in various seed production fields at IDPMC.

Curlycup gumweed seed has significant physiological dormancy mechanism and is typically put through a cold/moist stratification period of approximately 90 days to reach adequate germination (Nuzzo, 1978; Baskin and Baskin, 2002; Luna, 2008). However, it has been shown that submerging seed in oxygenated water effectively eliminates the need for stratification of some species, including curlycup gumweed (Tilley, 2013; Tilley and Pickett, 2019b). Hoary tansyaster exhibits no seed dormancy, but we have seen that it responds positively to soaking in an oxygenated water bath and quickens germination time (pers. obs). Therefore, we germinated gumweed and tansyaster using an oxygenated water bath to bypass the stratification requirement and to produce uniform germinants. Seed was primed in oxygenated deionized water for 24 hours in a Hoffman growth chamber (Hoffman Manufacturing, Inc., Corvallis, Oregon) with a 12-hour light/dark cycle with 22° C day and 15° C night temperatures and then seeded with a large eye-dropper at a rate of approximately 4 seeds for each desired plant. Cheatgrass and bluebunch wheatgrass were direct seeded with no pre-treatment at a similar rate. All plants were germinated within 7 days of one another. Additional germinants were thinned as necessary to meet the desired number of plants/pot for each species.

Figure 3. Seedlings were grown for 12 weeks under greenhouse conditions. Plant volume was measured weekly. Final volume and aboveground biomass were measured for statistical analysis at 12 weeks after planting. Photo by Derek Tilley.

Seed was planted into 40 ci pots filled with Sunshine Mix #4 soil, (Sungro Horticulture, Agawam, MA), in a completely randomized experimental design. Pots were irrigated as needed with overhead sprinklers following daily visual inspection. The plants were fertilized once at week 6 with Miracle Grow® 24-8-16 All Purpose Plant Food (Scotts Miracle-Gro, Marysville, OH). Pots were spread out as necessary to avoid shading from one pot to another.

Evaluations began 2 weeks after planting. We measured plant height (h) and 2 perpendicular diameters of each plant (d_1 and d_2) weekly to ascertain the canopy volume of each focus plant and the average canopy volume of the outer plants in each cone. Plant canopy volume calculations were adapted from Thorne et al. (2002) using the formula for the volume of half of an ellipsoid (ellipsoid divided in half to represent the aboveground parts of the plant):

$$V = \frac{2}{3}\pi h\left(\frac{d_1}{2} \times \frac{d_2}{2}\right)$$

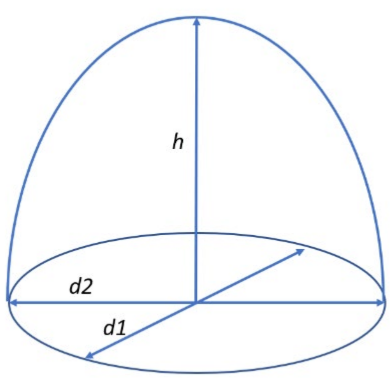


Figure 4. Plant volumes were calculated using the equation for one-half of an ellipsoid.

At week 12 we also measured aboveground biomass of each focus species and average aboveground biomass for the non-focus species. Biomass samples were oven dried at 60° C for three days prior to weighing.

Week 12 data were analyzed using Statistix 10® Analytical Software, Tallahassee (FL). Plant volume and biomass for curlycup gumweed and hoary tansyaster as well as plant volume for bluebunch wheatgrass were log transformed to adjust for normality. Bluebunch wheatgrass biomass data were transformed using a square root transformation. Cheatgrass volume and biomass were normally distributed and required no transformation. Normalized data were analyzed using one-way analysis of variance and means were separated using an LSD all-pairwise comparison with an alpha level of 0.05. Graphs were created using R (R Core Team, 2017).

RESULTS AND DISCUSSION

Curlycup gumweed alone (G) and with a single intraspecific competitor (GG) grew at essentially the same rate and showed little difference in the volume of the target plant over the first 12 weeks of growth (Figure 4). Gumweed growing with high and low-density cheatgrass (GB and G4B) grew at a much lower rate and plant volume was greatly inhibited. Gumweed grown at high-densities with members of the same species (G4G) likewise showed large reductions in volume, but not to the extent caused by cheatgrass.

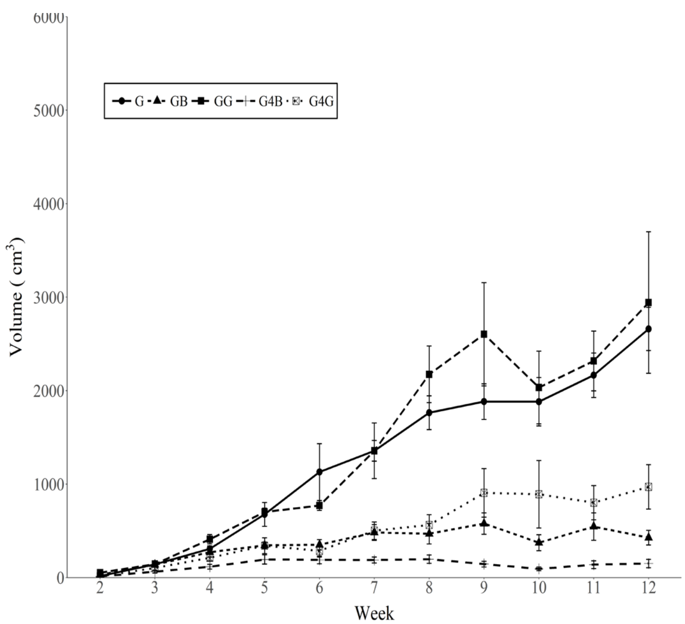


Figure 4. Volume of curlycup gumweed (cm^3) with same species competitor and high- and low- densities of cheatgrass from 2 to 12 weeks of growth. Error bars represent 1 standard deviation.

Hoary tansyaster plant volumes were greatly decreased in the presence of all competitors, including low-densities of other tansyaster seedlings (MM) (Figure 5). After approximately 5 weeks, competition became noticeable as hoary tansyaster plants grown without competition grew discernably larger and more quickly. Plants grown with competitors were noticeably stunted, even resulting in mortality of the target plant in some cases.

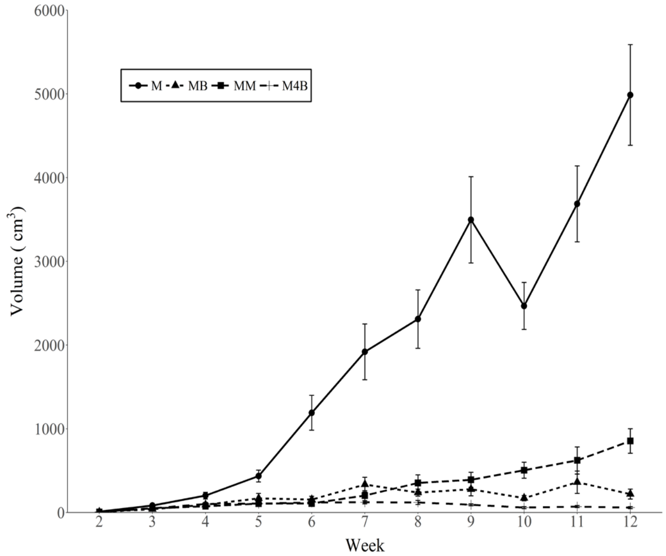


Figure 5. Volume of hoary tansyaster (cm^3) with same species competitor and high- and low- densities of cheatgrass from 2 to 12 weeks of growth. Error bars represent 1 standard deviation.

Bluebunch wheatgrass seedlings response to competition was similar to that observed from curlycup gumweed. Volumes were visibly reduced with competition, even from low-density bluebunch competitors (PP) (Figure 6); however, the greatest reductions were seen in the high-density bluebunch wheatgrass (P4P) and both densities of cheatgrass (PB and P4B).

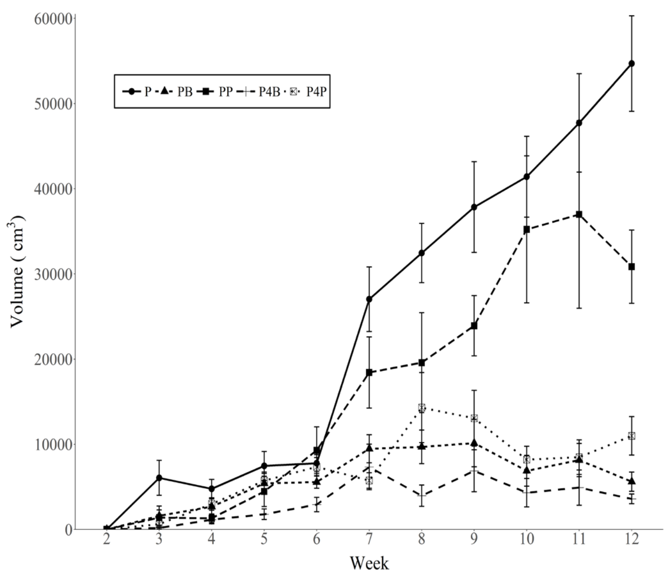
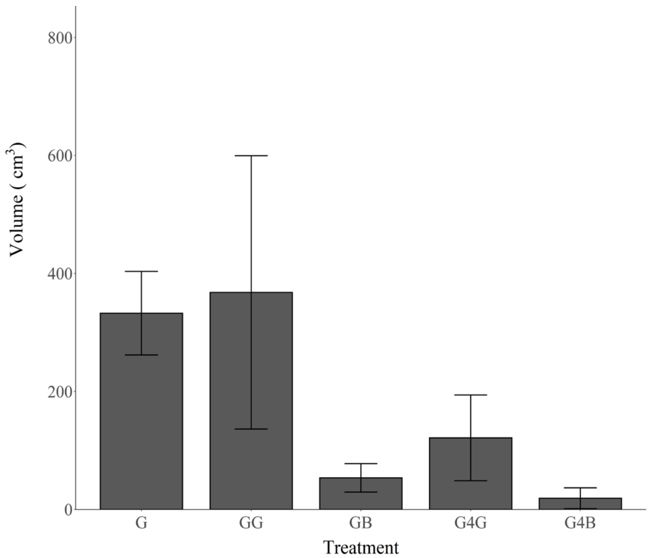


Figure 6. Volume of bluebunch wheatgrass (cm^3) with same species competitor and high- and low- densities of cheatgrass from 2 to 12 weeks of growth. Error bars represent 1 standard deviation.

Plant Volume and Aboveground Biomass at 12 Weeks

Curlycup Gumweed



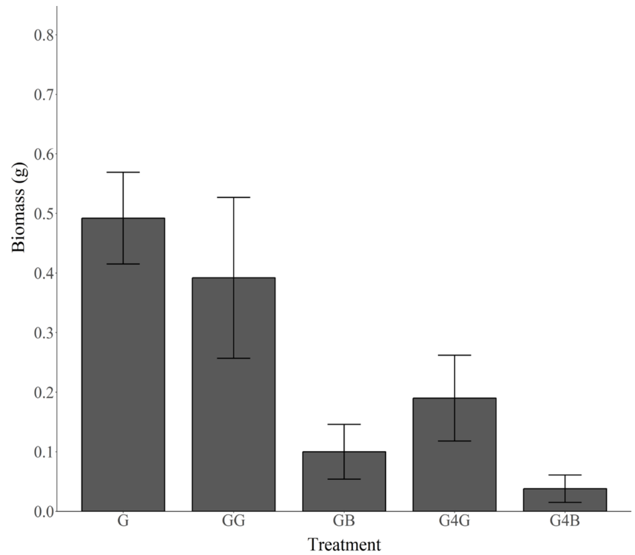


Figure 7. Curlycup gumweed target plant volume (l) and biomass (r) at 12 weeks when grown in the presence of an additional gumweed (GG), high-density gumweed (G4G), low-density cheatgrass (GB) and high-density cheatgrass (G4B). Volume and biomass were significantly reduced by all treatments. Error bars represent 1 standard deviation.

Curlycup gumweed volume was significantly reduced by the presence of low- and high-density cheatgrass (GB and G4B) as well as high densities of gumweed (G4G) after 12 weeks (p=0.0000) (Figure 7). Low-density cheatgrass (GB) caused decreases in plant volume of 85%, statistically equivalent to those of high-density intraspecific competition of gumweed (G4G). High densities of cheatgrass (G4B) resulted in target plant volumes significantly lower than all treatments (Figure 8), with a 95% reduction compared to gumweed grown alone (G). We saw no significant reduction in target plant volume however from low-density gumweed (GG).

Figure 8. Curlycup gumweed grown in high-density cheatgrass competition had significantly lower plant volume and biomass compared to a control grown alone. Photo by Derek Tilley.

Gumweed biomass results were significantly different (p=0.0000) with trends being very similar to those seen for gumweed volume. Adding a second G to the pot (GG) did not reduce plant biomass; however, adding a single cheatgrass reduced gumweed biomass by 80%. High-density gumweed (G4G) reduced target plant biomass by more than 50%, while high-density cheatgrass (G4B) caused a 90% reduction in the biomass of the target plant.

Figure 9. Hoary tansyaster grown in a low-density pot with a single cheatgrass competitor. Hoary tansyaster plant volumes and aboveground biomass were significantly reduced by all competitors including the native species evaluated. Photo by Derek Tilley.

Hoary Tansyaster

Hoary tansyaster (Figure 9) volumes were significantly reduced by all additions (p=0.0000) (Figure 10). Adding a single tansyaster competitor (MM) reduced the volume of the target plant by more than 80%, while adding a single cheatgrass reduced tansyaster volume by 95%. High-density cheatgrass reduced tansyaster volumes even further with average reductions of nearly 99%.

Tansyaster biomass at 12 weeks followed the same trend as plant volume. Slight increases in plant density (MM and MB) resulted in significant biomass reductions of the target plants (p=0.0000). The addition of a tansyaster plant caused a 75% reduction, while adding a single cheatgrass plant resulted in 93% less biomass. Even greater reductions were seen from high-density competition of cheatgrass (M4B) with reductions of biomass of (95%). These data would appear to confirm the findings of Parkinson et al. (2013).

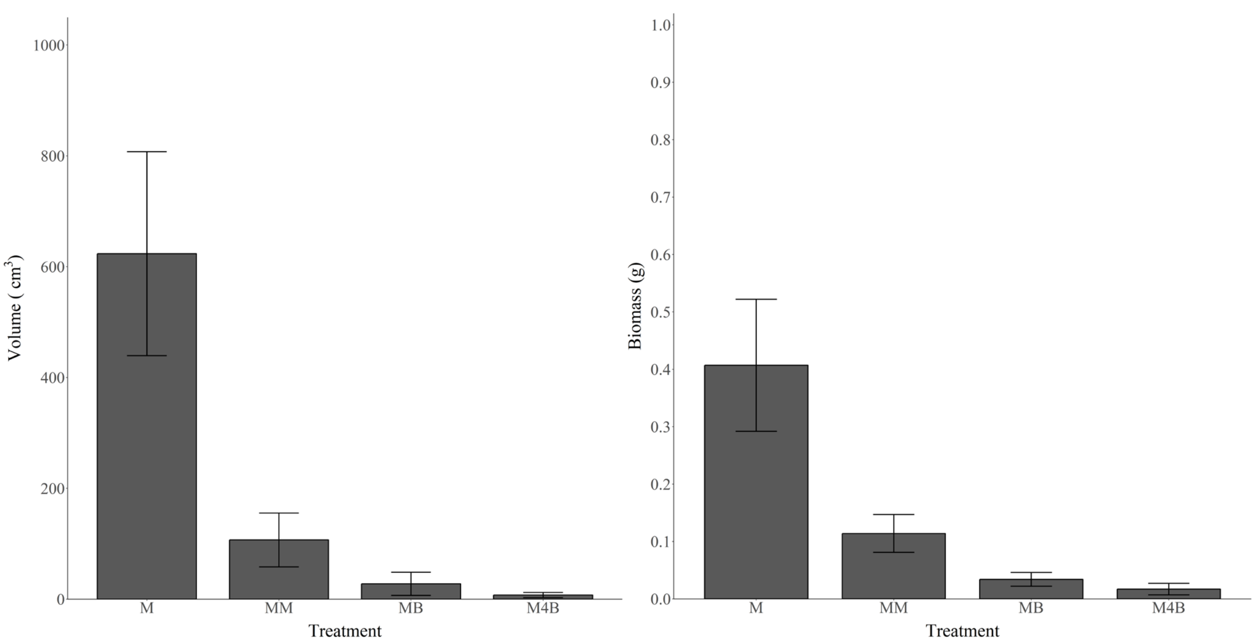


Figure 10. Hoary tansyaster target plant volume (l) and biomass (r) at 12 weeks when grown in the presence of an additional tansyaster (MM), low-density cheatgrass (MB) and high-density cheatgrass (M4B). Volume and biomass were significantly reduced by all treatments. Error bars represent 1 standard deviation.

Bluebunch Wheatgrass

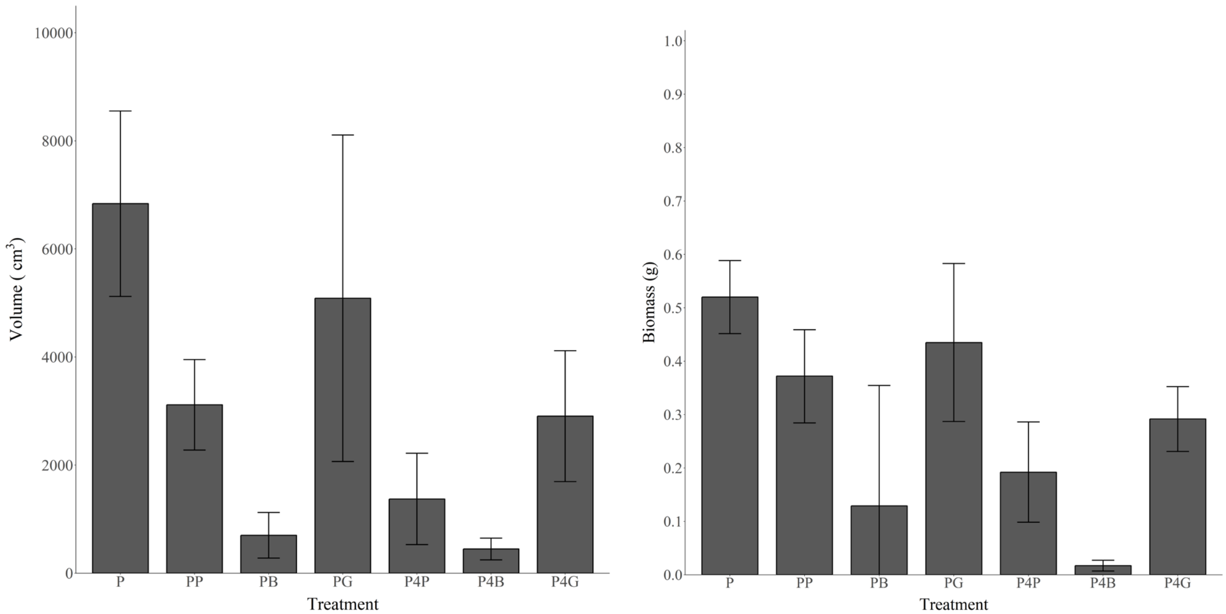


Figure 11. Bluebunch wheatgrass target plant volume (l) and biomass (r) at 12 weeks when grown in the presence of an additional bluebunch (PP), low-density curlycup gumweed (PG), high-density gumweed (P4G), low-density cheatgrass (PB) and high-density cheatgrass (P4B). Error bars represent 1 standard deviation.

Target bluebunch wheatgrass plant volumes were greatly reduced by the addition of low- and high-density cheatgrass (PB and P4B) resulting in 90% and 95% reductions respectively (Figure 11). Adding a single gumweed seedling to bluebunch wheatgrass did not reduce volume of the target plant; however, bluebunch wheatgrass volumes were reduced by a significant 50% by the addition of a bluebunch competitor (PP). High-density gumweed competition (P4G) reduced target plant volume by 60%, yet those volumes did not differ significantly from the PG or PP treatments.

Bluebunch target plant biomass trends were similar to trends observed from volume. A single cheatgrass seedling (PB) caused significant decreases in target species biomass, however low-densities of gumweed (PG) did not reduce target plant biomass significantly, and the low-density bluebunch (PP) treatment showed significant, though minor reductions in aboveground biomass. High-density treatments (P4P, P4G, and P4B) resulted in dramatic reductions in target plant biomass with the greatest reduction resulting from the high-density cheatgrass treatment (90%).

Effect of Early- and Late-seral Natives on Cheatgrass

None of the native species tested reduced cheatgrass volume when compared with being grown alone (p=0.099) (Figure 12). A single cheatgrass competitor reduced the average volume of the target plant by 40% but was not significant. Cheatgrass biomass was not reduced significantly by the two early-seral forbs but was significantly reduced by PSSP and an additional BRTE by 35% and 50% respectively (p=0.0014).

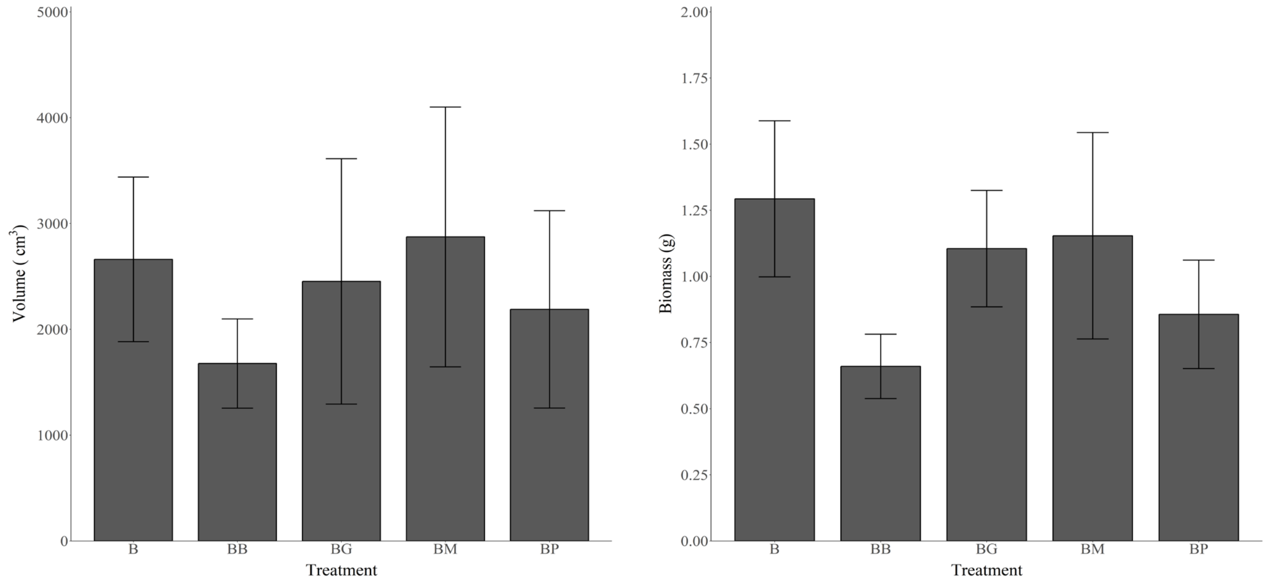


Figure 12. Cheatgrass target plant volume (l) and biomass (r) at 12 weeks when grown in the presence of an additional cheatgrass (BB), low-density curlycup gumweed (BG), low-density hoary tansyaster (BM), and low-density bluebunch wheatgrass (BP). Error bars represent 1 standard deviation.

DISCUSSION

After 12 weeks, cheatgrass had produced more biomass when grown alone than any of the other species tested; 2.5 times more than bluebunch wheatgrass and curlycup gumweed and 3 times more than hoary tansyaster. This ability to establish and grow quickly makes it highly competitive at acquiring water and sunlight. A single competitor of cheatgrass reduced biomass and volume of all 3 native species tested between 75 and 95% regardless of successional niche. Higher densities of cheatgrass had an even greater effect on the target species. This is highly disturbing when one considers we used 1,400 plants/m^2 for our high-density treatment when densities of 10,000 plants/m^2 have been reported.

Differences in natural germination timing may further complicate the issues. In this trial, we germinated all seed essentially simultaneously; however, cheatgrass seedlings often have a competitive advantage in the field from germinating at lower temperatures and with less available moisture than many native species. Cheatgrass has the distinct advantage of producing significant root growth far earlier than most native perennials. Even with the benefit of uniform germination times, the natives we tested were unable to compete effectively and suppress cheatgrass growth. In natural conditions, cheatgrass would easily be able to establish and reproduce against the competitors we provided.

Cheatgrass aboveground biomass, but not plant volume, was reduced significantly in the presence of bluebunch wheatgrass. While bluebunch itself was greatly reduced, it did have a moderate effect on cheatgrass production, at least more so than the forbs we tested. The two early-seral forbs tested were less effective in direct competition with cheatgrass than the late-seral climax perennial grass. These findings would seem to be in line with those of Parkinson et al. (2013) regarding hoary tansyaster. It is possible that curlycup gumweed and hoary tansyaster are better considered to be advantageous occupants of disturbed sites rather than highly-competitive colonizers.

Curlycup gumweed did not reduce the volume or biomass of bluebunch wheatgrass any more than the presence of more bluebunch seedlings. Despite being labeled a weed by some, it does not seem to pose a greater threat than intraspecific competition at the seedling stage, and the concern of competition from gumweed may be unfounded. While curlycup gumweed and the plants evaluated are compatible at these early growth stages, the authors are currently investigating if mature curlycup gumweed causes any allelopathic effects on the germination and growth of bluebunch wheatgrass or other plants.

CONCLUSION

The two early-seral native forbs tested were not effective at reducing or suppressing cheatgrass growth when germinated concurrently with cheatgrass. It is possible that species with similar germination timing as cheatgrass would be more effective at direct competition; however, finding desirable natives with those traits remains a challenge. Bluebunch wheatgrass was the strongest competitor against cheatgrass in our trial. Finally, we saw no suppressive effect from curlycup gumweed on bluebunch wheatgrass at this growth stage.

LITERATURE CITED

Abella, S.R., Craig, D.J., Smith, S.D., Newton, A.C., 2012. Identifying Native Vegetation for Reducing Exotic Species during the Restoration of Desert Ecosystems. Restoration Ecology 20, 781–787.

Allen, P.S. and S.E. Meyer. 2014. Community structure affects annual grass weed invasion during restoration of a shrub-steppe ecosystem. Invasive Plant Science and Management. 7: 1-13.

Arredondo, J.T., Jones, T.A. and D.A. Johnson. 1998. Seedling growth of Intermountain perennial and weedy annual grasses. Journal of Range Management. 51: 584-589.

Barak, R.S., Fant, J.B., Kramer, A.T. and A. Krissa. 2015. Assessing the value of potential "native winners" for restoration of cheatgrass-invaded habitat. Western North American Naturalist. 75(1):58-69.

Baskin, J.M. and C.C. Baskin. 2002. Propagation protocol for production of Container (plug) *Grindelia squarrosa* (Pursh) Dun. Plants. University of Kentucky Lexington (KY). In: Native Plant Network. URL: http://NativePlantNetwork.org (accessed 2017/12/05). US Department of Agriculture, Forest Service, National Center for Reforestation, Nurseries, and Genetic Resources.

Bazzaz, F.A. 1979. The physiological ecology of plant succession. Annual Review of Ecology and Systematics. 10: 351-371.

Booth, M.S., Caldwell, M.M., and J.M. Stark. 2003. Overlapping resource use in three Great Basin species: implications for community invisibility and vegetation dynamics. Journal of Ecology. 91: 36-48.

Brooks, M.L., D'Antonio, C.M., Richardson, D.M., Grace, J.B., Keeley, J.E., DiTomaso, J.M., Hobbs, R.J., Pellant, M, and D. Pyke. 2004. Effects of invasive alien plants on fire regimes. Bioscience. 54: 677-688.

Brooks, M.L. and D.A. Pyke. 2001. Invasive plants and fire in the deserts of North America. Pages 1-14 *in* Galley KEM, Wilson TP, eds. Proceedings of the invasive species workshop: the role of fire in the control and spread of invasive species. Fire conference 2000: the First

National Congress on Fire Ecology, Prevention and Management. Miscellaneous Publication No. 11, Tall Timbers Research Station, Tallahassee, FL.

Busby, R.R. 2011. Cheatgrass (*Bromus tectorum* L.) interactions with arbuscular mycorrhizal fungi in the North American steppe: Prevalence and diversity of associations, and divergence from native vegetation. PhD. Dissertation. Colorado State University. Fort Collins (CO). 127p.

Chambers, J.C., Bradley, B.A., Brown, C.S., D'Antonio, C., Germino, M.J., Grace, J.B., Hardegree, S.P., Miller, R.F. and D.A. Pyke. 2014. Resilience to stress and disturbance and resistance to *Bromus tectorum* L. invasion in cold desert shrublands of western North America. Ecosystems. 17: 360-375.

Chambers, J.C., Roundy, B.A., Blank, R.R. Meyer, S.E. and A. Whittaker. 2007. What makes Great Basin sagebrush ecosystems invasible by *Bromus tectorum*? Ecological Monographs. 77 (1): 117-145.

Cronquist, A., Holmgren, A.H., Holmgren, N.H., Reveal, J.L., and P.K. Holmgren. 1994. Intermountain Flora: Vascular Plants of the Intermountain West, U.S.A. Vol. 5: Asterales. The New York Botanical Garden. Bronx (NY). 496 p.

Emery, S.M. 2007. Limiting similarity between invaders and dominant species in herbaceous plant communities? Journal of Ecology. 95: 1045-1053.

[FICMNEW] Federal Interagency Committee for the Management of Noxious and Exotic Weeds. 1997. *Invasive plants – changing the landscape of America*. Washington, D.C.

Herron, C.M., Jonas, J.L., Meiman, P.J. and M.W. Paschke. 2013. Using native annual plants to restore post-fire habitats in western North America. International Journal of Wildland Fire.

Hull, A.C., Jr., Pechanec, Joseph F. 1947. Cheatgrass--a challenge to range research. Journal of Forestry. 45(8): 555-564.

[ITIS] Integrated Taxonomic Information System. 2019. URL: http://www.itis.gov (accessed 20 Aug 2019).

James, J.J., Drenovsky, R.E., Monaco, T.A., and M.J. Rinella. 2011. Managing soil nitrogen to restore annual grass infested plant communities: effective strategy or incomplete framework? Ecological Applications. 21: 490-502.

Jones, T.A. and D.A. Johnson. 1998. Integrating genetic concepts into planning rangeland seedings. Journal of Range Management. 51(6): 594-606.

Knapp, P.A. 1996. Cheatgrass (*Bromus tectorum*) dominance in the Great Basin Desert: history, influences, and persistence to human activities. Global Environmental Change. 6 (1): 37-52.

Koniak, S., and R.L. Everett. 1982. Seed reserves in soils of successional stages of pinyon woodlands. American Midland Naturalist. 108: 295-303

Leger, E.A. 2008. The adaptive value of remnant native plants in invaded communities: an example from the Great Basin. Ecological Applications. 18(5): 1226-1235.

Leger, E.A., E.M. Goergen, and T. Forbis De Queiroz. 2014. Can native annual forbs reduce *Bromus tectorum* biomass and indirectly facilitate establishment of a native perennial grass? Journal of Arid Environments. 102:9-16.

Luna, T. 2008. Propagation protocol for production of Container (plug) *Grindelia squarrosa* (Pursh) Dunal. plants 160 ml container; USDI NPS - Glacier National Park West Glacier (MT). In: Native Plant Network. URL: http://NativePlantNetwork.org (accessed 2017/12/05). US Department of Agriculture, Forest Service, National Center for Reforestation, Nurseries, and Genetic Resources.

Mack, R. 1981. Invasion of *Bromus tectorum* L. into western North America; an ecological chronical. Agro-ecosystems. 7:145-165.

Melgoza, G. and R.S. Nowak. 1991. Competition between cheatgrass and two native species after fire: implications from observations and measurements of root distribution. Journal of Range Management. 44: 27-33.

Norton, J.B., Monaco, T.A. and U. Norton. 2007. Mediterranean annual grasses in western North America: kids in a candy store. Plant and Soil. 298: 1-5.

Nuzzo, V. 1978. Propagation and planting of prairie forbs and grasses in southern Wisconsin. Dane County Highway Department. Madison, WI. In: Glenn-Lewin, D.C. and R.Q. Landers. Fifth Midwest Prairie Conference Proceedings: Iowa State University. Ames (IA). August 22-24, 1976.

Ogle, D.G., St John, L. and T.A. 2010. Plant guide for bluebunch wheatgrass (*Pseudoroegneria spicata*). USDA-Natural Resources Conservation Service. Idaho and Washington Plant Materials Program. 5p.

Ogle, D., Tilley, D., St. John, L., Stannard, M. and L. Holzworth. 2014. Technical Note 24: Grass, Grass-like, Forb, Legume, and Woody Species for the Intermountain West. USDA-NRCS, Boise, ID. 72p.

Ott, J.E., McArthur, E.D. and B.A. Roundy. 2003. Vegetation of chained and non-chained seedings after wildfire in Utah. Journal of Range Management. 56: 81-91.

Parkinson, H., Zabinski, C. and N. Shaw. 2013. Impact of native grasses and cheatgrass (*Bromus tectorum*) on Great Basin forb seedling growth. Rangeland Ecology and Management. 66 (2): 174-180.

Phillips, A.J. and E.A. Leger. 2015. Plastic responses of native plant root systems to the presence of an invasive annual grass. American Journal of Botany. 102(1): 73-84.

Prasser, N.P. and A.L. Hild. 2016. Competitive interactions between an exotic annual, *Halogeton glomeratus*, and 10 North American native species. Native Plants Journal. 17 (3): 244-254.

R Core Team. 2017. R: A language and environment for statistical computing. R Foundation for Statistical computing. Vienna, Austria. URL https://www.R-project.org/.

Roller, P. 2016. BLM National Seed Warehouse System (accessed online 3/7/2019) http://chapter.ser.org/southwest/files/2016/04/Galvan-National-Warehouse-System-Overview-3-19-2016.pdf

Row, C.L.J. and E.A. Leger. 2011. Competitive seedlings and inherited traits: a test of rapid evolution of *Elymus multisetus* (big squirreltail) in response to cheatgrass invasion. Evol Appl. 4(3): 485–498.

Shaw, N.L., Lambert, S.M., DeBolt, A.M. and M. Pellant. 2005. Increasing native forb seed supplies for the Great Basin. Pages 94-102 *in* Dumroese, R.K., Riley, L.E. and T.D. Landis, eds. National proceedings: Forest and Conservation Nursery Associations. Charleston, NC.

Stewart, G. and A.C. Hull. 1949. Cheatgrass (*Bromus tectorum* L.) and ecologic intruder in Southern Idaho. Ecology 30(1): 58-74.

Stubbendieck, J., Friisoe, G.Y. and M.R. Bolick. 1994. *Weeds of Nebraska and the Great Plains*. Nebraska Department of Agriculture, Bureau of Plant Industry. Lincoln, Nebraska.

Stube, C.J.K. 2012. Interactions between *Bromus tectorum* L. (cheatgrass) and native ruderal species in ecological restoration. Master's Thesis. Colorado State University. Fort Collins (CO). 64p.

Thorne, M.S., Q.D. Skinner, M.A. Smith, J.D. Rodgers, W.A. Laycock, and S.A. Cerekci. 2002. Evaluation of a technique for measuring canopy volume of shrubs. J. Range Mange. 55: 235-241.

Tilley, D.J. 2013. Soaking Nebraska sedge seeds in warm, aerated water improves germination. Native Plants Journal 14(1):55-58.

Tilley, D.J. 2016. Notice of release of Amethyst Germplasm hoary tansyaster: selected class of natural germplasm. Native Plants Journal. 16(1): 54-59.
Tilley D., Ogle, D. and L. St. John. 2010. Plant guide for hoary tansyaster (*Machaeranthera canescens*). USDA-Natural Resources Conservation Service, Idaho Plant Materials Center. Aberdeen, ID. 3p.
Tilley, D. and T. Pickett. 2016. Plant Guide for curlycup gumweed (*Grindelia squarrosa)*. USDA-Natural Resources Conservation Service, Aberdeen Plant Materials Center. Aberdeen, ID. 5p.
Tilley, D. and T. Pickett. 2019a. Curlycup gumweed initial evaluation planting, 2016-2018. Aberdeen (ID): USDA Natural Resources Conservation Service, Aberdeen Plant Materials Center. Progress Report. 15 p.
Tilley, D. and T. Picket. 2019b. Germination response of curlycup gumweed seed to oxygenated water treatment. Native Plants Journal. (in review).
[USDA NRCS] USDA Natural Resources Conservation Service. 2019. The PLANTS database. URL: http://plants.usda.gov (accessed 3 Mar 2019). Greensboro (NC): National Plant Data Team.
[USDI Fish and Wildlife Service]. 2015. Endangered and Threatened Wildlife and Plants; 12-Month Finding on a Petition to List Greater Sage-Grouse (*Centrocercus urophasianus*) as an Endangered or Threatened Species. Federal Register. 80: 59857-59942.
Uselman, S.M., Snyder, K.A., Leger, E.A. and S.E. Duke. 2015. Emergence and early survival of early versus late-seral species in Great Basin restoration in two different soil types. Applied Vegetation Science. 18: 624-636.
Welsh, S.L., Atwood, N.D., Goodrich, S. and L.C. Higgins. 2003. A Utah Flora. Third Edition, revised. Brigham Young University, Provo (UT). 912 p.
Weltz, M.A., Spaeth, K., Taylor, M.H., Rollins, K., Pierson, F., Jolley, L., Nearing, M., Goodrich, D., Hernandez, M., Nouwakpo, S.K. and C. Rossi. 2014. Cheatgrass invasion and woody species encroachment in the Great Basin: Benefits of conservation. Journal of Soil and Water Conservation. 69(2): 39A-44A.
Whisenant, S.G. 1990. Changing fire frequencies on Idaho's Snake River Plains: ecological and management implications. Pages 4-10 *in* McArthur ED, Romney EM, Smith SD, Tueller PT, compilers. Proceedings: symposium on cheatgrass invasion, shrub die-off and other aspects of shrub biology and management. USDA General Technical Report INT-276, Ogden, UT.
Whitson, T.D. (ed.), Burrill, L.C., Dewey, S.A., Cudney, D.W., Nelson, B.E., Lee, R.D. and R. Parker. 1996. *Weeds of the West*. Western Society of Weed Science in cooperation with Cooperative Extension Services, University of Wyoming. Laramie, Wyoming.
Young, J.A. and R.A. Evans. 1978. Population dynamics after wildfires in sagebrush grasslands. Journal of Range Management. 31:283-289.

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