In 2008, native annual cover was significantly higher in plots seeded with native annuals relative to those that had not received annual seed (P=0.0002) (Fig. 2b). There was a similar non-significant trend in 2010 and 2011.

The perennial seed treatment x year interaction had a significant affect on native perennial cover (P=0.001). Although native perennial cover was similar across perennial seed treatments in 2008 and 2009, plots seeded with perennial species had higher native perennial cover in 2010 and 2011 than those without perennial seed addition (Fig. 2c). Similarly, native perennial biomass was significantly higher in the perennial seed treatment (P=0.002) (Fig. 3).

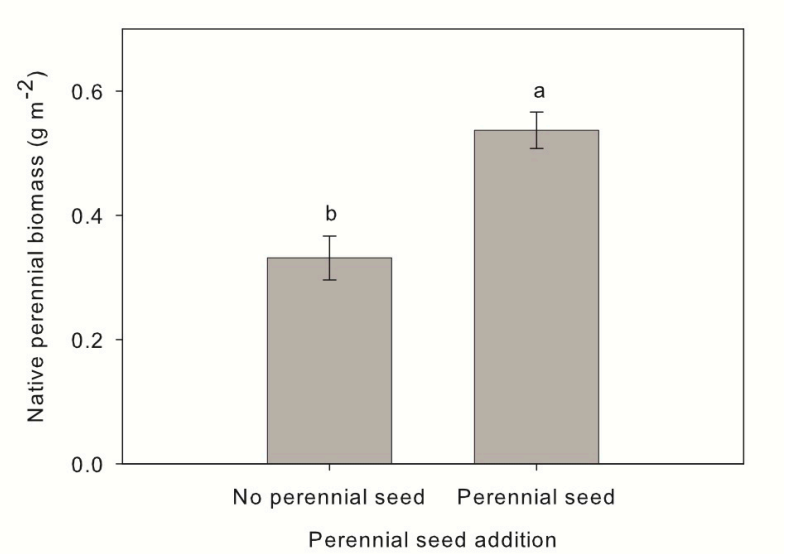

Figure 3. Average 2010 and 2011 native perennial biomass (g m^{-2}, ± SE) in treatments that were or were not seeded with native perennial species across all sites. Bars with different letters differ significantly at α=0.05.

The three study sites differed with regard to the extent of *B. tectorum* invasion based on the seedbank study and post-fire vegetation results. Dinosaur was further along in the invasion process with 25.2 (±0.7)% *B. tectorum* cover, while Craters was much more representative of an intact native plant community with only 1.1 (±0.2)% cover of *B. tectorum*.

Each site had unique environmental conditions (soils, vegetation, climate and fire effects), which likely resulted in distinct responses to the seeding treatments. The Craters site pre-burn vegetation was late-seral *Artemisia tridentata* Nutt. *ssp tridentata* (basin big sagebrush) – *Pseudoroegnaria spicata* (Pursh.) A. Löve (bluebunch wheatgrass) with a suite of other species characteristic of late-seral sagebrush steppe habitats. The Bear Den Butte fire that burned through this site was described as hot with severe behavior and spotting (Sammi 2007). nThe study site was located near an edge of the burn and was likely received seed rain from unburned surrounding vegetation. We also observed re-sprouting of the bunchgrasses and other perennial vegetation at this study site, which accounts for the strong presence of perennial vegetation in the first four years post-fire. Both Dinosaur (Steuwe fire) and DeBeque (Pyramid fire), were within the piñon-juniper habitat type (Soil Survey Staff, NRCS 2009) and experienced small ground fires ignited by lightning. However, the soils were different at the two sites (Table 1). The Dinosaur site had loamy soils with a clay component that exhibited a combination of Pinyon-juniper and sagebrush vegetation while the DeBeque site had very fine sandy loam soils that exhibited Pinyon-juniper vegetation with a strong herbaceous component.

Management Implications

Our results provide evidence that seeding with native species may help suppress exotic annual species and improve post-fire plant communities. We did not find that immediate post-fire seeding with native annual plant species provided improved initial plant cover as was hypothesized (H1). There was no effect of annual seed on plant cover in 2008, 2010, or 2011, and there was significantly less total cover associated with seeding native annual species in 2009. However, there was an overall significant decrease in exotic annual cover associated with the main effects of native annual seed (H2) and native perennial seed. The pattern was most pronounced in 2009 and responsible for the decrease in total cover observed in 2009. Importantly, our results also provide evidence that seeding both annual and perennial native species quickly after a fire can have a larger negative impact on exotic species than not seeding or seeding native annual or perennial species alone. Our results should be considered somewhat preliminary since the additive effect of annauls and perennials may have been confounded by increasing seed numbers in the combined treatment. However, since we did not observe differences in total plant cover between seeding treatments (data not shown) we suspect that differences in B. tectorum suppression between the seeding treatments were more likely due to species used in the seed mixes. Furthermore, because we only sampled these sites in the spring, it is possible that we were not able to capture the full spectrum of native annuals that may have emerged later in the growing season and perennial cover and biomass may have been underestimated by our study. During the second sampling year there were senesced skeletons of *Helianthus annuus* and *Cleome serrulata*, which were both seeded as part of the native annual seed treatments, that appeared to be from the previous growing season. These large native annual forbs may have contributed to the effects that we observed. Previous research has indicated that annual forb species may be effective competitors with *B. tectorum* for these resources (Young and Evans 1978; Pokorny et al 2005; Perry et al. 2009).

Including native annual species in post-fire seed mixes might be an effective management approach because of their tendency to grow in these early-seral conditions and for their ability to compete with exotic annuals at the phenological level (Chambers et al 2007). A major limitation of this management approach is the lack of native annual species that are commercially available from seed suppliers. Until there is a market for these species, it is not likely that a seed company will invest in producing them. However, due to the tendency of annuals to invest heavily in seed production (Smith et al 2010), commercially available native annual species might be easily produced relative to native perennials. Another advantage of using native annual species in post-fire reseeding is that they typically have broadly adapted genotypes with broad geographic ranges (Bazazz 1996). This means that local adaptations for a particular species' ecotype are less of a concern. Therefore, production and distribution of these species is generally compatible with their ecology. Furthermore, projects that have used ruderal annual species, especially forbs, in restoration efforts have shown superior establishment success (Smith et al 2010; Pywell et al. 2003).

While the idea of using native weedy species to combat exotic weeds is not a novel concept, we believe that the idea of using native annual species to combat exotic annuals in post-fire arid and semi-arid habitats represents a unique and promising management approach. This project has shown that the mixing native annuals and perennials in post fire seed mixes had significant effects on exotic annual (*B. tectorum*) cover. Based on these results, the addition of native annual plant species would be an easy modification to common perennial seed mixtures and may provide some competition for exotic annual plants during the few years post-fire. As indicated by Brown (2004), including multiple functional guilds in restoration seed mixtures may increase community competitiveness and provide a buffer against non-native plant invasions.

Future work needed

This study suggests that there should be more research on the use of native annuals in post-fire seed mixtures. This suggestion comes from our observation that including native annuals in a seed mix improves post-fire restoration success by reducing exotic annuals, especially *B. tectorum*. The number of native annual species that we used was limited by commercial availability because seed collecting was beyond the scope of our study. The results of our study suggest that there would be utility in testing additional native annual taxa that could be used in restoration. Our native annual seed mix contained only two native annual grasses due to limited commercial availability. Therefore, future work should explore the use of additional species of native annual grasses as well as forbs.

This study showed rather surprising results given the low level of establishment of our seeded species (Figures 1-3). We suspect that with greater establishment there would have been even greater restoration success. Future work looking at the use of native annuals should explore various seeding methods and rates for ensuring restoration success while minimizing expenditures on expensive native seed. We have recently initiated a follow-up study to explore the effects of seeding rates and seed mix diversity when using these and other species in restoration seed mixes. Give the context dependent nature of such studies, there is clearly need for many more investigations.

In our study we assumed that native annuals would provide benefits across a broad range of sites but this assumption needs further testing. Clearly, additional research is needed on the role of post-fire soil conditions in influencing the success of native annual seed treatments. Many of the results we observed varied across the three sites. A greater understanding of how best to match seed mixes to site conditions would be useful. Given that we only used three sites, we can only speculate as to why the sites may have differed in their response to seeding treatments. In order to get at such questions a study with much higher levels of site replication would be needed.

Deliverables

Table 4. Project deliverables, descriptions, delivery dates and status.

Deliverable	Description	Status	Delivery Dates
Annual reports	Summary of project progress	completed	August 07, 08, 09, 10 and 11
M.S. Thesis	Herron, C. M. 2010. Using native annual plants to suppress weedy invasive species in post-fire habitats. MS Thesis. Colorado State University, Department of Forest and Rangeland Stewardship. Fort Collins, CO. http://hdl.handle.net/10217/39332.	completed	July 2010
Refereed Publications	1) Initial study findings of plant community dynamics	Incomplete - Initial findings were not publishable	
	2) Herron, C.M., J.L. Jonas and M.W. Paschke. Using native annual plants in the restoration of post-fire habitats. Journal of Wildland Fire. *In review*	Manuscript in review	
Final JFSP Report	Summary of project findings with management recommendations	This report	2011
Presentations at Conferences, Workshops and Field Tours	1) Herron, C.M. and M.W. Paschke. 2009. Using native annual plant species to suppress weedy invasives in post-fire habitats. Front Range Student Ecology Symposium, February 2009, Fort Collins, CO. 2) Herron, C. and M.W. Paschke. 2009. Using native annual plant species to suppress weedy invasive species in post-fire habitats. Workshop: Developing a Successful Native Plant Program. April 2009, Ontario, OR. Poster presentation. 3) Field Tour. May 7, 2009. Colorado Division of Wildlife, western Colorado habitat revegetation tour for managers and biologists. This 2-day tour visited the 2 Colorado study sites to see study plots and discuss results. 4) Paschke, M.W. 2009. Ecological restoration and soil ecology. Invited Presentation. Western chapter International Erosion Control Association, The Sustainable Erosion Control BMP Training Workshop, Oct. 25-27, 2009, Kings Beach, California. 5) Herron, C. and M.W. Paschke. 2009. Using native annual plant species to suppress weedy invasive species in post-fire habitats. 4th Internation Fire Ecology & Management Congress. Savannah Georgia. Nov. 30 - Dec. 4, 2009 6) Herron, C.M. and M.W. Paschke. 2010. Using native annual plant species to suppress weedy invasives in post-fire habitats. High Altitude Revegetation conference, March 2010, Fort Collins, CO. 7) Busby, R., M. Paschke, C. Herron, J. Rieder. 2010. Utilization of native annuals for restoration. Native Plant Materials Development, Production & Use in Habitat Restoration. The National Native Seed Conference. Snowbird, Utah, May 17 - 21, 2010		

Table 4. Continued.

Deliverable	Description	Status	Delivery Dates
Websites	Description of project and results on websites: 1) http://warnercnr.colostate.edu/rel-projects/		Completed and ongoing
	2) InsideNPS		March 2012*
	3) http://www.fws.gov/fire/ifcc/esr/Library/Library.htm		Spring 2012*
Interpretive Materials	Draft "common-language" project summary (for use in newsletters, websites, etc)		December 2011
	NPS Naturally Speaking newsletter		Spring 2012*
Interpretive Materials	NPS/NIFC Fire Education newsletters		Spring 2012*
Interpretive Materials	Talking points, pamphlets, etc for site-based interpreters		Spring 2012*

* These products will be timed for early fire season meetings and planning

While our original plan committed us to develop interpretive materials for a general National Park Service and land manager audience (as will be addressed above), we also have initiated work with two of the new JFSP Science Delivery Consortia – Great Basin and Southern Rockies to a) evaluate this project with similar work (for example, Beth Leger's work in the Great Basin) and b) identify additional opportunities for scientist-manager information exchange (such as webinars, field trips and BAER meetings as they are scheduled for 2012).

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