



Great Basin Native Plant Project

2014 Progress Report

Providing the knowledge and technology required to improve the availability of native plant materials for restoring diverse native plant communities across the Great Basin.

GREAT BASIN NATIVE PLANT PROJECT

2014 PROGRESS REPORT

USDA FOREST SERVICE, ROCKY MOUNTAIN RESEARCH STATION
AND USDI BUREAU OF LAND MANAGEMENT, BOISE, ID

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The Interagency Native Plant Materials Development Program outlined in the 2002 United States Department of Agriculture (USDA) and United States Department of Interior (USDI) Report to Congress encouraged use of native plant materials for rangeland rehabilitation and restoration where feasible. The Great Basin Native Plant Project is a cooperative project lead by the Bureau of Land Management (BLM) Plant Conservation Program and the United States Forest Service (USFS), Rocky Mountain Research Station that was initiated to provide information that will be useful to managers when making decisions about the selection of genetically appropriate materials and technologies for vegetation restoration. The Project is supported by the USDI Bureau of Land Management, Plant Conservation Program and administered by the USFS Rocky Mountain Research Station's Grassland, Shrubland and Desert Ecosystem Research Program.

Research priorities are to:

- Increase the variety of native plant materials available for restoration in the Great Basin.
- Provide an understanding of species variability and potential response to climate change to improve seed transfer guidelines.
- Develop seeding technology and equipment for successful reestablishment of native plant communities.
- Transfer research results to land managers, private sector seed growers, and restoration contractors.

We thank our many collaborators for their dedication and their institutions for their in-kind contributions. The wide array of expertise represented by this group has made it possible to address the many challenges involved with this endeavor. We especially thank Alexis Malcomb for the many hours she spent carefully editing and compiling this report and other outreach materials and Nancy Shaw and Jeff Ott for help in editing, as well as Corey Gucker for help in managing our financial reporting. Special thanks also to our resident students and volunteers: Matt Fisk, Jameson Rigg, and Kristof Bihari for managing our field and laboratory research.

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Great Basin Native Plant Project

<http://www.fs.fed.us/rm/boise/research/shrub/greatbasin.shtml>

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HIGHLIGHTS FOR 2014

GENETICS AND SEED ZONES

Genetic Diversity and Genecology of Prairie Junegrass (*Koeleria macrantha*) and Squirreltail (*Elymus elymoides*)

Francis Kilkenny and Brad St. Clair

- Common gardens were established in contrasting sites for prairie junegrass (*Koeleria macrantha*) and squirreltail (*Elymus elymoides*).
- We evaluated and compared growth, morphology, and reproductive traits for populations of each both species.
- General patterns that emerged from the preliminary analysis of prairie junegrass common gardens were largely congruent with large-scale ecoregions, suggesting that Omernick's Level III ecoregions may be useful for seed zones. A preliminary seed zone map was developed.
- Analyses from squirreltail common gardens suggest that squirreltail traits are highly plastic with phenological traits varying primarily by year, and size traits varying primarily by planting site.

Testing the Efficacy of Seed Zones for Re-establishment and Adaptation of Bluebunch Wheatgrass (*Pseudoroegneria spicata*)

Holly Prendeville, Francis Kilkenny and Brad St. Clair

- The locations for 16 common gardens test sites in the Blue Mountains, Columbia Plateau, Snake River Plain, and Northern Basin and Range ecoregions were finalized and sites prepared for establishment.
- The common garden sites were planted in the fall of 2014 with 20 replicate plugs from 78 populations, one cultivar and one selected germplasm of bluebunch wheatgrass (*Pseudoroegneria spicata*).

Conservation, Adaptation, and Seed Zones for Key Great Basin Species

Richard C. Johnson, Erin K. Espeland, Matt Horning, Elizabeth Leger, Mike Cashman, and Ken Vance-Borland

- Seed zones for Sandberg bluegrass (*Poa secunda*) across the Inter-mountain West and the Great Basin have been mapped and published.
- Seed zones have been modeled for Thurber's needlegrass (*Achnatherum thurberianum*) for the Great Basin and will be mapped and submitted for publication in 2015.
- Basin wildrye (*Leymus cinereus*) data collection on 112 source populations in common gardens at two sites and three years has been completed. Initial analysis indicates climate linked genetic variation and interactions with ploidy are important for adaptation. Seed zones will be developed and published.
- Data collection in common gardens is completed for bottlebrush squirreltail (*Elymus elymoides*) and is being analyzed at the Rocky Mountain Research Station for seed zone development.

- A common garden study of sulphur-flower buckwheat (*Eriogonum umbellatum*) collected in the Intermountain West and Great Basin was established and data will be collected in 2015 and 2016.

Ecological Genetics of Big Sagebrush (*Artemisia tridentata*): Genetic Structure and Climate Based Seed Zone Mapping

Bryce Richardson, Nancy Shaw, and Matthew J. Germino

- Analyses of growth and seed yield indicate subspecies *tridentata* and *wyomingensis* have highly similar adaptive responses to climate.
- Overall, clinal patterns of growth and seed yield appear to be shaped by the accumulation of summer heat and the seasonal timing of precipitation.
- Plants from lower basins in the western regions of big sagebrush have increased growth and seed yield under hot-dry summers.

Factors Affecting Initial Establishment of Big Sagebrush Outplants: Land Treatments, Seed Sources, and Climate Effects

Matthew J. Germino, Martha Brabec, and Bryce Richardson

- Land treatments such as mowing, herbicide application, and drill seeding affect the abundance of herbs that sagebrush seedlings interact (and apparently compete) with, and they influence initial survival of sagebrush outplants.
- Growth and initial survival of sagebrush seedlings differed among subspecies, cytotypes, and populations, and the variation was most related to differences in response to freezing, generally supporting the use of minimum temperatures in provisional seed zones.
- Paradoxically, mountain big sagebrush consistently expressed less ability to withstand freezing than the low-elevation subspecies, suggesting that further inquiry is needed to understand broad-scale climate adaptation of big sagebrush.

Species and Population-level Variation in Germination Strategies of Cold Desert Forbs

Elizabeth A. Leger and Sara Barga

- We identified the dominant germination strategies of ten Great Basin annual and perennial herbaceous species.
- A majority of species had no preference for after-ripening temperature.
- Species exhibited differences in their preference for cold stratification.
- Five species were identified as facultative winter germinators by their ability to germinate at cold (2°C) temperatures, including *Agoseris grandiflora*, *Blepharipappus scaber*, *Collinsia parviflora*, *Cryptantha pterocarya*.
- We found that *Agoseris grandiflora*, *Collinsia parviflora*, *Cryptantha pterocarya*, and *Microsteris gracilis* were able to germinate under a broad range of conditions.
- In contrast, *Gilia inconspicua*, *Mentzelia albicaulis*, and *Phacelia hastata* possessed high levels of dormancy.
- All species displayed population level differences in germination strategies.

Dynamics of cold hardiness accumulation and loss in Sulphur-flower buckwheat (*Eriogonum umbellatum*)

Anthony S. Davis, Matthew R. Fisk, and Kent G. Apostol

- October 2013 - October 2014 field collections and sample processing completed for sulphur-flower buckwheat (*Eriogonum umbellatum*) cold hardiness study.
- Initial results indicate cold hardiness variation across sulphur-flower buckwheat species range and annual seasonality.
- Sulphur-flower buckwheat cold hardiness data analysis models in development.

Community Structure of Arbuscular Mycorrhizal Fungi Colonizing Wyoming Big Sagebrush Seedlings

Marcelo D. Serpe and Bill E. Davidson

- Pre-inoculation of Wyoming big sagebrush seedlings with native arbuscular mycorrhizae (AMF) increased colonization of the roots that developed after transplanting, but did not affect the AMF taxa colonizing the seedlings.
- Sagebrush seedlings were colonized by a diversity of AMF taxa. However, four taxa were dominant. Similar results were obtained for non-inoculated and inoculated seedlings as well as for seedlings harvested in different seasons or from roots collected at different depths.

Smoke-induced Germination of Great Basin Native Forbs

Robert Cox

- Extensive literature reviews for all focal species have been conducted and species have been prioritized by germination requirements and potential for smoke response
- 19 species have been tested for smoke response in germination, with results being analyzed now.

Herbicide Impacts on Forb Performance in Degraded Sagebrush Steppe Ecosystems

Marie-Anne De Graff and Aislinn Johns

- Two greenhouse experiments were conducted in which we (1) applied a gradient of imazapic concentrations, and (2) varied the timing of application relative to seeding of *Astragalus filipes*, *Achillia millefolium*, and *Sphaeralcea grossulariifolia*.
- Soils used were collected in degraded burned and unburned sagebrush ecosystems (0-10 cm depth) at the Morley Nelson Birds of Prey National Conservation Area.

PLANT MATERIALS AND CULTURAL PRACTICES

Increasing the Availability and Integration of Great Basin Native Plant Project Tools for BLM Restoration Practitioners

Anne Halford

- Apply science and research to improve the identification and protection of resistant and resilient sagebrush-steppe landscapes and the development of biocontrols and other tools for cheatgrass control to improve capability for long-term restoration of sagebrush-steppe ecosystems.

- To the extent practicable, utilize locally-adapted seeds and native plant materials appropriate to the location, conditions, and management objectives for vegetation management and restoration activities, including strategic sourcing for acquiring, storing, and utilizing genetically appropriate seeds and other plant materials native to the sagebrush-steppe ecosystem.

Developing Protocols for Maximizing Establishment of Great Basin Legume Species

Douglas A. Johnson and B. Shaun Bushman

- Recent greenhouse studies showed substantial progress in obtaining high germination rates of basalt milkvetch (*Astragalus filipes*).
- Seeded plots were planted at three sites in Oregon: Oregon State University (OSU) Ontario Research Farm, BLM site near Clarno, and a USFS field near Prineville. Three plantings have been attempted at each site, comprising a fall and spring planting. Fall 2011/spring 2012 showed the benefits of non-scarified seed planted in early spring. Fall 2013/spring 2014 resulted in no seedling establishment because of extremely low spring and summer precipitation; however, basalt milkvetch germinated and emerged the following year and plants from the previous year survived. Fall 2014 was planted in October and the spring 2015 will be planted in March.
- Seed collections were made of ecotypes of Utah trefoil (*Lotus utahensis*) in southern Utah, Nevada, and Utah. These collections will be evaluated in common gardens, and a DNA marker technique will be used to evaluate genetic diversity among collections.

Native Forb Increase and Research at the Great Basin Research Center

Kevin Gunnell and Jason Stettler

- Cushion Buckwheat (*Eriogonum ovalifolium*) common gardens to analyze: seed production, G1 production seed, and drought tolerance.
- Identify a practical and effective method to treat iron deficiency chlorosis (IDC) for improved establishment in *Lupine* species.
- Increase seed from wildland collections to support further research and increase distribution of native seed to commercial growers.
- Develop and test methods to increase germination and establishment in agronomic settings.
- Determine the effects of N-sulate® fabric on germination and establishment of native forb species in a wildland setting.
- Evaluate native forb establishment in Wyoming big sagebrush communities using four different pieces of planting equipment: Truax drill, Lawson aerator, Dixie pipe harrow, and Ely chain.

Plant Material Work at the Provo Shrub Sciences Lab

Scott Jensen

- Added 72 new database location records representing 21 species.
- Made 45 wildland seed collections representing three species.
- Distributed 24 sources of two species for seed increase.
- Distributed 38 sources of eight species for commercial seed production.
- Study installation evaluating emergence rates of 20 native forb species.

- Study installation comparing emergence rates of Basin wildrye sources.

Aberdeen Plant Materials Center Report of Activities

Derek Tilley

- Release of Amethyst Germplasm Hoary Tansyaster.
- Progress towards release of Wyeth buckwheat.
- Development of NRCS Plant Guides.

Bee Pollination and Breeding Biology Studies

James H. Cane

- In the aftermath of a huge wildfire in sage steppe, we sampled native bee faunas at scattered remnant stands of sunflowers growing in ditches along gravel roads that served as fire lines.
- Comparable quantitative samples of bees were taken at co-flowering sunflowers outside the burn. Most all of the bee species were non-social and soil nesting.
- The bee faunas largely survived the fire intact (but for one surface-nesting species). Females even continued to collect pollen for their nests.
- The fire had passed the sample sites at night, a time when female bees are in their nest (and thus safe underground).
- Another sample of bees and bloom in a year-old fire found much the same result at blooming *Penstemon* and *Balsamorhiza* that has also survived the fire to bloom the following year.

Seed Production of Great Basin Native Forbs

Clinton C. Shock, Erik B. Feibert, Joel Felix, Nancy Shaw, and Francis Kilkenny

- Plant establishment report.
- Trial of post emergence herbicides.
- Irrigation trials for the first set of species that we have worked on for 9 years.
- Irrigation trials on a second set of species that we have worked on for 5 years.
- Irrigation trials on a third set of species that we have worked on for 2 years.

SEED INCREASE

Coordination of Great Basin Native Plant Project Plant Materials Development, Seed Increase, and Use

Berta Youtie

- Preparation and planting of bluebunch wheatgrass (*Pseudoroegneria spicata*) test sites in recently burned areas within seed zones to test the efficacy of using species-specific provisional seed zones and seed transfer guidelines in native plant restoration efforts after fires.
- Increase of native seed collections for the Great Basin Native Plant Project (GBNPP) in Eastern Oregon and Northern Nevada.

SPECIES INTERACTIONS

Use of Native Annual Forbs and Early- Seral Species in Seeding Mixtures for Improved Success in Great Basin Restoration

Keirith A. Snyder and Shauna M. Uselman

- Seedling emergence and early survival of early seral native species was generally greater than that of late seral native species when seeded with cheatgrass or medusahead.
- Native grasses were more successful than native forbs and shrubs in terms of seedling emergence and early survival, especially in a coarse-textured soil.
- Emergence and survival of medusahead was consistently very high on divergent soil types, supporting the need for preventive measures against its further spread in the Intermountain West.
- Early seral natives show promise for improving success of rangeland restoration/rehabilitation reseeding efforts in the Great Basin.
- When the early seral native forb bristly fiddleneck (*Amsinckia tessellata*) was able to establish, its substantial biomass and reproductive output suppressed the biomass and reproductive output of the exotic annual grass medusahead.

Restoration of Native Understory Plants in Degraded Sagebrush Steppe Ecosystems

David A. Pyke and Kari Veblen

- Seeds and seedlings were monitored twice at three loamy Wyoming Big Sagebrush project sites, one each in the Snake River Plains, Owyhee Plateau, and Great Salt Lake MLRAs. Monitoring will be repeated in spring/summer 2015.
- Preliminary results suggest higher success of seedling plantings than seedings.

SCIENCE DELIVERY

Science Delivery for the Great Basin Native Plant Project

Corey Gucker

- Maintaining contact with Great Basin Native Plant Program (GBNPP) cooperators through regular correspondence, event alerts, and communication of project due dates.
- Updating and producing hard copy posters and brochures for Great Basin events and meetings.
- Regularly updating the GBNPP website with meeting announcements, new publications, and updated cooperator information.
- Helping to develop the agenda and secure presenters for the annual GBNPP meeting.
- Tracking and reporting GBNPP accomplishments.

CRESTED WHEATGRASS DIVERSIFICATION

Evaluating Strategies for Increasing Plant Diversity in Crested Wheatgrass Seedings

Kent McAdoo and John Swanson

- Project objectives were to evaluate various treatments for reducing crested wheatgrass in near-monoculture rangelands and determine the effect of crested wheatgrass control methods on establishment of seeded native species.
- Mechanical treatment (disking) was less successful at reducing crested wheatgrass than was herbicide.
- Herbicide, but not mechanical treatment, increased the density of seeded native species in both trials.
- Glyphosate treatments, but not disking or other herbicides, increased the density of seeded species in two separate trial studies by effectively reducing the competitive cover of crested wheatgrass.

The Ecology of Great Basin Native Forb Establishment

Jeremy James

- Simultaneously seeding crested wheatgrass and forbs does not decrease forb establishment.
- Field germination of native forbs can vary 20-fold across sites within a year but even in the best germination scenarios more than 98% of germinated seeds die before they establish.
- Seedbed favorability for germination and emergence varied across the nine study sites but this variation did not significantly influence forb recruitment.
- Improving our ability to increase forb and forb diversity in restoration may be facilitated by identifying traits and populations that have greater germination and emergence probabilities or by applying seed treatments that accelerate germination or minimize exposure of seeds to abiotic stresses.

Presence of Native Vegetation in Crested Wheatgrass Seedings and the Influence of Crested Wheatgrass on Native Vegetation

Kirk Davies and Aleta Nafus

- We measured basal cover, density, species richness and diversity on 121 sites that spanned a 54230 km² area in southeastern Oregon.
- Plant community composition of crested wheatgrass stands was quite variable. Some seedings were a monoculture of crested wheatgrass while others contained a more diverse assemblage of native species.
- Environmental factors explained a range of functional group variability ranging from 24% of annual forb density to 51% of annual grass density.
- Soil texture appeared to be the most important environmental characteristic explaining functional group cover and density 10-50 years post seeding and was included in the best regression models for all plant functional groups.
- Native vegetation was, for all functional groups, positively correlated with soils lower in sand content.
- Our results suggest that environmental differences explain a large amount of the variability of native vegetation in crested wheatgrass stands and this information can

likely be invaluable in assessing the effects of seeding crested wheatgrass and the potential for native vegetation to co-occupy seeded sites with crested wheatgrass.

RESTORATION STRATEGIES AND EQUIPMENT

Seeding Native Species Following Wildfire in Wyoming Big Sagebrush (*Artemisia tridentata* ssp. *wyomingensis*): Effects of a New Fire Incident

Jeff Ott and Nancy Shaw

- An operational-scale experiment was carried out to test equipment and strategies for seeding native plants following wildfire on Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) sites in the northern Great Basin. One of the study sites (Saylor Creek) was hit by a second wildfire two years after the first, creating an opportunity to examine resilience of native seedlings to burning. Because the fire did not burn the entire study area, it was possible to compare burned and unburned sections and thereby evaluate fire impacts on plant species cover and density.
- Seeded species began to establish in seeded treatments the first year then increased dramatically in cover by the second year. By the third year, following the new fire, seeded species cover decreased to levels intermediate between the first and second years. Non-seeded species generally followed a similar trajectory, although cheatgrass (*Bromus tectorum*) did not decrease in non-seeded treatments where it faced less competition from perennials.
- Seeded forbs and shrubs fell into three groups based on density data: those that initially had high densities, but declined in density by the third year (*Achillea millefolium*, *Penstemon speciosus*, *Artemisia tridentata* ssp. *wyomingensis*), those with lower initial densities followed by an increase (*Sphaeralcea munroana*, *Ericameria nauseosa*), and *Astragalus filipes*, which had low initial density followed by a decrease.
- To assess whether changes in cover and density were due to the fire as opposed to other factors, we tested for deviations from expected ratios in burned and unburned sections of the study area. Results suggest that some species were negatively affected by the fire (*Artemisia tridentata*, *Ericameria nauseosa*, *Achillea millefolium*, *Poa secunda*), others were positively affected (*Penstemon speciosus*, *Achnatherum hymenoides*) and others minimally affected (*Pseudoroegneria spicata*, *Elymus elymoides*, *Sphaeralcea munroana*, *Astragalus filipes*).

A New Biological Control Strategy for Cheatgrass and *Ventenata dubia* Based on Fungal Endophytes

George Newcombe

- Manuscript accepted pending revision (*PLOS ONE*) on the ecology of *Sordaria fimicola* and its effects on *Bromus tectorum*.
- Manuscripts being prepared on: the effects of *Fusarium* endophytes isolated from cheatgrass (*Bromus tectorum*) and ventenata (*Ventenata dubia*) on these two species and native bluebunch wheatgrass (*Pseudoroegneria spicata*); and the effects of *Sordaria fimicola* (CID 323) on *B. tectorum* in field experiments in MPG Ranch, MT.
- Collaborated and shared work at a Biological Invasion Working Group of the Mountain Social Ecological Observatory Network (MtnSEON) meeting, at which were discussed

the processes, patterns, and mechanisms of *Ventenata dubia* invasion in complex western landscapes.

- Collaborated and shared work at two Blue Mountains Working Group of MtnSEON meetings, focused on social-ecological systems (including annual grass invasion) research centered on the USFS Starkey Experimental Forest and Range.
- Conducted disease surveys in Latah County Idaho. While diseases were present in many neighboring grasses, no signs or symptoms of disease were found on invasive grass species *ventenata*.
- Conducted greenhouse and lab experiments on susceptibility of *V. dubia* to the wheat pathogen *Fusarium culmorum*, and tested the hypothesis that *B. tectorum* and *V. dubia* endophytic *Fusarium* strains should protect *V. dubia* from the effects of disease caused by *F. culmorum*.
- Collected specimens of non-native *ventenata* across northern Idaho, western Montana, and northeast Oregon. Samples currently in first stages of metagenomics analyses to look at fungal communities living within *ventenata* grass tissues.
- A manuscript is being prepared on the native range of *Ventenata dubia*. This invader is commonly called ‘North Africa grass’ but its current Eurasian range does not include populations in North Africa.

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Project Title Genetic Diversity and Genecology of Prairie Junegrass (*Koeleria macrantha*) and Squirreltail (*Elymus elymoides*)

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Project Description

Prairie junegrass

Prairie junegrass (*Koeleria macrantha*) is a highly variable, moderately long-lived, cool season perennial bunchgrass that grows 15 to 60 cm (0.5 to 2 ft) tall. It is adapted to a wide variety of climates and soils and is an important component of many native plant communities. Prairie junegrass is often used in seed mixes for restoration of native prairie, savanna, coastal scrub, chaparral, and open forest habitats across much of North America. Good drought tolerance and fibrous roots also make it beneficial for revegetation and erosion control on mined lands, over septic systems, in construction areas, on burned sites, and in other disturbed areas. There is a need for greater genetic knowledge of prairie junegrass to ensure adapted populations are used for restoration and revegetation projects. Most information will be generated from two common garden studies conducted on separate and contrasting environments in Oregon.

Objectives

- 1) Use common gardens to determine the magnitude and patterns of genetic variation among prairie junegrass populations from a wide range of source environments in Oregon, Washington, and Idaho.
- 2) Relate genetic variation to environmental variation at collection locations.
- 3) Develop seed transfer guidelines.

Methods

Seed was collected from endemic stands of prairie junegrass during the summers of 2003 to 2006. Populations came from Oregon, Washington, and adjacent areas of Idaho, primarily east of the Cascade Mountains. Two families (maternal parents) were sampled from each of 114 populations, while only a single family was sampled from 12 populations, for a total of 240 families from 126 populations. Common garden studies were established in 2008 at two contrasting sites in Oregon: the USDA Natural Resources Conservation, Plant Materials Center in Corvallis, Oregon, and Oregon State University's Agricultural Experiment Station at Powell Butte, Oregon. A variety of traits were measured in 2009 and 2010 assess plant growth, morphology, phenology, and fecundity. Analyses have been done to evaluate differences among test sites, years, populations, families within populations, and interactions between these factors. Analyses have also investigated the relationship between population variation and climatic variation at source locations. Maps of genetic variation across the landscape have been produced, and preliminary seed zones have been delineated based on the results.

Results

Traits at Corvallis were significantly different from traits at Powell Butte. Plants at Corvallis were larger and had earlier phenology in both 2009 and 2010. Plants at Powell Butte flowered much more profusely than plants at Corvallis in 2009, but Corvallis plants had a higher inflorescence number in 2010. Variation among populations for size traits was much greater when plants were grown at Corvallis in both years, and plants grown at Powell Butte generally had higher variation among populations in phenology traits for both years. The percentage of the total phenotypic variation (populations, families, and residual) found within populations was high for most traits, especially crown width, leaf width, leaf ratio, and heading and bloom dates.

The population $\times$ site interaction was significant for most traits. Correlations of population means between test sites were higher in 2009 than in 2010, and correlations between years within sites were generally high. Populations that had wide crowns, more flowers, wide leaves, upright habit, and later phenology at one site were generally the same as those at the other site.

Traits that had large population variation and were correlated with climates at the source locations were biomass, crown width, inflorescence number, leaf width, leaf ratio, heading date, and bloom date. As might be expected, leaf width was strongly correlated with leaf ratio ($r = -0.73$), and bloom date was strongly correlated with heading date ($r = 0.93$) though only moderately correlated with maturation date ($r = 0.46$). These traits are generally correlated with temperatures, precipitation, and aridity (as measured by the heat moisture index, which is a function of the ratio of temperature to precipitation). Regression equations of traits on source climates used various combinations of temperature, precipitation, or aridity variables. Regression models were used to map patterns of variation for biomass, inflorescence number, leaf ratio, and bloom date. The R^2 values ranged from 0.29 to 0.36. Although the magnitudes and nature of the relationships between the source climates and traits differ somewhat between the four traits, general patterns of variation emerged. Populations from the Columbia Basin had less biomass, narrower leaves, fewer inflorescences, and later phenology when grown together in a common environment. Populations from the Blue Mountains had greater biomass, wider leaves, more inflorescences, and earlier phenology. Populations from the northern Great Basin were similar to the Columbia Basin in having narrow leaves and lower biomass but were more similar to the

Blue Mountains in having earlier phenology. The few populations from western Oregon had wider leaves, greater biomass, and the latest phenology. From an adaptation perspective, we expect narrow leaves from areas of greater aridity, less precipitation, and warmer summer temperatures, and we expect earlier phenology from areas with colder winter temperatures (i.e., selection for quicker responses to springtime warming).

To determine whether climatic seasonality at source locations was related to traits expressed in the common gardens, Pearson correlations were run between monthly climate variables (monthly average temperature, and monthly average precipitation) and three important phenotypic traits (heading date, leaf length:width ratio, and biomass; Figure 1). High leaf length:width ratio values, thinner leaves with respect to size, were strongly correlated with high temperatures from March through November, whereas high biomass and later heading date values were correlated with high temperatures for October or November through March. This makes sense, given that the environments conducive to high biomass and late heading tended to be the milder climates, with warmer winter temperatures, of western Washington and Oregon on the western side of the Cascades, while the environments conducive to thin leaves tended to be the more continental climates of the Intermountain West, with their hot summers. High biomass and late heading were also correlated with high precipitation from October through March or April, again indicating an association with the environments west of the Cascades. Whereas, high values of leaf length:width ratio were negatively correlated with precipitation throughout the entire year, indicating that thin leaves are generally associated with dry areas.

The general patterns that emerged from this preliminary analysis were largely congruent with large-scale ecoregions, suggesting that Omernick's Level III ecoregions may be useful for seed zones. These seed zones are also similar to other published bunchgrass seed zones. Preliminary seed zones are presented in Figure 2.

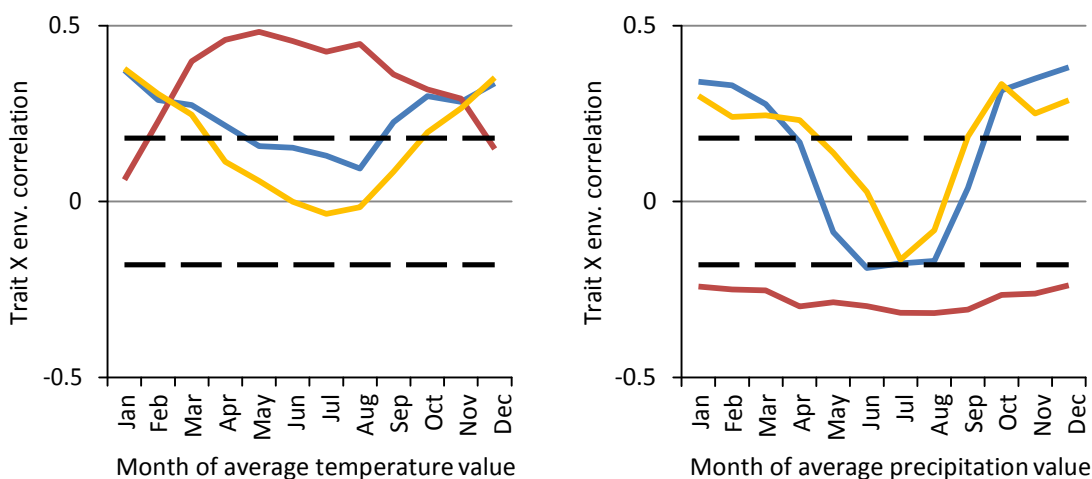


Figure 1. Trait correlations with monthly average temperature (left graph) and monthly average precipitation (right graph) for heading date (blue line), leaf width:length ratio (red), and biomass (orange). Areas outside the dashed lines represent significance of greater than 0.05.

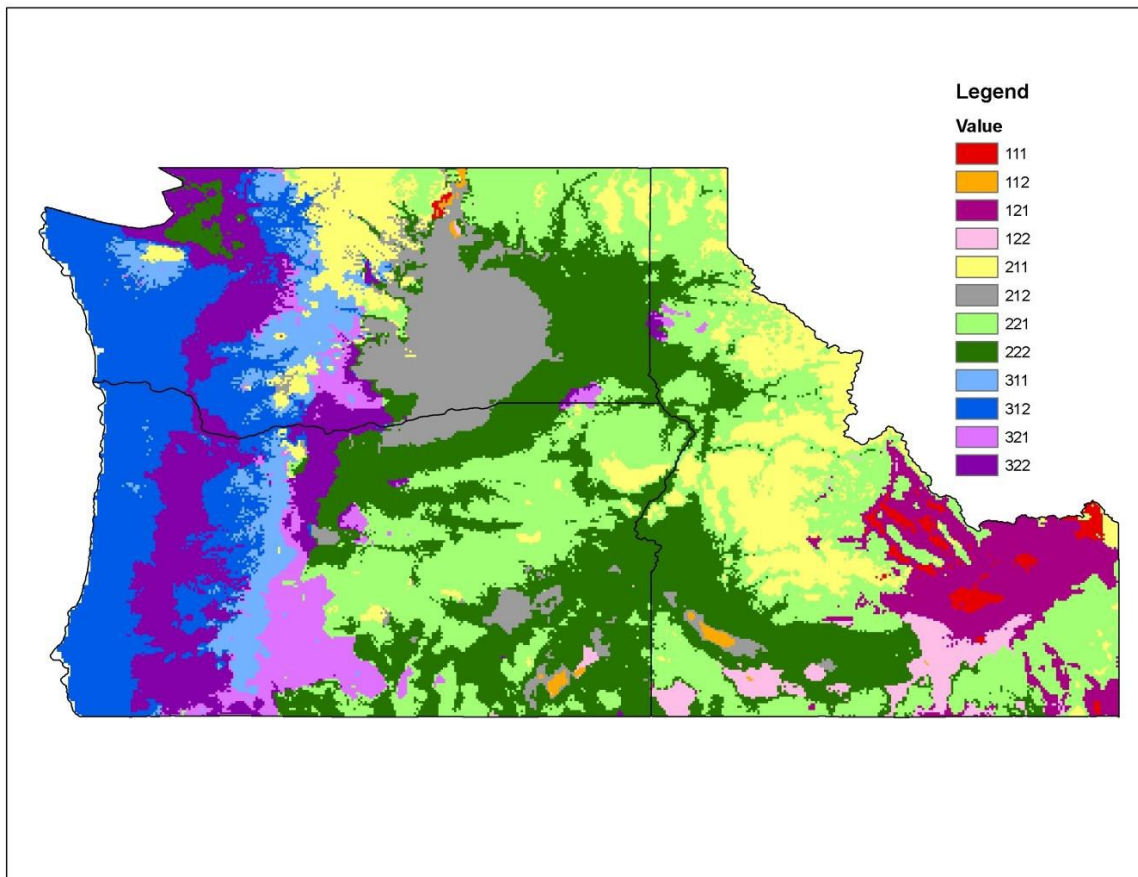


Figure 2. Preliminary seed zones for prairie junegrass where each color represents a different seed zone. Seed zones are based on dividing the area in three principle components that represent small, intermediate, or large plant size, early or late phenology, and narrow or wide leaves.

Squirreltail

Squirreltail (*Elymus elymoides*) is a cool-season, short-lived, self-pollinating, perennial bunchgrass of semi-arid regions of western North America. It is found in a wide variety of habitats from the Pacific Coast to the Great Plains and from Canada to Mexico at elevations from 2,000 to 11,500 feet (600-3,500 m). Squirreltail is considered a “workhorse” species in native plant restoration. It can rapidly colonize disturbed sites, is relatively fire-tolerant, and is a potential competitor with medusahead (*Taeniatherum caput-medusae*) and cheatgrass (*Bromus tectorum*). There are seven cultivars and pre-variety germplasm (PVG) collections of squirreltail that have been or are being developed for restoration purposes; however, only one variety, Toe Jam Creek, is currently used extensively. Previous studies indicate that there is strong ecotypic divergence in squirreltail. However, few studies have evaluated genetic variation in relation to climatic factors across the Great Basin or the greater range of the species in a large set of diverse populations or to compare the mean and variation of cultivars with that of the species as a whole. Determining the extent to which adaptive genetic variation is related to climatic variation is needed to ensure that the proper germplasm is chosen for revegetation and restoration.

Furthermore, comparisons of cultivars with the natural range of variation will address questions of the suitability of cultivars over larger areas.

Objectives

- 1) Explore genetic variation in putative adaptive traits in bottlebrush squirreltail from a wide range of source environments in the inland West.
- 2) Relate genetic variation to environmental variation at collection locations.
- 3) Develop seed transfer guidelines.

Methods

With the help of collaborators from a variety of organizations interested in restoration using squirreltail (including the Forest Service, Bureau of Land Management, National Park Service, Fish and Wildlife Service, Department of Defense, the Nature Conservancy, Washington Department of Natural Resources, and the Yakama Nation), seed was collected from two maternal families from 110 populations from five western states, primarily from the northern and central Great Basin. In addition to the squirreltail populations, we obtained seed from cultivars and PVGs of squirreltail for inclusion in the common garden studies. The cultivars and PVGs included Toe Jam Creek, Fish Creek, Rattlesnake, Tusas, Pleasant Valley Antelope Creek, and Sand Hollow (*E. multisetus*). Common garden studies have been established at three contrasting sites: 1) Reno, Nevada, 2) Powell Butte, Oregon, and 3) Central Ferry, Washington. A variety of traits were measured to assess plant growth, morphology, phenology, and fecundity in 2009 and 2010. Analyses have been done to evaluate differences among test sites, years, populations, families within populations, and interactions between these factors. Analyses have also investigated the relationship between population variation and climatic variation at source locations. All wild collected populations were identified to subspecies. Maps of genetic variation across the landscape are in progress, and preliminary seed zones will be delineated based on the results.

Results

Site, year, subspecies, population, and family were all significant contributors to variation in most measured traits. Inflorescence number was not significantly affected by either subspecies or population, and family did not significantly affect flower maturity or leaf length. When broken down into components, most of the explained variation in all traits was due either to year or site effects. Year explained 72.7 to 78.8% of the variation in phenological traits, 41.4% of the variation in reproductive traits, and between 3.0 to 32.1% of the variation in size traits. Site explained between 6.0 and 9.0% of the variation in phenological traits, 33.3% of the variation in reproductive traits, and between 21.6 and 69.2% of the variation in size traits. Subspecies never explained more than 4.8% (biomass) and population never explained more than 7.5% (leaf width) of the variation in any traits. The unexplained variation ranged from 9.7 to 39.0%. Altogether, this suggests that squirreltail traits are highly plastic, with phenological traits varying primarily by year and size traits varying primarily by planting site.

To determine the relationships between squirreltail traits and climate variables, correlations between phenotypic traits and annual climate variables were run. In this report, the strong correlations between three traits (heading date, inflorescence number, and biomass) and four climate variables (mean warmest month temperature [MWMT], temperature differential [TD],

mean annual precipitation [MAP], and annual heat:moisture index [AHM]) are shown (Figure 3). For each of the shown traits, the correlations are in the same direction, though the direction of the correlation changes depending on the climate variable. For MWMT, correlations for heading date, inflorescence number, and biomass are all negative, suggesting that small plants with low reproduction and late flowering are associated with hotter environments. Negative correlations are also present for TD and AHM, again suggesting that small, late, and low reproduction populations are associated with more continental (TD) and more arid (AHM) environments. All three traits were positively correlated with MAP, indicating that large, early, high-reproduction plants are associated with wetter environments. These correlations, particularly associations with above ground biomass, are generally in line with other bunchgrass studies.

Leaf length:width ratio, which has tended to have a strong correlation with aridity variables, such as annual heat:moisture index, in other bunchgrasses in the western United States, did not show as strong correlations in squirreltail ($R = 0.23$ for leaf length:width ratio $\times$ AHM). There are two reasonable possibilities for this discrepancy. First is the possibility of phenotypic plasticity driven by garden site by trait interactions reduced the strength of the correlations (R for leaf length:width ratio $\times$ AHM for Central Ferry = 0.14, Powell Butte = 0.29, Reno = 0.04). This makes sense, given that Reno was the driest site tested and also had the lowest correlation, indicating that all plants in Reno demonstrated similar leaf thinness. Second, many more squirreltail populations tested in this study tended to be primarily from more arid locations than the tested populations of other bunchgrasses. For example, the average AHM for tested squirreltail populations was 59 (± 22 S.D.) whereas the average AHM for tested prairie junegrass populations was 34 (± 15 S.D.). This indicates that a majority of squirreltail populations may have been under selection pressure to reduce moisture loss, which may have reduced the variation in leaf thinness among populations.

Management Applications and Seed Production Guidelines:

These studies indicate that populations of prairie junegrass and squirreltail differ greatly across the landscapes of the Great Basin, Columbia Basin, Blue Mountains, and adjacent ecoregions for traits of plant size, flowering phenology, and leaf width. Much of the variation in prairie junegrass is associated with climates of the source locations, indicating adaptive significance. However, even though genetic differences exist, squirreltail appears to have highly plastic traits, suggesting that most ecotypes are broadly adapted. Seed zones for prairie junegrass are presented for recommendations of bulking seed collections and producing plant material for adapted, diverse, and sustainable populations for revegetation and restoration. Different levels of acceptable risk may be accommodated by choosing whether or not to bulk materials from the same zones but in different Level III ecoregions. Results indicate that sources may be consolidated over fairly broad areas of similar climate, and thus may be shared between districts, forests, and different ownerships.

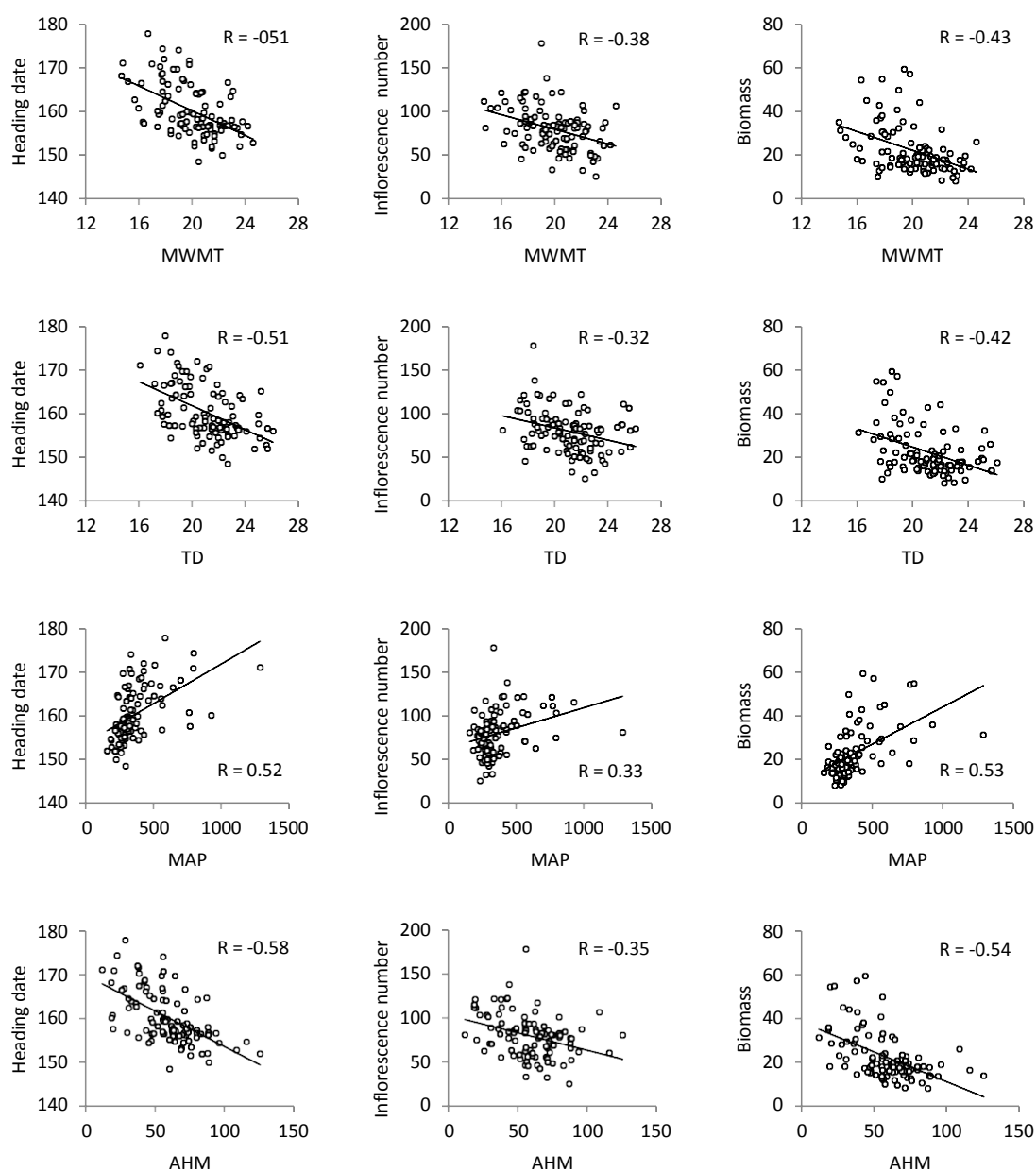


Figure 3. Correlations between squirreltail traits heading date, inflorescence number, and biomass and source climate variables mean warmest month temperature (MWMT), temperature differential (TD), mean annual precipitation (MAP), and annual heat:moisture index (AHM). Pearson correlation values are displayed.

Publications

Kilkenny, F. F.; St. Clair, J. B.; Darris, D.; Horning, M.; Erickson, V. [In preparation].
Genecology of prairie junegrass (*Koeleria macrantha*). Evolutionary Applications.

Kilkenny, F. F.; St. Clair, J. B.; Horning, M. 2013. Climate change and the future of seed zones. National Proceedings: Forest and Conservation Nursery Associations - 2012. Proceedings RMRS-P-69. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 87- 89.

St. Clair, J. B.; Kilkenny, F. F. Genecology of prairie junegrass (*Koeleria macrantha*): Final Report. Technical report for NRCS Corvallis Plant Materials Center.

Presentations

Kilkenny, F. F.; 2015. Seed Zones and Climate Change. Great Basin Fires Science Exchange, 2015 Webinar Series; 2015 May 20th.

Kilkenny, F. F. 2015. Predicting the effects of climate change on bunchgrass populations using common garden studies. 3rd National Native Seed Conference; 2015 April 13-16; Santa Fe, NM.

Kilkenny, F. F. 2014. Characterization of current and future climates within and among seed zones to evaluate options for adapting to climate change. Society for Ecological Restoration, Northwest and Great Basin Chapters, Joint Regional Conference; 2014 October 6-10; Redmond, OR.

Kilkenny, F. F. 2013. Seed zones. Restoration and reforestation technical exchange study tour; USFS Lucky Peak Nursery, Boise, ID; 2013 September 9. USAID sponsored tour for Ecuadoran government officials.

Kilkenny, F. F.; St. Clair, J. B.; Horning, M.; Johnson, R. C.; Leger, E.; Shaw, N. 2013. Genecology of three native bunchgrasses: implications for management during climate change. Intermountain Native Plant Summit; 2013 March 26-27; Boise, ID.

Kilkenny, F. F.; St. Clair, J. B. 2013. Characterization of current and future climates within and among seed zones to evaluate options for adapting to climate change. 2nd National Native Seed Conference; 2013 April 8-11; Santa Fe, NM.

Kilkenny, F. F.; St. Clair, J. B.; Horning, M.; Johnson, R. C.; Leger, E.; Shaw, N. 2013. Genecology and seed zones for prairie junegrass and bottlebrush squirreltail. 2nd National Native Seed Conference; 2013 April 8-11; Santa Fe, NM.

Kilkenny, F. F.; St. Clair, J. B.; Shaw, N.; Richardson, B. 2013. Efficiency of using species-specific seed zones for re-establishment of native bunchgrass populations after fire. Poster presented at the 2nd National Native Seed Conference; 2013 April 8-11; Santa Fe, NM.

Additional Products

This study provides seed zones and seed transfer guidelines for developing adapted plant materials of prairie junegrass for revegetation and restoration in the Great Basin and adjacent areas and guidelines for conservation of germplasm within the National Plant Germplasm System. Results for prairie junegrass are being submitted to a peer-reviewed journal and will be disseminated through symposia, field tours, training sessions, and/or workshops.

Project Title Testing the Efficacy of Seed Zones for Re-Establishment and Adaptation of Bluebunch Wheatgrass (*Pseudoroegneria spicata*)

Project Agreement No. 13-IA-11221632-161

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Project Description

Objectives

- Evaluate adaptation (i.e. establishment, survival, growth and reproduction) of bluebunch wheatgrass (*Pseudoroegneria spicata*) populations from local seed zones relative to non-local seed zones.
- Model adaptation as a function of source location and common garden climates.
- Characterize traits and climatic factors important for adaptation.
- Model effects of climate change on native populations and consequences of assisted migration for responding to climate change.

Methods

Previous research funded by the Great Basin Native Plant Project (GBNPP) found that bluebunch wheatgrass (*Pseudoroegneria spicata*) populations differed in traits important for adaptation to precipitation and temperature (St. Clair et al. 2013). From this work, seed zones

were delineated for the Interior Northwest including the Great Basin, Snake River Plain, Columbia Plateau, and Blue Mountains (St. Clair et al. 2013). In this study we investigate the efficacy of these seed zones by comparing differences in establishment, survival and reproduction of bluebunch wheatgrass populations from local seed zones compared to non-local seed zones. We hypothesize that in the long-term, populations from local seed zones will better establish, survive and reproduce. To test this hypothesis, we established a reciprocal transplant study in two broad regions (i.e., transects) each with eight seed zones and each seed zone represented by four to five wild populations. The two broad regions include (1) a transect from the hot, dry climates of the lower Snake River Plain to the cool, somewhat wet climates of the transverse ranges of the Great Basin to the cold, dry climates of the upper Snake River Plain; and (2) a transect from the hot, dry climates of the Columbia Plateau to the cool, wet climates of the Blue Mountains to the cold, dry climates east of the Blue Mountains.

Eight common gardens were established in each transect with each garden representing the climate of the local seed zone. Each common garden was planted with bluebunch wheatgrass from each seed zone within a region (transect). In addition to bluebunch wheatgrass populations from each seed zone, one widely used variety and one selected germplasm were included at each common garden. The experimental design at each common garden is a split-plot design with a plot represented by 25 plants (five plants per population) from each seed zone and the subplots as five populations per seed zone. Each site includes four replicates. Planting spacing is 0.6 m x 0.8 m between plants.

Results and Discussion

This study was initiated in 2013 beginning with seed collections from 138 populations from throughout the two broad regions. From these, 78 populations were chosen for inclusion in the study based on their distribution within each of the seed zones and the amount of available seed (only four populations, not five, were available from the hottest, driest seed zone within each transect). The University of Idaho was contracted to produce the containerized planting stock for the study in 2014. Potential collaborators were contacted to help with providing common garden sites on their lands. In August-December 2014, 16 common gardens were prepared and established. Most common gardens are protected from large mammal herbivory with fencing. Most common gardens were planted with four replicates of 39 populations from eight seed zones, one cultivar, and one selected germplasm for a total of 1,000 plants surrounded by two rows of buffer plants. A few sites included an extra treatment of a seed zone from the other transect or an extra selected germplasm.

Future Plans

The remaining common gardens at risk of large mammal herbivory will be fenced. In the spring and summer of 2015 and 2016, monitoring and data collection for each of the 16 common gardens will occur. In the spring, plant survival, reproductive phenology, occurrence of herbivory, and presence of fungus will be recorded at each common garden. Weather data loggers will be placed at each common garden to record local temperature during the course of the study. Common gardens will be managed to control weeds to allow for establishment to be largely a function of local climate rather than differences among test sites in competing vegetation. At each common garden, plant survival and reproduction will be recorded along with occurrence of herbivory and presence of fungus. Crown width, a measure of plant size including

biomass, will be measured on each plant. A single representative leaf and reproductive stalk will be collected from each plant to measure leaf width and seeds per reproductive stalk, respectively. These measurements will be repeated in 2016. Measurements will continue at each site, every year for an indefinite length of time. Reporting of early results will be presented after the first two growing seasons (2015 and 2016).

Management Applications and/or Seed Production Guidelines

Bluebunch wheatgrass is an ecologically important restoration species (Daubenmire 1942; Harris 1967). This study will examine the efficacy of seed zones for bluebunch wheatgrass to ensure successful establishment and allow for long-term adaptation by maintaining genetic diversity. The results of this study will help land managers determine sources of bluebunch wheatgrass populations for post-fire restoration of an area. Furthermore, this study will explore the consequences of changing climates for adaptation by substituting space for time to evaluate different populations in different climates. Results from this portion of the study will aid land managers in maintaining and restoring areas considering future climate changes. Long-term productivity and adaptation will be modeled to allow evaluation of trade-offs between different management options for current and future climates. Population movement guidelines and associated seed zones can be adjusted based on results from this study and management objectives.

Presentations

St. Clair, B.; Kilkenny, F.; Shaw, N. 2014. Progress on establishment of reciprocal transplant tests to study adaptation of bluebunch wheatgrass. Great Basin Native Plant Annual Meeting; 2014 March 17-18; Boise, ID.

St. Clair, J. Bradley; Kilkenny, Francis F.; Shaw, Nancy L. 2014. Testing the efficacy of seed zones for bluebunch wheatgrass. Great Basin Native Plant Project Annual Meeting; 2014 March 17-18; Boise, ID. [Available at http://www.fs.fed.us/rm/boise/research/shrub/projects/PowerPoint_Presentations/2013/StClair.pdf].

St. Clair, J. Bradley. 2014. Development and use of seed zones to ensure adapted plant materials for restoration: Introduction. Society of Ecological Restoration Regional Conference, Northwest and Great Basin Chapters; 2014 October 6-10; Redmond, OR.

Additional Products

Seed zone maps and map layers for bluebunch wheatgrass are available for download and use at the USFS Western Wildland Environmental Threat and Assessment Center. [Available at http://www.fs.fed.us/wwetac/threat_map/SeedZones_Intro.html].

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Harris, G. A. 1967. Competitive relationships between *Agropyron spicatum* and *Bromus tectorum*. Ecological Monographs 37: 89-111

St. Clair, J. B.; Kilkenny, F. F.; Johnson, R. C.; Shaw, N. L.; Weaver, G. 2013. Genetic variation in adaptive traits and seed transfer zones for *Pseudoroegneria spicata* (bluebunch wheatgrass) in the northwestern United States. *Evolutionary Applications* 6: 933-948

Project Title Conservation, Adaptation and Seed Zones for Key Great Basin Species

Project Agreement No. 10-IA-11221632-023 and 14-IA-11221632-013

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Project Description

Native plant species are critical for wildlife habitat, livestock grazing, soil stabilization, and ecosystem function in the Western United States and the Great Basin. Yet current germplasm releases of these species do not specifically match natural genetic diversity with local climates which often drive adaptation. We are developing seed zones that match climate with genetic variation that facilitate management decisions, ensure restoration with adapted plant material, and promote biodiversity needed for future natural selection with climate change. Over the course of the project, seed zones have been completed and published for tapertip onion (*Allium acuminatum* Hook.), Indian ricegrass (*Achnatherum hymenoides* [Roem. & Schult.] Barkworth), bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] Á. Löve) and Sandberg bluegrass (*Poa secunda* J. Presl; Johnson et al. 2012; Johnson et al. 2013; St. Clair et al. 2013; Johnson et al. 2015). Ongoing work with additional Great Basin species includes Basin wildrye (*Leymus cinereus* [Scribn. & Merr.] Á. Löve), Thurber's needlegrass (*Achnatherum thurberianum* [Piper] Barkworth), bottlebrush squirreltail (*Elymus elymoides* [Raf.] Swezey), and Sulphur-flower buckwheat (*Eriogonum umbellatum* Torr.).

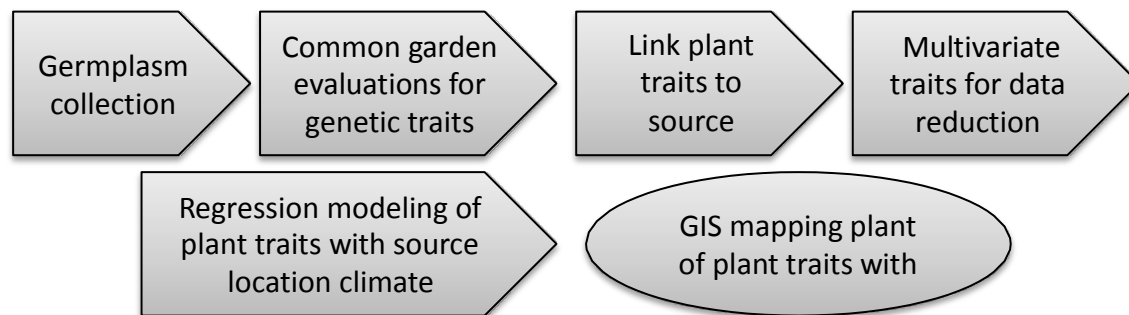


Figure 1. Schematic showing the steps for genecology studies to establish seed zones.

Our objectives are to:

1. Collect key Great Basin species and establish common garden studies quantifying genetic variation in plant traits associated with phenology, production, and morphology.
2. Uncover adaptive plant traits in common gardens linked to seed source location climates and develop composite plant traits using multivariate statistics.
3. Develop regression models linking composite plant traits with source climates and map seed zones for use in restoration.

Sandberg bluegrass

Genetic variation for potentially adaptive traits of the key restoration species Sandberg bluegrass (*Poa secunda* J. Presl; Johnson et al. 2012, 2013, 2015; St. Clair et al. 2013) was assessed over the Intermountain Western United States in relation to source population climate (Johnson et al. 2015). Common gardens were established at two Intermountain West sites with progeny from two maternal parents from each of 130 wild populations. Data was collected over 2 years at each site on 15 plant traits associated with production, phenology, and morphology. Analyses of variance revealed strong population differences for all plant traits ($P < 0.0001$), indicating genetic variation. Both the canonical correlation and linear correlation

established associations between source populations and climate variability. Populations from warmer, more arid climates had generally lower dry weight, earlier phenology, and smaller, narrower leaves than those from cooler, moister climates. The first three canonical variates were regressed with climate variables resulting in significant models ($P < 0.0001$) used to map 12 seed zones. Of the 700 981 km² mapped, four seed zones represented 92% of the area in typically semi-arid and arid regions (Figure 2). The association of genetic variation with source climates in the Intermountain West suggested climate driven natural selection and evolution (Johnson et al. 2015). We recommend seed transfer zones and population movement guidelines to enhance adaptation and diversity for large-scale restoration projects involving Sandberg bluegrass. Populations of plants from seed zones are being grown in the greenhouse and will be transplanted to the field for seed increase in spring 2015, and then further increased for use in large scale restoration.

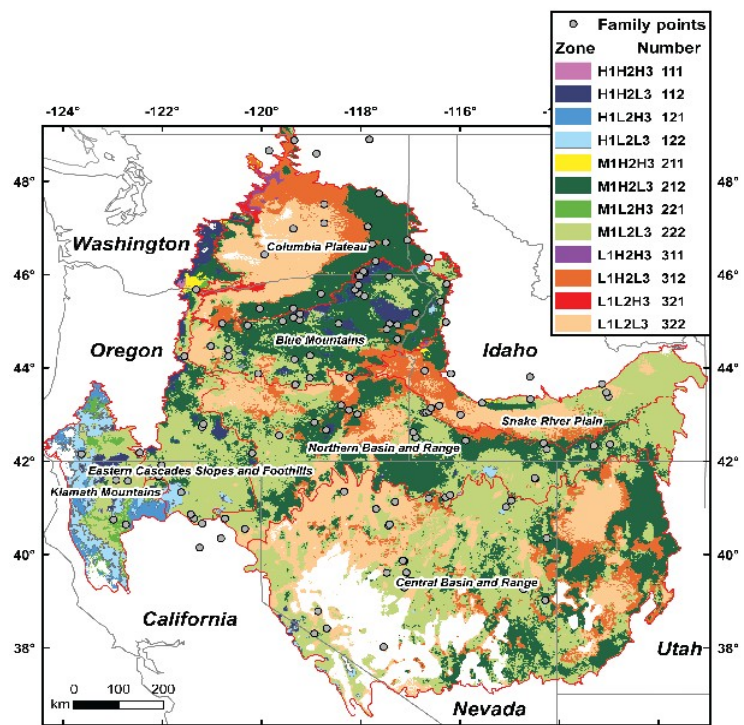


Figure 2. Proposed seed zones for Sandberg bluegrass in the Intermountain West and Great Basin regions.

Thurber's needlegrass

Thurber's needle grass common gardens were established at Central Ferry, WA, and Reno, NV in 2010. The study consisted of 67 source locations predominantly from the Northern and Central Basin and Range ecoregions. Data were collected in 2012 and 2013 on numerous phenology, production, and morphological traits. Data analyses revealed extensive genetic variation in Thurber's needlegrass across the Great Basin sampling region (Table 1). Genetic variation in wild populations of grasses and forbs has been reported for other species from the Great Basin

and Intermountain West (Johnson et al. 2010, 2012, 2013, 2015; St. Clair et al. 2013) and is generally observed in common garden research in other regions (St. Clair et al. 2005; Leimu and Fischer 2008; Horning et al. 2010). Interactions between source populations in different garden environments showed the expected presence of plasticity, that is, variation associated with different environments (Johnson et al. 2013, 2015; St. Clair et al. 2013).

Table 1. Summary of F-ratios and P-values from analyses of variance for Thurber’s needlegrass traits measured in common gardens at Central Ferry, WA and Reno, NV on source populations collected from Great Basin over two years (2012 and 2013).

Trait	mean	Site(S)		Pop. (P)		SxP		Year(Y)		YxS	
		F	P	F	P	F	P	F	P	F	P
Phenology†											
Heading, day of year	135	27.9	<.01	8.9	<.01	2.01	<.01	187.6	<.01	27.8	<.01
Blooming, day of year	133	17.2	<.01	6.9	<.01	1.8	<.01	78.8	<.01	2.0	0.16
Maturity, day of year	161	36.1	<.01	3.4	<.01	1.47	0.01	2109.8	<.01	.	.
Morphology‡											
Leaf length x width, cm ²	1.64	263.2	<.01	4.2	<.01	1.47	0.01	125.4	<.01	147.4	<.01
Leaf length to width	74.5	41.4	<.01	1.7	<.02	1.42	0.02	27.9	<.01	85.6	<.01
Culm length, cm	37.0	715.2	<.01	3.2	<.01	2.67	<.01	98.6	<.01	0.3	0.56
Panicle length, cm	12.2	3.9	0.07	4.7	<.01	2.32	<.01	30.7	<.01	7.2	<.01
Awn length, cm	4.1	0.0	0.91	6.6	<.01	1.27	0.09	2.3	0.13	1.6	0.21
Production§											
Survival	0.71	11.2	<.01	6.5	<.01	3.01	<.01	54.9	<.01	11.0	<.01
Panicle, number	32.4	145.8	<.01	2.5	<.01	1.61	<.01	186.7	<.01	96.4	<.01
Biomass, g	12.8	230.2	<.01	3.0	<.01	2.66	<.01	17.4	<.01	14.3	<.01
Crown area, cm ²	62.8	96.5	<.01	2.0	<.01	1.67	<.01	213.0	<.01	13.7	<.01

†Heading was at complete emergence of a lead panicle from its sheath, blooming was the initial appearance of anthers, and maturity when seed appeared mature in more than half the panicles.

‡Leaf length and width were measured on the last fully emerged leaf of a lead culm after heading; culm length, panicle length, and awn length (twice geniculate measured in three sections and summed) were measured on a lead culm after full extension.

§Panicles on each plant were counted after heading, harvest for dry weight was after maturity to within 4 cm of the soil, and after harvest crown area was estimated as the product of two perpendicular crown diameter measurements.

To simplify canonical correlation, traits were averaged over sites and years when correlations between specific traits were positive and significant ($P < 0.01$), indicating considerable correspondence for plants growing in different environments. This process reduced traits from a potential of 48 for all site-year combinations (12 traits times 4 environments) to 24 (Table 2). These were used for canonical correlation with 21 ‘annual’ climate variables (Table 3) as defined by Wang et al. (2012). Since only the first canonical variate was significant ($P < 0.001$), explaining 44% of the variation, it was the only variate used in regression modeling with the 21 climate variables.

Table 2. Plant traits used in canonical correlation of Thurber's needlegrass growing at common gardens at Central Ferry (CF), WA and Reno (RE), NV in 2012 and 2013.

Heading†	Panicle length RE12
Blooming	Panicle length RE13
Maturity CF	Awn length
Maturity RE	Survival CF
Leaf length x width	Survival RE
Leaf length to width CF 2012	Panicle number CF
Leaf length to width CF 2013	Panicle number RE
Leaf length to width RE 2012	Biomass CF
Leaf length to width RE 2013	Biomass RE
Culm length CF	Crown area CF
Culm length RE	Crown area RE 2012
Panicle length CF	Crown area RE 2013

†See Table 1 for detailed descriptions of plants traits. Plant traits were averaged over years and/or sites if correlations among of populations between year and site combinations were positive and significant at $P < 0.01$

Pearson's linear correlations between climate variables and canonical variate 1 were often highly significant ($P < 0.01$; Table 3) establishing a strong link between plant trait variation and climate across seed sources. The best regression model for canonical variate 1 and climates had 14 climate variables and explained 96% of the variation (Table 4), an exceptionally high amount. Regression R^2 for other studies using multivariate plant traits with climate perennial bunchgrasses in the Intermountain West were substantially less. For Sandberg bluegrass, Johnson et al. (2015) reported regression model R^2 values of 0.71 to 0.48 for canonical variates 1 and 2, respectively. For bluebunch wheatgrass, St. Clair et al. (2013), found regression R^2 values of 0.51 and 0.28 for principal component (PC) 1 and PC 2, and Johnson et al. (2010) reported R^2 values between 0.40 and 0.46 for mountain brome PC 1 and PC 2. For Indian ricegrass, regression models with canonical variates and climate ranged from 0.16 to 0.43 (Johnson et al. 2012). Among conifers, Douglas fir is considered closely adapted to differing environments and regression models between canonical variates and climate resulted in R^2 values of 0.50 and 0.68 (St. Clair et al. 2005). Horning et al. (2010) developed a regression model for oceanspray (*Holodiscus discolor* [Pursh] Maxim) from the first PC and climate with an R^2 of 0.86, which approached our model for Thurber's needlegrass. Thus the high R^2 for the regression model for Thurber's needlegrass (Table 5) indicated that canonical variate 1 was closely associated with climate variability across the Great Basin and suitable for seed zone development and mapping.

As in other genecology studies, Thurber's needlegrass showed plant trait variation likely resulting from climate driven natural selection and evolution. The regression model (Table 4) will be used to develop seed zones and maps for Thurber's needlegrass to guide the choice of germplasm for Great Basin restoration projects.

Table 3. Pearson correlation coefficient (r) between canonical variate 1 for plant traits and 21 climatic variables derived from each source population of Thurber's needlegrass (n=60).

Climate variable†	r	P-value
Mean average temperature (MAT)	0.53	<.01
Mean warmest monthly temperature (MWMT)	0.58	<.01
Mean coldest monthly temperature (MCMT)	0.20	0.13
Continentality, MWMT-MCMT	0.43	<.01
Mean Annual Precipitation (MAP)	-0.15	0.26
Mean summer precipitation (MSP)	0.04	0.78
Annual heat moisture index, (MAT+10)/(MAP/1000)	0.37	<.01
Summer heat moisture index ((MWMT)/(MSP/1000))	0.30	0.02
Chilling degree days (degree days <0°C)	-0.27	0.04
Growing degree days (degree days >5°C)	0.58	<.01
Heating degree days (degree days <18°C)	-0.50	<.01
Cooling degree days (degree days >18°C)	0.53	<.01
Number of frost free days (NFFD)	0.35	<.01
Frost free period (FFP)	-0.41	<.01
Day of year when FFP begins (bFFP)	0.38	<.01
Day of year when FFP ends(eFFP)	0.42	<.01
Precipitation as snow (PAS)	-0.32	<.01
Extreme minimum temperature over 30 years (EMT)	0.14	0.29
Extreme maximum temperature over 30 years (EXT)	0.48	<.01
Hargreaves reference temperature (Eref)	0.58	<.01
Hargreaves climatic moisture index (CMD)	0.45	<.01

† See Wang et al. 2012 for additional climate variable definitions and details

Table 4. Coefficient of determination (R^2) and the regression equation developed between canonical variate 1 and climatic variables for Thurber's needlegrass.

Trait	R^2	Regression equation†
Canonical variate 1	0.96	27.79+5.957(MAT)- 0.0132(MAP) +0.0387(MSP) +0.0118(SHM) +0.0432(DD<0)-0.0204(DD>18) -0.2356(NFFD)-0.0568(bFFP) +0.0623(FFP) +0.0212(PAS) +0.7153(EMT)-0.7993(EXT) +0.0235(Eref)-0.0193(CMD)

† Annual climatic variables as given in Table 3 and by Wang et al. (2012)

Basin wildrye

Collections of Basin wildrye were made in the Columbia Plateau in Washington State where the octoploid form is common, and in the Great Basin where the tetraploid and octoploid can be found. Ploidy for all collection locations was determined as described by Jakubowski et al. (2011). The analysis of field collected sources revealed 58 octoploids and 56 tetraploids.

Common gardens of Basin wildrye were established at Pullman and Central Ferry, WA, sites in 2010 with plants from 114 collection locations that were randomized in complete blocks with six replications. Data collection for phenology, production, and morphology traits was completed 2011, 2012, and 2013. Initial data analyses indicate considerable plant trait variation, as expected. There were also differences associated with ploidy, so ploidy will be considered in climate adaption models. Seed zones for Basin wildrye will be developed in 2015.

Bottlebrush squirreltail

Common gardens of Bottlebrush squirrel-tail were established in at Central Ferry WA, Powell Butte, OR, and Reno, NV, and data collection at Central Ferry was completed for numerous phenology, production, and morphological traits. Data has been sent to Francis Kilkenny at the Rocky Mountain Research Station for consolidation with other sites, data analysis, and publication.

Sulphur-flower buckwheat

Collection of Sulphur-flower buckwheat was completed by the Western Regional Plant Introduction Station (WRPIS) in 2012 resulting in 21 accessions. There has also been ongoing collection through the BLM Seeds of Success (SOS) program resulting in 48 accessions. Seeds from the WRPIS and SOS collections were used to establish plants in the greenhouse in 2014. In the fall of 2014, these were transplanted to a common garden at the WRPIS farm at Pullman, WA. Taxonomy will be verified and data collected on phenology, production, and morphology plant traits in 2015 and 2016.

Seeds of Success activities

Seeds of Success (SOS) and the National Plant Germplasm System (NPGS) have partnered to collect, distribute, and evaluate key native plant materials needed for conservation and restoration. Accession and distribution numbers continue to grow. In 2014, 1,403 new native plant accessions were added to the SOS-NPGS collection, which now totals 10,515 accessions. Since 2006, nearly 4,500 seed distributions have been made for research projects including federal, state, U. S. commerce and private cooperators (Figure 2).

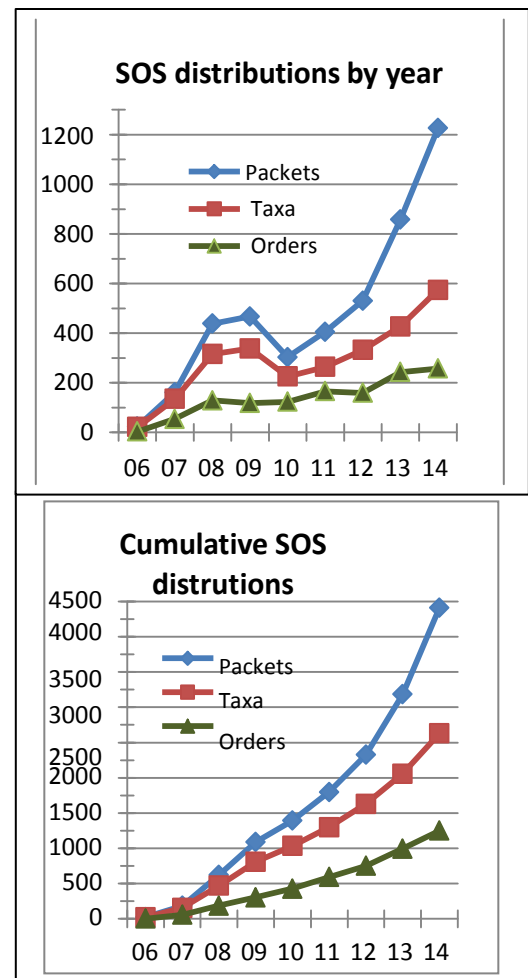


Figure 2. Distribution data for Seeds of Success accessions within the National Plant Germplasm System from 2006 through 2014.

Publications

Johnson, R. C.; Horning, M. E.; Espeland, E.; Vance-Borland, K. 2015. Genetic variation and climate interactions of *Poa secunda* (Sandberg bluegrass) from the Intermountain Western United States. *Evolutionary Applications* 8: 172-184.

Dugan F. M.; Cashman, M. J.; Johnson, R. C.; Wang, M.; Xianming C. 2014. Differential resistance to stripe rust (*Puccinia striiformis*) in collections of basin wild rye (*Leymus cinereus*). *Plant Health Progress* 15: 34-38.

Johnson, R. C. 2014. Genecology and seed zone research for native forbs and grasses of the interior West. In: *Proceedings Society of Ecological Restoration Regional Conference, Redmond, Northwest and Great Basin Chapter, 2014 October 6-10; Redmond, OR.*

Presentations

Conservation, Adaptation, and Seed Zones for Key Great Basin Species for the Great Basin Native Plant Project Annual Meeting; 2014 March 17; Boise, ID.

Management Applications and Seed Production Guidelines

- Maps visualizing the interaction of genetic variability and climate for restoration species allow informed decisions regarding the suitability of genetic resources for restoration in varying Great Basin and Southwestern environments.
- The recommended seed zone boundaries may be modified based on management resources and land manager experience without changing their basic form or the relationship between genetic variation and climate.
- We recommend utilization of multiple populations of a given species within each seed zone to promote the biodiversity needed for sustainable restoration and genetic conservation.
- Collections representing each seed zone should be released, grown, and used for ongoing restoration projects.

Products

- Seed zones are for key Great Basin restoration species to ensure plant materials used for restoration are adapted, suitable, and diverse.
- Collection and conservation of native plant germplasm through cooperation between the National Plant Germplasm System (NPGS), the Western Regional Plant Introduction Station, Pullman, WA, the U. S. Forest Service, and the Seeds of Success (SOS) program under BLM. This ensures availability of native plant genetic resources that otherwise may be lost as a result of disturbances such as fire, invasive weeds, and climate change.

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Project Title Ecological Genetics of Big Sagebrush (*Artemisia tridentata*): Genetic Structure and Climate-based Seed Zone Mapping

Project Agreement No. 13-IA-11221632-161

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Project Description

Plant species that occupy large geographic distributions contend with highly varied climates. Such climatic differences frequently require genetic adaptation. Failure to understand how these species are adapted to climate will impede restoration. In this study we assess the growth and seed yield of big sagebrush (*Artemisia tridentata* subspecies *tridentata*, *vaseyana* and *wyomingensis*) from two common gardens over four years. Using linear-mixed models, growth and seed yield variation is associated with source-location derived climate variables (temperature, precipitation and their interactions). Overall, continentality strongly affects climate adaptation in big sagebrush. We discuss the genetic patterns and development of seed transfer zones based on these data.

Objectives

- 1) Establish common gardens from collected seed sources across the range of big sagebrush.
- 2) Determine climatic factors important to adaptation within and among big sagebrush ecological races.
- 3) Develop climate based seed transfer zone maps across the range of big sagebrush.

Methods

Common Garden Establishment and Measurements

Collection of seed and plant tissue began in autumn of 2009. A total of 93 seed sources were collected, largely by collaborators, in 11 western states. In January 2010, seeds were planted in greenhouse containers. Up to ten families from each of 55 seed sources were outplanted at each of the common gardens (Table 1). Outplanting of seedlings occurred in May and June of 2010. First-year measurements were conducted in October and November of 2010. Plants were supplemented with water until August 2010 and mortality was minimal for the first year at <2%. No supplemental water was added in subsequent years.

Plant growth was determined by height and crown area. Plant heights were measured from the ground to the highest, living, non-flowering stem. Crown areas were calculated from overhead digital photos. Photos were analyzed by cropping green leaves from a white background placed under the plant using the color threshold feature in ImageJ ver 1.45. Pixel size of the cropped area was scaled to a known standard on each photo. Measurements were taken in October 2010 and in May 2011 and 2012. Heights and crown areas were used to estimate volume based on an ellipsoid volume equation from measurements that occurred within 2 weeks of each other.

Seed yield was estimated for two plants per population in both gardens during 2012 and 2013 growing seasons. Plants were randomly selected from each population. In August, two flowering stems of approximately the same size were fitted with 13x45cm bags constructed from mosquito netting. The bags were tied at the base of the stems with string. The remaining unbagged flowering stems were counted. The bags were then harvested in early December after seed ripening. Contents of each bag were cleaned to remove any chaff and the seed was weighed. An estimate of total seed yield per plant was calculated by multiplying the seed yield from each bag and the total number of inflorescence stems.

Table 1. Location information of three big sagebrush common garden sites.

<u>Site name</u>	<u>Latitude</u>	<u>Longitude</u>	<u>Elevation (m)</u>
Orchard, Idaho	43.328	-116.003	976
Ephraim, Utah	39.369	-111.580	1686
Majors Flat, Utah	39.337	-111.521	2088

Common Garden Analyses

In this report we focus on modeling climate associated with growth and seed yield of subspecies *tridentata* and *wyomingensis* from Majors Flat and Orchard gardens. Seed and growth were the response variables for linear-mixed models. The predictors in these models were divided into fixed and random effects. Fixed effects included original seed-source climate variables and random effects included a nested hierarchy of garden, year (seed yield only), population and family. The original seed-source climate variables were estimated from a spline model based

upon weather station data recorded between 1961-1990 (<http://forest.moscowfsl.wsu.edu/climate/>). Mapping of the model outputs was completed using the slope(s) and intercept from the fixed (climate) effects and individual cell values, 0.00833° ($\sim 1 \text{ km}^2$) from the relevant climate-surface variables. These grids were mapped with the predicted climatic niche of a subspecies *wyomingensis* bioclimate model (Still and Richardson 2015).

Results and Discussion

Among the climate (fixed) effects, summer dryness index (SDI) was an important predictor for both growth and seed yield ($p < 0.0001$ and $p < 0.05$, respectively). In addition, winter precipitation was important for seed yield ($p < 0.001$). The predicted values from the growth and seed yield models were highly and positively correlated ($r = 0.72$, $p < 0.0001$). Among random effects, subspecies-ploidy groups were significant for both growth and seed yield ($p < 0.0001$). Population variance was significant for growth ($p < 0.0001$) and family variance was significant for seed yield ($p < 0.0001$). It is important to note that subspecies-ploidy, population and family variances were nested within garden. However, garden alone was not a significant random effect in either model.

To illustrate the model prediction, fixed (climate) effects of seed yield and growth are projected within the predicted bioclimate niche of subspecies *wyomingensis*. For seed yield, the mapped patterns predict that *tridentata* and *wyomingensis* populations from areas with greater winter precipitation and drier and warmer summers have higher fecundity at the common gardens than populations that receive more summer precipitation and cooler summers (Figure 1). Differences in seed yield among populations appear especially true for the Orchard garden, which experiences relatively warmer temperatures and precipitation that principally falls in winter compared to regions further east. For example at the Orchard garden, seed yield ranged from an average of 0.1g from populations in Montana and southern Utah to 41g from the local Orchard, Idaho source.

As mentioned above, growth followed a similar pattern as seed yield. Plants from warmer, drier summer climates had greater growth than plants originating from areas further east that receive more frequent summer precipitation and cooler temperatures (Figure 2). These differences in growth were most pronounced at the Orchard garden compared to Majors Flat. It is expected that if a garden were established in a region that received greater summer precipitation (e.g., Montana) the reciprocal would be true. Plants from areas acclimated to receive greater summer precipitation would have greater growth.

Future plans

Data collection for the project is complete and final data analyses and manuscripts will be submitted to peer-reviewed journals. Confidence intervals will need to be calculated to break the continuous variation (Figure 1 and Figure 2) into climatypes and seed, growth and survivorship (not shown) models will be combined to construct seed transfer zones. The association between trait responses and physiology remains.

Management Applications

The highlighted data and models are the foundation for development of seed transfer zones for big sagebrush. Synthesis of these models into seed zones is underway. Published seed transfer guidelines will be developed into a web-based tool for land managers.

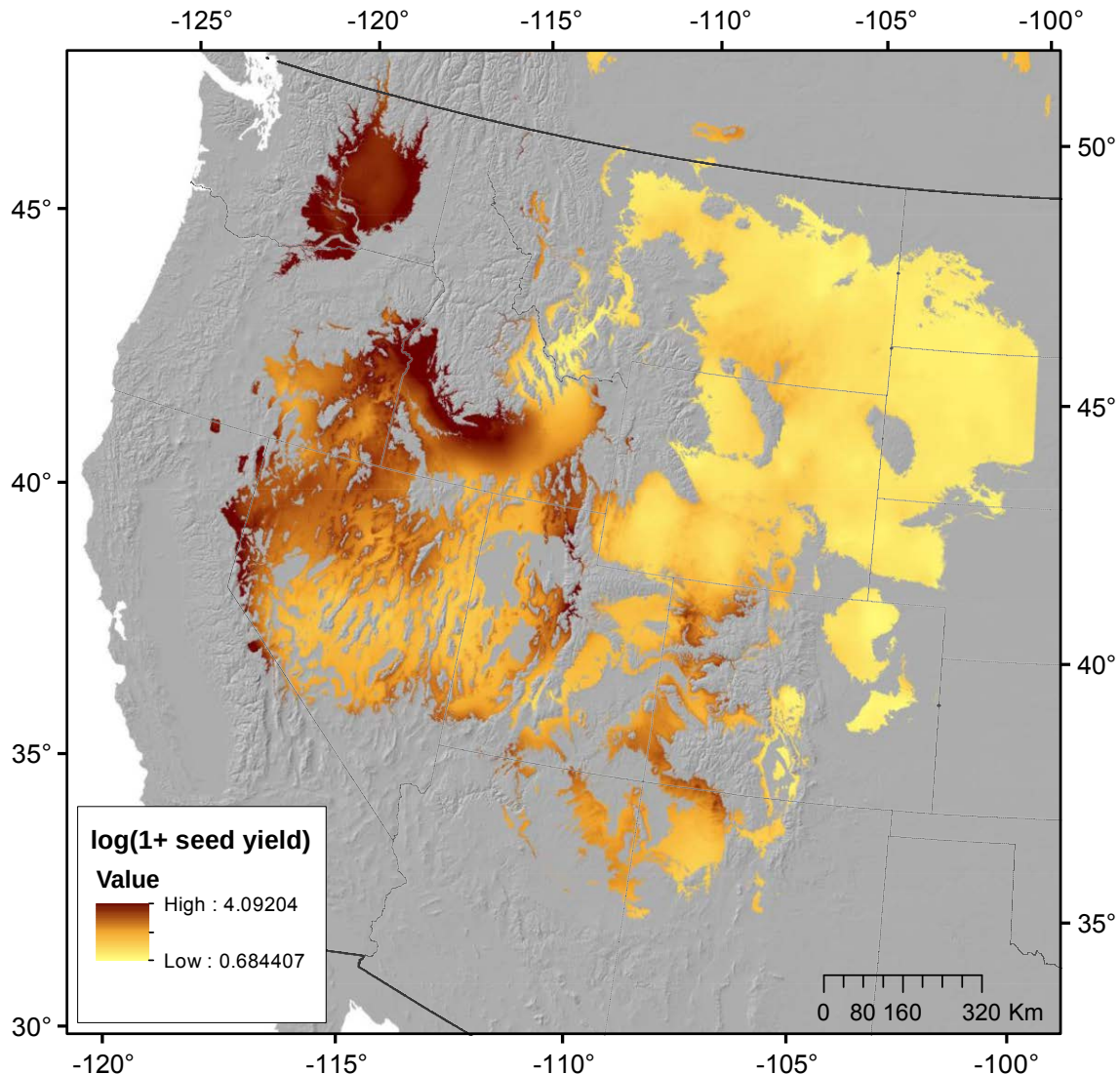


Figure 1. Mapped linear mixed model of fixed effects (climate) of seed yield (g) for basin big sagebrush (*Artemisia tridentata* ssp. *tridentata*) and Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*). Colors corresponded to the predicted values of the model displayed as log (1+seed yield). For example, values of 4.09 and 0.68 equate to 58.7 and 0.9g of seed per plant. The values are mapped within the predicted climate niche of Wyoming big sagebrush (Still and Richardson 2015).

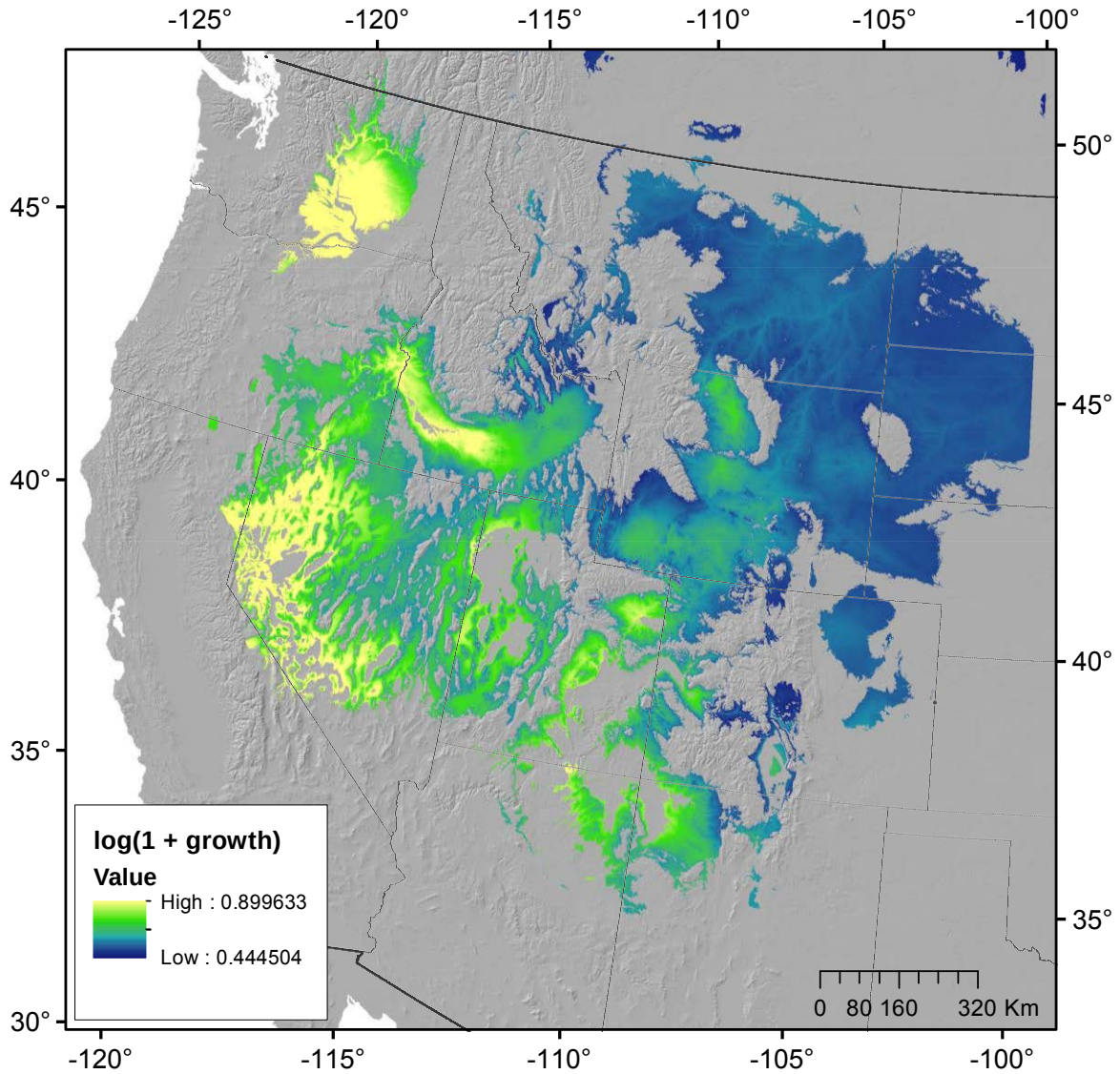


Figure 2. Mapped linear mixed model of fixed effects (climate) of growth (m^3) for basin big sagebrush (*Artemisia tridentata* ssp. *tridentata*) and Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*). Colors correspond to the predicted values of the model displayed as $\log(1 + \text{seed yield})$. For example, values of 0.89 and 0.44 equate to 1.43 and 0.55 m^2 of growth. The values are mapped within the predicted climate niche of Wyoming big sagebrush (Still and Richardson 2015).

Presentations

Richardson, B. Development of tools and technology to improve the success and planning of restoration of big sagebrush ecosystems. Great Basin Landscape Conservation Cooperative Webinar; 2014, September 16.

Richardson, Bryce R.; Shaw, Nancy L.; Germino, Matt; Ortiz, Hector; Carlson, Stephanie; Sanderson, Stewart; Still, Shannon. Development of tools and technology to improve the success and planning of restoration of big sagebrush ecosystems. Great Basin Consortium Conference; 2013 December 9-10; Reno, NV. Abstract and Poster.

Richardson, B. A.; Shaw, N. L.; Germino, M. J.; Still, S. M. Comparisons of contemporary and future predictions of the climate niche and ecological genetics of big sagebrush and blackbrush. Society for Ecological Restoration Regional Conference, Northwest and Great Basin Chapters; 2014 October 6-10; Redmond, OR.

Richardson, B.; Shaw, N. Germino, M.; Still, S. Relationships between common garden responses and climate in big sagebrush (*Artemisia tridentata*). Great Basin Native Plant Annual Meeting; 2014 March 17-18; Boise, ID.

Additional Products

- Leveraged funding: National Fire Plan 2013-2016 (\$72,000 per year).
- Leveraged funding: Great Basin LCC 2013-2015 (\$35,000).

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Still, S. M.; Richardson, B. A. 2015. Projections of Contemporary and Future Climate Niche for Wyoming Big Sagebrush (*Artemisia tridentata* subsp. *wyomingensis*): A Guide for Restoration. Natural Areas Journal 35: 30–43.

Project Title Factors Affecting Initial Establishment of Big Sagebrush Outplants: Land Treatments, Seed Sources, and Climate Effects

Project agreement No. 14-IA-11221632-012 and 11-IA-11221632-098

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Project Description

Increased wildfire activity poses a major challenge for big sagebrush (*Artemisia tridentata*) and its dependent species due to a lack of fire adaptation in big sagebrush. Big sagebrush seeding and planting are becoming increasingly common, particularly in light of conservation concerns of sage grouse (*Centrocercus urophasianus*), but success has been mixed. Climate and weather variability, appropriateness of seeds, and site conditions relating to management are all factors

that may help explain success of sagebrush restoration efforts. Consideration of these factors may improve seeding or planting success.

Big sagebrush has high intraspecific diversity, and selection of appropriate seed source is increasingly a concern in designing and implementing big sagebrush restoration treatments. Diversity in big sagebrush results from subspecies, cytotypes, and population-level variability. Seedling survival is recognized as a primary bottleneck for sagebrush establishment, and information on climate adaptation and ecological responses at this stage are a priority need.

Big sagebrush seeding or planting treatments are often accompanied by treatments that reduce wildfire fuel loads and invasive annuals or increase native herbs through mowing, herbicide applications, or rangeland drill seeding. Neighboring herbs can have strong effects on big sagebrush seedlings, which can relate to competition for water and other soil resources.

Objectives

1. Assess the influence of management treatments of herbs on seedlings of different seed sources of big sagebrush.
2. Compare growth, survival, and underlying ecophysiological mechanisms and thresholds among seedlings of the different subspecies, cytotypes, and populations of big sagebrush.

Methods

Objective 1: Effect of Management Treatments

We planted seedlings in 48 1-ha experimental plots in the Birds of Prey National Conservation Area (BOP NCA) in Idaho, on an *A. tridentata wyomingensis* site that burned in 1998 and had become dominated by cheatgrass and Sandberg's bluegrass (*Poa secunda*). Experimental plots were placed in three replicate blocks using a full-factorial, completely randomized combination of four management practices (no treatment, 4 oz/acre of Impazic herbicide, mowing, and mowing plus herbicide) and two seeding treatments (seeded and unseeded). All treatments were implemented in fall 2012. A native seed mix containing grasses, forbs, and shrubs was applied using a Truax minimum-till seed drill.

Seven-month old sagebrush seedlings of cone-tainer stock (shoots were ≤ 4 cm tall) were outplanted in spring 2013. Seedlings of four subspecies of *A. tridentata* ssp. *tridentata* were bare-root transplanted into small holes and outplanted into all 48 plots (nine seedlings per subspecies per plot). Seed sources included diploids local to the study site (IDT2) or from a relatively dry site in California (CAT-2) or a warm and dry site in Oregon (ORT2, known to be fast-growing), and a tetraploid population from a relatively dry site in New Mexico (NMT2).

Survival of outplants was measured quarterly from April 2013-May 2014. For Objective one (and two), differences in survival and significance of factors related to survivorship were determined using Cox's hazard of death analyses and general estimating equations along with conditional logistic regression (Brabec 2014).

Objective 2: Variation Among Seedlings of Different Subspecies, Cytotypes, and Populations

Eleven different seed sources were utilized to assess how initial establishment and factors affecting it vary among subspecies, cytotypes, and population of big sagebrush (Table 1) and seedlings were reared as in Objective 1. Plots were established in five separate sites (statistical blocks) that burned in the summer of 2012 at BOP NCA, south of Boise, Idaho, in a randomized complete block design. Each block was fenced to prevent cattle disturbance and grazing on the plots. Seedlings were outplanted in November 2012 and average seedling heights ranged from 2.25-3.83cm, with ten seedlings per plot and 10cm spacing between seedlings. Height and survival of sagebrush seedlings were recorded in monthly increments to May 2014. Soil moisture and temperatures in the seedling's depth or height of roots or shoots (respectively) were measured in each plot and are reported in Brabec (2014).

Table 1. Description of big sagebrush seed sources utilized in this study.

<i>Provenance</i>	<i>State</i>	<i>Location</i>	<i>Subspecies</i>	<i>Climate-of-origin</i>	<i>Ploidy</i>
IDT-2	ID	Orchard (Local)	Tridentata	Local	2N
BOP-W	ID	Birds of Prey	Wyomingensis	Local	4N
IDV-2	ID	(Nearest Mtn)	Vaseyana	Cool/Wet	2N
NMT-2	NM	San Luis Mesa	Tridentata	Dry	4N
UTT-1	UT	Canyon B.	Tridentata	Cool/Wet	2N
IDW-2	ID	Orchard (Local)	Wyomingensis	Local	4N
ORT-2	OR	Echo	Tridentata	Warm/Dry	2N
MTW-3	MT	Montana	Wyomingensis	Cool/Wet	4N
ORV-1	OR	Lookout Mountain	Vaseyana	Cool/Wet	4N
IDW-3	ID	Sommer Camp	Wyomingensis	Dry	4N
IDV-3	ID	Stanley	Vaseyana	Cool/Wet	2N

Freezing points were determined from exothermic heat pulses released when leaves reached their freezing points during controlled cooling experiments in the lab. To assess freezing tolerance, we measured F_v/F_{m50} , the temperature causing 50% loss of chlorophyll *a* fluorescence. ANOVA was used to assess physiological differences among subspecies, cytotype, and climate-of-origin to freezing. Freezing resistance mechanisms (avoidance or tolerance) were determined by assessment of the difference between F_v/F_{m50} and freezing point.

Results and Discussion

We observed high mortality during the first year of the study, which corresponded to unusually cold and dry conditions.

Objective 1: Effect of Management Treatments

Management treatments, drill seeding, and big sagebrush population seed source all influenced seedling survival times ($\chi^2=69.8$, $p<0.001$). Mortality risks increased 2- to 15-fold on drill-seeded compared to unseeded plots that also had treatment combinations resulting in reduced herbaceous cover (i.e., mowing, mowing+herbicide; Figure 1), although substantive emergence of seeded species was not readily detected in the treatments. Mean cheatgrass cover was $25.21\pm7.9\%$ on seeded plots and $18.02\pm6.2\%$ on non-seeded plots, and seeded plots also had less mean bare soil cover ($19.84\pm2.7\%$) compared to non-seeded plots ($25.03\pm2.6\%$).

A hypothetical explanation for our results is that establishment of sagebrush outplants was negatively affected by increased competition from invasive herbaceous species, particularly in drill-seeded plots. Reduced spacing between neighboring herbs such as cheatgrass and sagebrush seedlings on the drill-seeded plots could have exacerbated competition. Conversely, the reduced intensity of plant interactions in communities on non-seeded plots may have increased water and nutrient availability for seedlings and thus survival.

Objective 2: Variation Among Seedlings of Different Subspecies, Cytotypes, and Populations

As predicted, seedling survival over the entire duration of the experiment was less for *A. t. vaseyana* relative to both *A. t. tridentata* and ssp. *wyomingensis*. Survival of tetraploid groups was consistently greater than diploids, for comparisons within subspecies; $\chi^2=6.8$, $p=0.009$ for *A. t. vaseyana* and $\chi^2=4.4$, $p=0.036$ for *A. t. tridentata*. Diploid *A. t. tridentata* had the greatest average heights of all populations and their survivorship was at 12% and 16% (6.13 and 5.76 cm respectively). Survival of other populations was 20-30%, and heights ranged 3.0-4.5 cm. Survival of *A. t. wyomingensis* was 24%, and height averaged 4.65 cm.

Mortality patterns over all seedlings were related more to minimum temperatures of the soil surface than to growing degree days $>10^\circ\text{C}$ or volumetric water content (from conditional logistic regression; Information criterion coefficient = 1378 compared to 1462 or 1466, respectively). The sensitivity of survival to minimum temperatures did not relate to climate-of-origin of populations, but statistical inference was complicated by high mortality among blocks.

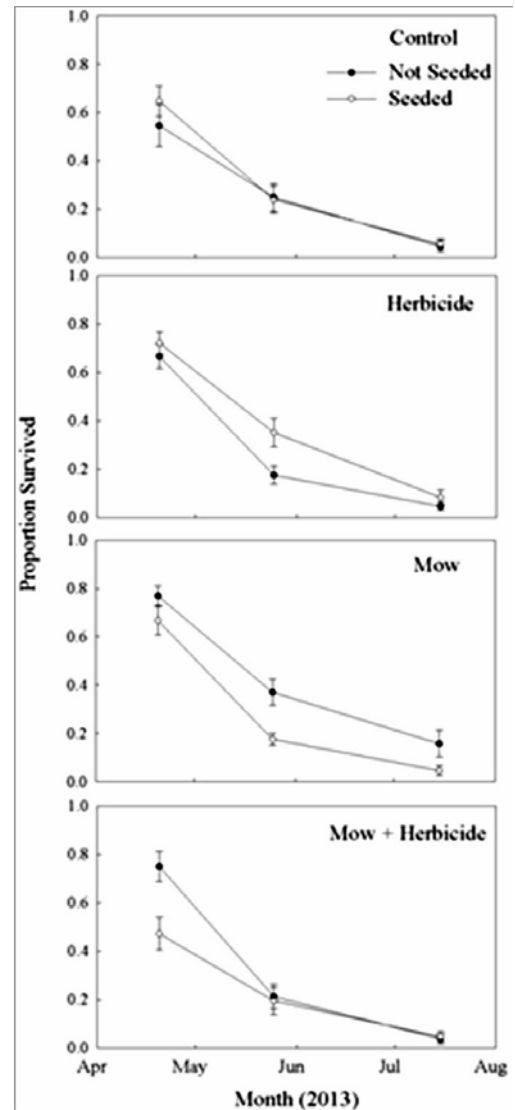


Figure 1. Differences in survivorship among 8 treatments in April, May, and June 2013 (from Brabec et al., in review).

Freezing points of *A. t. vaseyana* populations were 2-3°C significantly warmer than for *A. t. wyomingensis* populations (Figure 2). *A. t. tridentata* froze at $-10.51 \pm 0.71^\circ\text{C}$. The range of F_v/F_{m50} among subspecies x cytotypes was much smaller than that observed for freezing point (Figure 2). Among subspecies, *A. t. wyomingensis* had greater freezing resistance than both *A. t. vaseyana* and ssp. *tridentata* by approximately 1.1°C ($p = 0.0017$). There were no differences in F_v/F_{m50} between cytotypes within each subspecies, but *A. t. wyomingensis* had 1.4°C greater freezing resistance than diploid *A. t. vaseyana*. The difference (in °C) between F_v/F_{m50} and freezing point (F_v/F_{m50} – freezing point) revealed variable freezing response strategies among subspecies and cytotypes (Figure 2). Tetraploid *A. t. tridentata* had a significantly higher F_v/F_{m50} – freezing point than tetraploid *A. t. vaseyana* indicating. F_v/F_{m50} – freezing point was not associated with climate-of-origin for any subspecies.

Cytotype appears to be an important factor in explaining functional diversity, possibly even as important as subspecies itself for seedling establishment and survival. Using the criteria for freezing avoidance versus tolerance, our data suggest big sagebrush's freezing resistance strategy is classified as freezing tolerance, except for tetraploid *A. t. tridentata*, an avoider (Figure 2). “Avoiders” had the most mortality in March, whereas freezing “tolerators” experienced consistent mortality due to minimum temperatures from April to June. A putative investment in freezing tolerance at the expense of other growth (competitive) traits may limit the ability of seedlings to compete with faster growing species when freezing events are infrequent, resulting in mortality.

In spite of its freezing tolerance strategy, *A. t. vaseyana* had the greatest vulnerability to minimum temperatures and thus least capacity to cope with freezing. The relatively higher elevations of *A. t. vaseyana* habitat may on one hand be cooler, but on the other hand is more likely to be insulated from temperature extremes by snow cover.

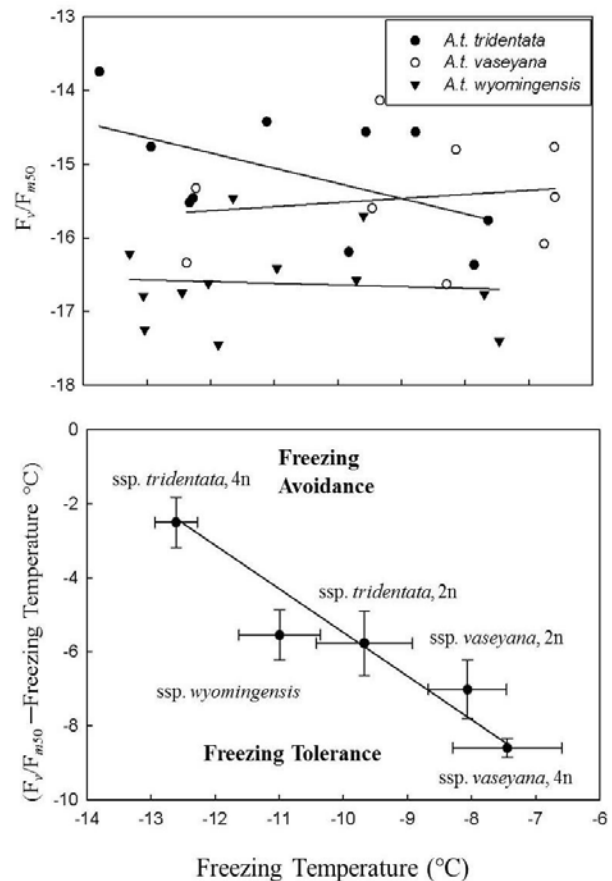


Figure 2. The relationship of temperature causing 50% loss of F_v/F_m (F_v/F_{m50}) to freezing point (A , R^2 all three regression lines <0.05) in contrast to the relationship of the difference between F_v/F_{m50} and freezing point (“ F_v/F_{m50} – Freezing Point °C”) to freezing point by subspecies and cytotype ($R^2=0.776$) (from Brabec et al., in review).

Management Applications and/or Seed Production Guidelines

Interactions among species in seed mixes are rarely considered, except where aggressive non-native species (e.g. crested wheatgrass or forage kochia) are part of the seed mix. Our preliminary data suggest that treatments resulting in temporary reduction of herb cover may increase success in situations where establishment of big sagebrush is a priority. Our preliminary data indicate that seedling mortality, growth, and response to freezing differ at the subspecies, cytotype, and population level. Cytotype may be as important as subspecies in explaining adaptation and functional diversity in big sagebrush. Consideration of this functional diversity may improve sagebrush planting success.

Presentations

Germino, M. J. Evolution and conservation of sagebrush. Ecology and Evolution Class, College of Idaho; 2014 October 29; Caldwell, ID.

Germino, M. J. 2014. Sagebrush responses to shifting climate and fire disturbances: basic insights for restoration. Sage Steppe Partner Forum Webinar Series; 2013 January 21; Boise, ID.

Brabec, M. M.; Germino, M. J.; Richardson, B. A.; Vander Veen, J.; Lazarus, B. 2014. Big sagebrush changing climate context; the effects of genotype and climate variability on success of sagebrush seedlings. Ecological Society of America Annual Meeting, Sacramento CA; Aug 10-15. Poster.

The loss of big sagebrush (*Artemisia tridentata*) due to wildfire has motivated efforts to restore it through seeding and planting. Restoration success has been mixed, despite large investment. Big sagebrush displays high intraspecific diversity, and appropriate seed source is an increasing management concern in post-fire restoration. Currently, there are unmet data needs for establishing seed transfer zones for big sagebrush under future climate regimes and a major pending question is whether seeds sources from warmer and drier sites will be better suited than local seed sources. Our primary objectives in this study were to assess climate responsiveness of seedlings of different provenances on burned areas and relate ecophysiological-climate adaptation in seedlings to that of established plants from a common garden study. Experimental passive warming chambers paired with unwarmed control plots were installed at Birds of Prey National Conservation Area on five sites burned in 2012. We evaluated eleven different seed sources of big sagebrush from all three subspecies, dissimilar climates of origin, and different ploidy levels to assess how genotype affects initial establishment of sagebrush. A suite of dependent variables were measured; including survival, growth, chlorophyll fluorescence, isotopic assessment of water-use efficiency, and differential thermal analysis. Preliminary results suggest that experimental warming enhanced overall seedling survival revealing the sensitivity of sagebrush to temperature (particularly daily minima). Among the three subspecies of sagebrush, basin big sagebrush had the lowest mortality under warming, which may relate to access to deeper soil water resources ($p=0.001$). Overall, we did not observe consistent strong support for local adaptation. Local genotypes exhibited greater stress and photoinhibition after freezing and light treatments than distant genotypes ($p=0.01$). Isotopic assessment of water-use efficiency of distant vs. local seedlings revealed that seedlings from warmer and drier climates have greater water use efficiency under current climate conditions ($p=0.04$). During initial establishment, there is an emerging pattern that implies a tradeoff between growth and survival. Genotypes with most overall growth also had the highest overall mortality, and this trend contrasts with patterns observed in more mature sagebrush. These findings indicate the

importance of drawing inference on ecophysiological adaptation from multiple demographic stages while establishing seed transfer zones for big sagebrush restoration.

Germino, M. J. 2014. Sagebrush responses to shifting climate and fire disturbances: basic insights for restoration. Society for Ecological Restoration Regional Conference of Northwest and Great Basin Chapters, 2014 October 6-10; Redmond, OR.

The Birds of Prey National Conservation Area (BOPNCA) has experienced considerable loss of big sagebrush as fire and invasive grasses have increased in recent decades, similar to many other regions in the western United States. Management efforts aimed at promoting recovery of sagebrush and wildlife habitat are faced with climate, weather, and other landscape challenges. Our research program is evaluating climate responses of adult and seedling sagebrush, and the effect of management options for post-fire seeding on recovery. To test the hypothesis that warming is hindering sagebrush persistence or post-fire establishment, and to evaluate genetic variability in responses, we established experimental warming and control plots on five new wildfire sites and on nearby unburned sites that still had sagebrush. Seedlings of a variety of populations of the three primary subspecies of big sagebrush were planted onto the burned plots. Preliminary data suggest little effect of warming on adult big sagebrush, which contrasts with positive effects observed elsewhere at higher elevations. Also in contrast, warming affected seedling survival and growth. Considerable variation was evident among subspecies and populations, indicating importance of selecting appropriate seed sources in restoration or rehabilitation seedings. In an associated pilot study, we attempted to evaluate how choice of seed source has related to success of sagebrush recovery in >20 post-fire seedings in and around the BOPNCA, in light of weather, climate, and many other factors affecting establishment. In contrast to the climate experiment, the pilot study did not reveal a strong effect of sagebrush seed source on seeding outcomes, in spite of a tendency for non-target subspecies from higher elevation climates to have been seeded. To provide a stronger test of how choice of sagebrush seed has affected seeding outcomes, we are expanding the analysis to include many more seeding projects distributed throughout the Great Basin and elsewhere.

Brabec, M.; Germino, M. J.; Richardson, B. A. 2014. Big sagebrush in a changing climate context: effects of cytotype and climate variability on success of sagebrush seedlings. Society of Ecological Restoration Regional Conference of Northwest and Great Basin Chapters; 2014 October 6-10; Redmond, OR.

Big sagebrush (*Artemisia tridentata*) is a genetically diverse species that shows high diversity in its response to climate. Three subspecies are widely recognized; mountain, basin, and Wyoming. Wyoming sagebrush is universally tetraploid and mountain and basin subspecies are often diploid, but tetraploid populations can occur. Data suggests that cytotype is as important a factor in explaining functional diversity as subspecies, and polyploidy and inter- and intraspecific hybridization are likely to be important mechanisms in big sagebrush adaptation and landscape dominance. The loss of big sagebrush due to wildfire has motivated efforts to restore it, and appropriate seed source is an increasing management concern in post-fire restoration. A number of sagebrush common-garden studies have been conducted in the Great Basin and have revealed key ways that adult sagebrush differ by subspecies and cytotype, particularly in climate response. However, little is known about climate responses of seedlings during the initial establishment phase. To assess differences in climate responsiveness among sagebrush seedlings, we evaluated eleven different seed sources of big sagebrush from all three subspecies,

dissimilar climates of origin, and different ploidy levels at Birds of Prey National Conservation Area. A suite of dependent variables were measured including survival, growth, chlorophyll fluorescence, isotopic assessment of water-use efficiency, and freezing resistance and tolerance. Preliminary results suggest that freezing tolerance and resistance differ among cytotypes and may be an important factor in seedling survival. Exposure to cold temperatures in May resulted in higher probabilities of mortality in diploid basin big sagebrush and Wyoming big sagebrush. Tetraploid basin and mountain populations demonstrated higher survival rates relative to their diploid counterparts, providing further evidence ploidy level influences seedling stress responses. These findings indicate the importance of understanding climate responses of different subspecies and cytotypes when establishing seed zones for big sagebrush restoration.

Publications

Brabec, M.; Germino, M. J.; Richardson, B. [Submitted February 2015]. Intraspecific variation in big sagebrush seedling responses to post-fire weather indicate importance of minimum temperatures to establishment. *Journal of Applied Ecology*. (*Paper submitted to the journal, but not yet accepted*).

Brabec, M.; Germino, M. J. [Submitted February 2015]. Experimental warming supports importance of minimum temperature to post-fire establishment. *Ecosphere*. (*Paper submitted to the journal, but not yet accepted*).

Brabec, M.; Germino, M.; Shinneman, D.; Pilliod, D. S.; McIlroy, S.; Arkle, R. S. [Submitted February 2015]. Response of young sagebrush seedlings to management treatments of herbs. *Rangeland Ecology and Management*. (*Paper submitted to the journal, but not yet accepted*).

Brabec, Martha. 2014. Big sagebrush in a shifting climate context: assessment of seedling responses to climate. Boise, ID: Boise State University. 95 p. Thesis.

Additional Products

We procured additional, leveraged funding for the management-treatment aspects of this project from the U. S. Fish and Wildlife Service contributions to the Great Basin Landscape Conservation Cooperative.

This research was made possible by cooperative efforts from D. Shinneman, R. Arkle, D. Pilliod, and S. McIlroy of the U. S. Geological Survey, Boise, ID; volunteer planting crews via Mary Dudley and Mike Young, Idaho Department of Fish and Game, University of Idaho class involvement for help in data collection through Beth Newingham, and supplementary funding from the Great Basin Landscape Conservation Cooperative.

Project Title Species and Population-level Variation in Germination Strategies of Cold Desert Forbs

Project Agreement No. 13-JV-11221632-080

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Project Description

Background

There is an increasing interest in the restoration of degraded sagebrush communities that lack a native, herbaceous understory. Native forbs are not only desired for their value to wildlife, but also for their potential to suppress annual invaders, such as cheatgrass. Currently, there is a lack of knowledge regarding the germination strategies of many cold desert forbs, making it difficult for land managers to successfully incorporate herbaceous species into their restoration protocols.

Increasing our knowledge of species specific germination strategies of native forbs can inform seed increase protocols, the choice of restoration species in different areas, and the relative importance of local seed sourcing for different species. The seed germination of forbs can be more challenging than germination of many grasses, and exposing forb seeds to their preferred dormancy breaking conditions can dramatically increase their germination success. In addition, different species express different amounts of within-species variation in germination cues, which may positively correlate with the importance of local seed sourcing for a species.

Objectives

The objective of this project was to assess the germination strategies of ten cold desert forbs, including identifying their dominant germination strategy and their level of within-species variation in germination cues. We determined seed germination requirements for some common species that have not yet been studied and identified species that possess high levels of seed dormancy.



Figure 1. Photos of plants and seeds of annual forbs included in the germination experiment
A) *Blepharipappus scaber* B) *Collinsia parviflora* C) *Cryptantha pterocarya* D) *Gilia inconspicua*
E) *Mentzelia albicaulis* F) *Microsteris gracilis*



Figure 2. Photos of plants and seeds of perennial forbs included in the germination experiment
A) *Agoseris grandiflora* B) *Chaenactis douglasii* C) *Crepis intermedia* D) *Phacelia hastata*

Methods

This study focused on 10 species of annual and short-lived native forbs that are commonly found in sagebrush steppe ecosystems and are of interest due to their potential importance as a food source for sage-grouse during early life stages (Figure 1 and Figure 2).

Seeds were collected from multiple populations in the vicinity of Reno, NV and Carson City, NV in the spring and summer of 2013. Seeds were placed in petri dishes on wet germination paper, and treatments varied after-ripening temperatures (either room temperature or 40°C) and exposure to wet, cold conditions (2°C for 0, 2, 4, or 6 weeks) before placement in a moderate (15°C) temperature in a factorial design, with each treatment replicated in five dishes. These treatments were designed to determine if seeds require warm or cold temperatures to break dormancy, which are both common dormancy mechanisms in desert plants. The *Survival* package within Program R (2.12.2) was used to perform survival analysis using the germination data.

Results

Species varied in preference for after-ripening temperature and cold stratification (Figure 3). Hot after-ripening stimulated earlier germination in *A. grandiflora*, *M. gracilis*, and *P. hastata*; however, the total number of germinated seeds did not differ between after-ripening treatments. Cool after-ripening resulted in both earlier and higher total number of germinated seeds for *C. douglasii*. Species with high levels of germination during cold stratification (potential fall germinators) included *A. grandiflora*, *B. scaber*, *C. parviflora*, *C. pterocarya*, and *M. gracilis*. Other species germinated best in warmer temperatures after exposure to cold, including *B. scaber*, *C. douglasii*, *C. intermedia*, and *P. hastata*. Those that germinated best when placed directly into 15°C included *M. albicaulis* and *G. inconspicua*.

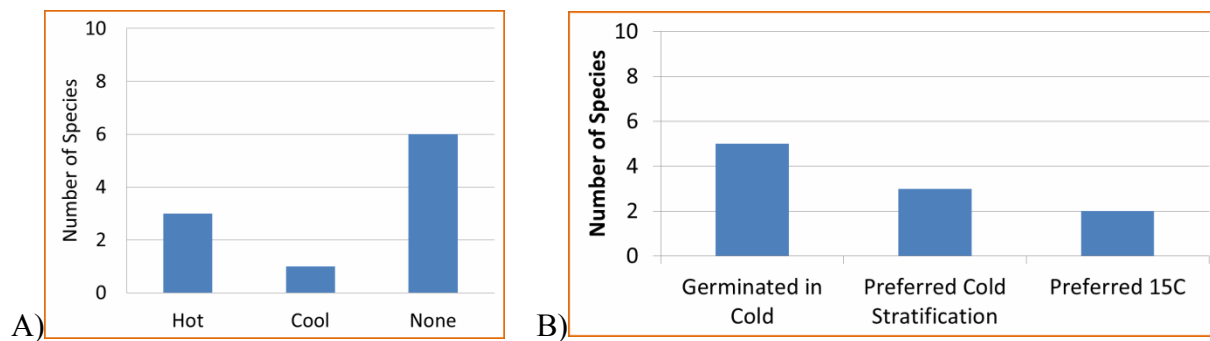


Figure 3. Histograms of species preferences for A) after-ripening temperature and B) cold stratification.

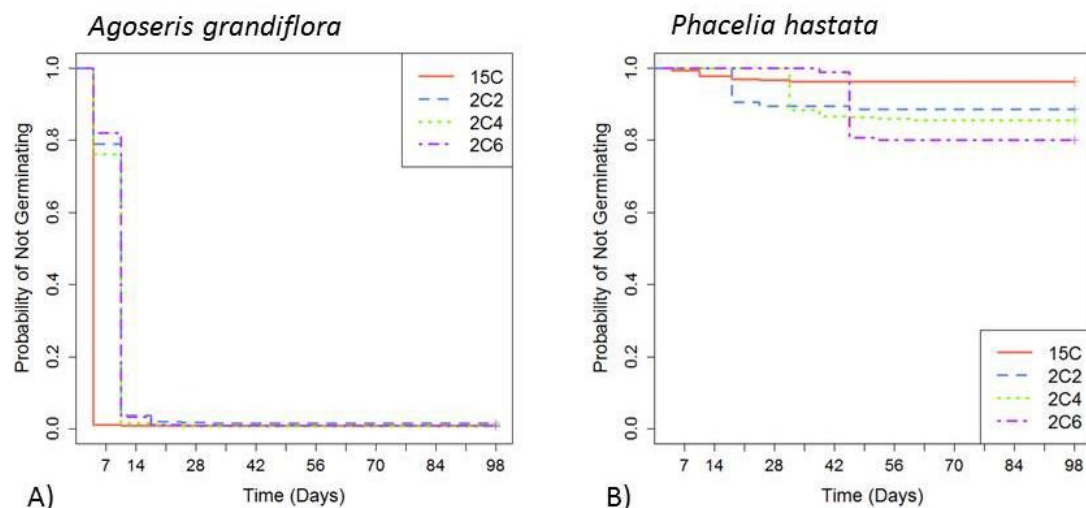


Figure 4. Examples of survival analysis using the results of cold stratification for A) a generalist species and B) a species with high dormancy. As the colored lines fall from left to right, they indicate an increase in total seed germination with time.

Survival analysis compares differences in both the timing of germination and the overall quantity of germinated seeds based on different treatments (Figure 4). This analysis method allowed for identification of generalist species (*A. grandiflora*, *C. parviflora*, *C. pterocarya*, and *M. gracilis*) that germinate under a broad range of conditions and others that possess high levels of dormancy, including *G. inconspicua*, *M. albicaulis*, and *P. hastata* (Figure 4). While seed dormancy is a strategy that can increase plant fitness over longer time scales, it can be undesirable when restoration outcomes depend on seed germination over shorter time scales. We also identified population level differences in germination strategies for all species; although some differences were more dramatic than others (Figure 5).

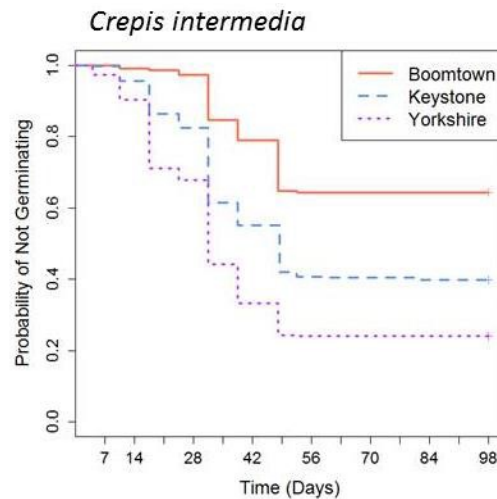


Figure 5. Example of survival analysis showing dramatic population-level difference for *C. intermedia*.

Table 1. Species specific details for the results of the survival analyses for key treatments.

Species	After Ripening (Hot/Cool)	Germinated in Cold	Population Differences	Number of Populations	Number of seeds	Annual or Perennial
<i>Agoseris grandiflora</i>	Hot	Yes	Yes	3	2400	Perennial
<i>Blepharipappus scaber</i>	None	Yes	Yes	2	1600	Annual
<i>Chaenactis douglasii</i>	Cool	No	Yes	3	2400	Perennial
<i>Collinsia parviflora</i>	None	Yes	Yes	3	1800	Annual
<i>Crepis intermedia</i>	None	No	Yes	3	2200	Perennial
<i>Cryptantha pterocarya</i>	None	Yes	Yes	3	1300	Annual
<i>Gilia inconspicua</i>	None	No	Yes	3	2200	Annual
<i>Mentzelia albicaulis</i>	None	No	Yes	3	2400	Annual
<i>Microsteris gracilis</i>	Hot	Yes	Yes	3	800	Annual
<i>Phacelia hastata</i>	Hot	No	Yes	3	1400	Perennial

Conclusions

Our ten focal species represented a variety of germination strategies (Table 1). We identified some species as facultative winter germinators, if they germinated in cold temperatures. We also identified summer germinators as those that germinated best in 15°C, although some required cold stratification to achieve optimum germination. We found that all species exhibited population level differences in their germination strategies, indicating that seeds may possess germination strategies that are closely associated with the environmental conditions at their collection location. We are also in the process of assessing what additional environmental cues might break dormancy in species expressing high levels of dormancy in this experiment, including the addition of soil and smoke treatments.

Our current research aims to identify which environmental characteristics drive variation within a species. We are quantifying the level of within-species variation that exists for each species using our survival analyses. We will then determine if higher levels of variation in different environmental variables, such as precipitation and climate water deficit over the range of a species, are correlated with increased population variation in germination requirements. In a related project, we are also exploring how variation in type and quantity of disturbance can affect seed bank dynamics of understory forbs in sagebrush steppe ecosystems.

Management Applications

Screening plants for their ability to tolerate a variety of field growing conditions will provide seed developers with promising species to add to production fields. Further, knowledge about species-specific germination preferences and seeding techniques will help managers identify methods for incorporating native forbs into restoration protocols. This work will provide information on how to germinate species of interest for improving sage-grouse nesting habitat, and has the potential to improve recruitment success in areas where food resources are limiting for chick development.

Presentations

Barga, S.; Leger, E. A. Species and Population-Level Variation in Germination Strategies of Cold Desert Forbs. Oral presentation at the Ecological Society of America 99th Annual Meeting, 2014 August 10-15; Sacramento, CA.

Barga, S.; Leger, E. A. 2013. Germination Ecology of Great Basin Forbs. Poster presentation at the Great Basin Consortium Annual Meeting, 2013 December 9-10; Reno, NV.

Project Title Dynamics of cold hardiness accumulation and loss in Sulphur-flower buckwheat (*Eriogonum umbellatum*)

Project Agreement No. 13-JV-11221632-066

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Project Description

Objectives

Cold hardiness, defined as the capacity of a plant tissue to survive exposure to freezing temperatures, is variable across species geographic distribution and annual seasonality. It is a well-known indicator of species tolerance and distribution ranges and limits. This is an important factor to consider in Great Basin restoration work as diurnal and seasonal temperature fluctuations within the region can be extreme. Knowing where the thresholds of temperature tolerances lie within individual species is a key component in determining population and regional potential for restoration success.

The current research goals are to provide a streamlined strategy for plant producers and restoration specialists in the Great Basin to test cold hardiness of forb species and specific genetic sources in an effort to provide better guidelines for developing and testing seed zones, as

well as producing a greater understanding of the influence of changing climatic conditions on plant populations. Using common and valuable candidate Great Basin species, we are working with public and private collaborators to build a short guide to cold hardiness. This will greatly enhance our ability to both understand the role cold temperatures play in native plant establishment following planting, as well as potential implications of changing climatic conditions for restoration in the Great Basin.

Materials and Methods

Sulphur-flower buckwheat (*Eriogonum umbellatum*) is a common, native, valuable subshrub whose natural range covers much of the Great Basin region. It has been selected for initial investigation to help provide the basis for understanding seasonal cold tolerance accumulation and loss within Great Basin native species.

In the fall of 2006 a sulphur-flower buckwheat common garden consisting of seventeen distinct populations was established in Boise, ID (Figure 1). In October 2013, five accessions of the surviving populations were selected as representatives for the species geographic distribution (Table 1). From these five specific accessions, we examined different aspects of the species, including geographical range, longitudinal seed production, seed zones, ecoregions, and elevational and longitudinal gradients. A sixth population component was also added to the study. This sixth component was designed to include one original wildland collection site from the five selected accessions growing in the common garden to evaluate localized effects on populations.



Figure 1. Sulphur-flower buckwheat common garden located in Boise, ID.

Table 1. Sulphur-flower buckwheat population site details.

Accession	County	State	Elevation (meters)	Omernik Level III Ecoregion	Omernik Level IV Ecoregion
ERUM 01 (M)	Boise	Idaho	964	16 - Idaho Batholith	16k - Southern Forested Mountains
ERUM 13 (J)	Malheur	Oregon	855	80 - Northern Basin & Range	80f - Owyhee Uplands & Canyons
ERUM 25 (B)	Elko	Nevada	1856	13 - Central Basin & Range	13m - Upper Humboldt Plains
ERUM 36 (C)	Elmore	Idaho	1607	12 - Snake River Plain	12f - Semiarid Foothills
ERUM 37 (W)	Box Elder	Utah	1385	19 - Wasatch and Uinta Mountains	19f - Semiarid Foothills

The freeze-induced electrolyte leakage (FIEL) technique was deployed to evaluate the cold tolerance of leaf tissue samples. Index of injury, that is the relative amount of electrolytes leaked, was calculated across a range of temperatures and used to determine LT₅₀ values. LT₅₀, the temperature at which 50% of cell damage occurs, was selected as the basis of population comparison. Tissue samples were collected from the field across an entire calendar year, starting in October 2013 on a 6 week cycle. Nine sets of samples were collected and processed to complete the year. All samples were transported to Moscow, ID for processing at the University of Idaho Seedling Quality Assessment laboratory. Sample collection and processing all took place within 48 hours.

Results and Discussion

All field collections and sample processing has been completed. Statistical models are currently being designed to calculate LT₅₀ values based on fitting 3-parameter Weibull curves. Initial results are showing geographic and seasonal differences among accessions. October 2013 data shows a difference of 9°C across population LT₅₀ levels (Figure 2). Figure 3 shows the 3-parameter Weibull fitted curves for five September 2013 plant replications of population ERUM 01 (M).

Future Plans

The remaining tissue samples from field collections not used in the FIEL tests have been oven dried, organized, and stored with the future potential to further investigate cold tolerance acclimation and loss via carbohydrate analysis or other means. These types of analysis are not time sensitive and can be completed at any future date. Interest in further investigation will be based on the results from the FIEL work.

A Master's thesis and journal publications are expected to come out of this work in the next year.

Management Applications and/or Seed Production Guidelines

The techniques from this work can easily be deployed to other species. Upon further investigation on plant materials across geographic distributions, we will be able to determine the degree to which cold hardiness results can be extrapolated and applied across species and populations. The project will provide a streamlined strategy for plant producers and restoration specialists in the Great Basin to test cold hardiness of native species, particular genetic sources,

and other plant materials in an effort to provide better guidelines for developing and testing seed zones, as well as a greater understanding of the influence of changing climatic conditions on plant distributions. In order to fill major knowledge gaps, there is a definite need for further developed guidelines on cold hardiness.

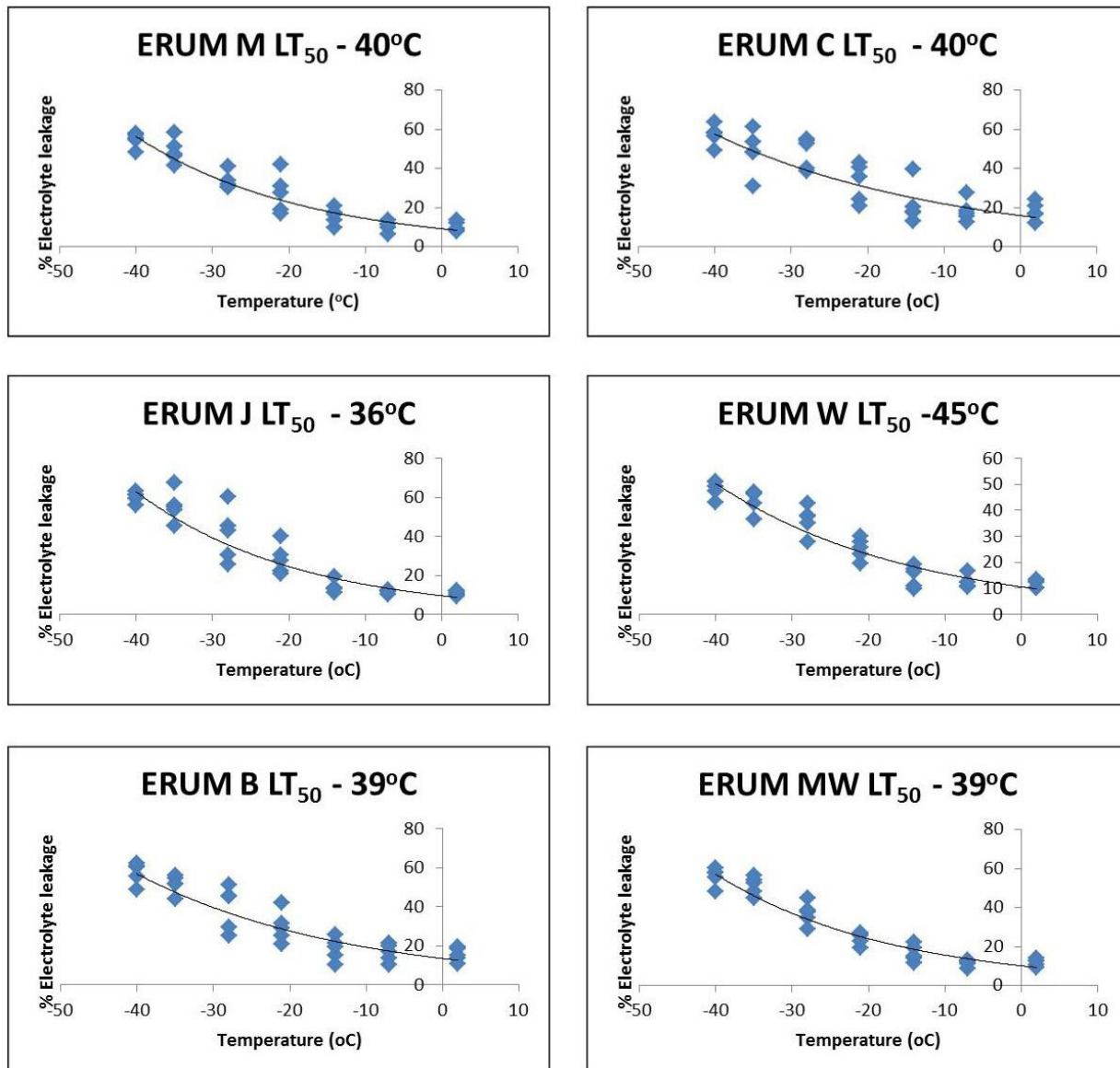


Figure 2. Percent electrolyte leakage across temperatures for five distinct Sulphur-flower buckwheat populations and one wildland collection site.

September 2013 Weibull Curve Model
for Population ERUM 01 (M)

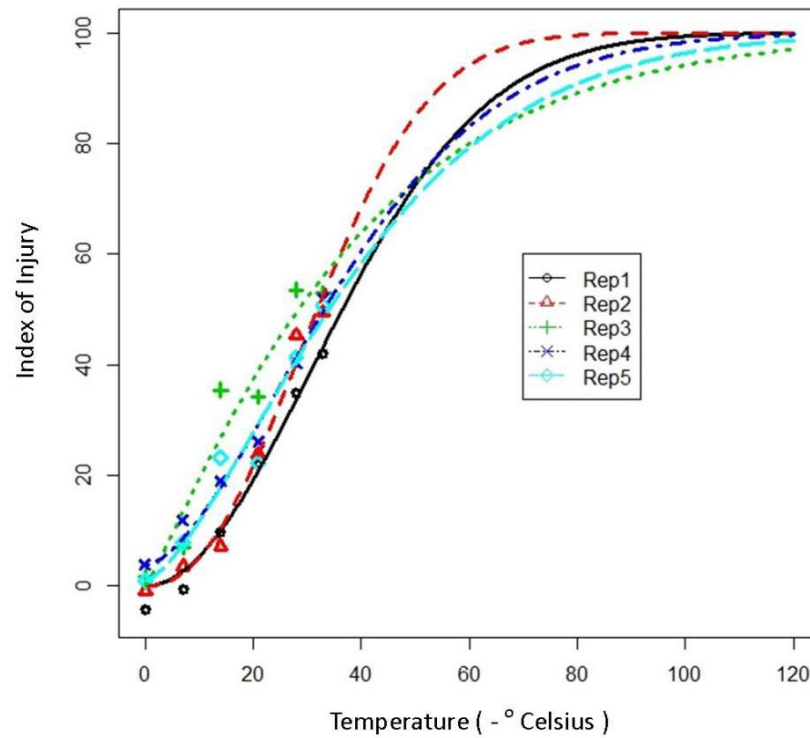


Figure 3. 3-parameter Weibull fitted curves for five September 2013 sulphur-flower buckwheat replications from accession ERUM 01 (M) used to calculate LT_{50} of -40° Celsius.

Presentations

Davis, A. S.; J. R. Pinto; Dumroese, R. K. The Target Plant Concept: case studies in improving restoration success. IUFRO World Congress, USA Booth; 2014 October 9; Salt Lake City, UT. Invited.

Davis, A. S.; Pinto, J. R. Using the target plant concept to improve dryland restoration success. Society for Ecological Restoration: Northwest and Great Basin joint meeting; 2014 October 8; Redmond, OR. Invited.

Fisk, M. R.; Pete, K. W.; Apostol, K. G.; Davis, A. S. Dynamics of Germination and Cold Hardiness for Great Basin Native Plants (*Eriogonum umbellatum*). Great Basin Native Plant Project Annual Meeting; 2014 September 17-18; Boise, ID. Invited.

Fisk, M. R.; Pete, K. W.; Apostol, K. G.; Pinto, J. R.; Dumroese, R. K.; Davis, A. S. Dynamics of Germination and Cold Hardiness for Great Basin Native Plants (*Eriogonum umbellatum*). The Latest & Greatest In Nursery Technology Joint Annual Meeting of The INC, WFCNA, And ICSGA; 2014 September 9-11; Boise, ID. Invited.

Pete, K.; Fisk, M. R.; Pinto, J. R.; Davis, A. S. Germination Characteristics of Northern Great Basin (*Eriogonum umbellatum*). American Indian Science and Engineering Society National Conference; November 13-15; 2014; Orlando, FL.

Moderator

Fisk, M. R. Re-establishing Big Sagebrush: Integration of Planting Stock to Leverage Restoration Success Session, Society for Ecological Restoration, Northwest & Great Basin Joint Regional Conference, October 6-10; 2014; Redmond, OR. Invited.

Instructor

Fisk, M. R. Seed Collection for Restoration and Conservation Training; National Training Center Course 1730-06; 2014 May 13-15; Boise, ID. Invited.

Fisk, M. R. Freeze Induced Electrolyte Leakage Training. 2014 February 23-28; Hilo, HI. Invited.

Exhibitor

Native Wildflower Seed Production Field Day. Ontario, OR. Great Basin Native Plant Selection and Increase Project; 2014 May 15; Ontario, OR.

Project Title Community Structure of Arbuscular Mycorrhizal Fungi Colonizing Wyoming Big Sagebrush Seedlings

Project Agreement No. 10-JV-11221632-062

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Project Description

Introduction

Arbuscular mycorrhizal fungi (AMF) are obligate biotrophs that obtain organic carbon from the host plant and in return facilitate nutrient uptake (Smith et al. 2010). Other effects of mycorrhizae on plants have received less attention, but there is evidence that mycorrhizae can enhance tolerance to drought (Finley 2008; Auge 2001; Jayne and Quigley 2014), and pathogens (Azcon-Aguilar and Barea 1996; Lindermann 2000). All AMF belong to the fungal phylum Glomeromycota, which comprises four orders and includes 200 described morphospecies (Redecker et al. 2013). However, molecular studies indicate that the number of morphospecies might vastly underestimate the true Glomeromycota diversity (Redecker and Raab 2006). AMF have low host specificity; a particular AMF species can colonize many plant species. Yet, the effects of AMF on nutrient uptake and plant growth vary depending on the fungal/plant genotype involved in the association and can range from parasitic to mutualistic (Klironomos 2003; Jones and Smith 2004). The differential growth responses that result from specific plant/AM symbiosis appear to play a major role in determining seedling establishment and plant community composition (van der Heijden et al. 1998; van der Heijden et al. 2008).

Host plant preferences and variation in the abiotic environment can affect the composition of AMF assemblages (Bell et al. 2009; Torrecillas et al. 2012; Busby et al. 2013). In addition, inoculation of seedlings can alter the AMF taxa present in the roots after transplanting (Mummey et al. 2009). Results described in more detail in a previous report (Serpe and Davidson 2013) showed that inoculation of sagebrush seedlings with native AMF increased colonization of sagebrush seedlings over the levels naturally occurring in the soil. Moreover, the increase in

colonization was associated with an increase in seedling establishment. This increase in establishment may be simply related to higher rates of colonization, but could also reflect difference in the AMF taxa colonizing the roots. The AMF taxa used for inoculation were native to a sagebrush habitat, but the inoculum was developed from soil collected at only one site. This inoculum was introduced into a new site in one of the experiments, which could have led to differences in AMF composition between non-inoculated and inoculated seedlings. Furthermore, multiplication of AMF for the production of inoculum can change the AMF community (Sykorova et al. 2007; Carter et al. 2014). To assess the effect of inoculation on the AMF taxa colonizing the roots, the same samples that were used to determine colonization were analyzed for AMF community composition using molecular methods. An additional motivation for these analyses was to characterize the diversity of AMF taxa present in sagebrush seedlings and to investigate possible seasonal changes in AMF.

Objectives

- 1) Determine whether pre-inoculation with native AMF alters the structure of AMF communities colonizing Wyoming big sagebrush seedlings.
- 2) Gain knowledge of AMF taxa colonizing Wyoming big sagebrush seedlings.
- 3) Investigate possible seasonal changes in AMF taxa.

Methods

To produce mycorrhizal inoculum, sandy-loamy soil was collected from Kuna Butte, Idaho (43°26.161'N, 116°25.848'W). The AMF present in the soil were multiplied in pot cultures that were prepared as previously described using Sudan grass as a host (Carter et al. 2014). Wyoming big sagebrush seedlings were first grown in a greenhouse in sterilized soil (non-inoculated seedlings) or soil containing the mixture of native mycorrhizal species from the pot cultures (inoculated seedlings). Three-month old seedlings were transplanted outdoors to 24 L pots filled with soil from Kuna Butte or to a recently burned sagebrush habitat near Bigfoot Butte, ID (43°18'48.43"N, 116°21'48.57"W), within the Morely Nelson Snake River Birds of Prey NCA. Seedlings were transplanted to pots (mesocosm experiments) in the spring and fall of 2011 and to the burned site in the spring and fall of 2012. Samples for analyses of colonization and AMF community composition were collected approximately 4 and 7 months after spring and fall transplanting, respectively. These samples were stored at -20°C until used for DNA extraction, amplification, and cloning. The AMF taxa colonizing individual seedlings were identified based on phylogenetic analysis of sequences from the large subunit-D2 rDNA region (Mummey and Rillig 2007). Sequences were also grouped into operational taxonomic units (OTUs) with sequence similarities $\geq 94\%$ using the Mothur program (Schloss et al. 2009; Wang et al. 2011). Possible differences in AMF composition between non-inoculated and inoculated seedlings were analyzed using non-metric multidimensional scaling (NMDS). This analysis was also used to characterize variations in AMF communities among seasons or between shallow and deep roots. NMDS is an unconstrained ordination method that arranges communities according to their similarities in species composition (Minchin 1987).

Results and Discussion

Phylogenetic and Diversity Analyses

The phylogenetic analysis revealed that all the sequences obtained were in the order Glomerales (Figure 1). About 5% of these sequences belonged to the family Claroideoglomeraceae and the

rest to the Glomeraceae. Within the Claroideoglomeraceae, the analysis resolved two phylotypes, *Claroideoglomus I* and *II*. These sequences had less than 94% similarity with *Claroideoglomus claroideum*; but had up to 99% similarity with several published sequences of uncultured glomeromycetes (Mummey and Rillig 2007; Verbruggen et al. 2010; Carter et al. 2014). Within the Glomeraceae, the analysis resolved four phylotypes. Two phylotypes were within the *Glomus* genus and were designated *Glomus I* and *Glomus II*. Sequences within *Glomus I* clustered with *Glomus macrocarpum*. *Glomus II* was the phylotype with more sequences. A few of these sequences clustered with *Glomus microaggregatum*. However, the majority of the sequences within *Glomus II* did not cluster with known species, but showed high similarity with published sequences of uncultured and unnamed glomeromycetes (Mummey and Rillig 2007; Torrecillas et al. 2012; Carter et al. 2014). Sequences were also identified within the *Funneliformis* and *Rhizophagus* genera. The former clustered with sequences obtained from single spore of *F. mosseae* or isolates of *F. mossea*. Similarly, sequences within the *Rhizophagus* phylotype clustered with *Rhizophagus intraradices* or *R. irregularis*.

The phylotypes obtained by the Maximum Parsimony analysis were compared with results from pairwise distance analysis. There was a good agreement between the results of these analyses; a particular OTU was only present in one phylotype (Figure 1). On the other hand, all phylotypes included more than one OTU. The largest number of OTUs was detected in *Rhizophagus* followed by *Glomus II*; which had eight and seven OTUs, respectively. *Glomus II* included sequences showing pairwise differences of up to 22%. Considerable genetic variation was also observed in the other phylotypes. *Funneliformis*, *Glomus I*, and *Claroideoglomus I* and *II* contained 5, 4, 3, and 2 OTUs, respectively. Furthermore, pairwise differences within these phylotypes ranged from 12% in *Claroideoglomus II* to 25% in *Funneliformis*.

AMF Community Composition in Non-inoculated and Inoculated Seedlings

To evaluate whether inoculation altered the AMF community of the roots, we compared the richness and diversity of OTUs in non-inoculated and inoculated seedlings. Within a particular experiment, no differences were detected in the richness index (*S*) between non-inoculated and inoculated seedlings (Table 1). Among experiments, the average *S* values ranged from 3 to 5, indicating that most seedlings were colonized by AMF in more than one OTU. However, the Shannon index of diversity (*H'*) was much lower, suggesting the predominance of certain OTUs over others (Table 1). Like for *S*, the *H'* values did not differ among treatments, except for the spring field experiment. In this experiment, *H'* was somewhat higher in non-inoculated than inoculated seedlings.

Although richness and diversity were similar, the particular OTUs colonizing the roots could have been different among treatments. This possibility was analyzed by nonmetric multidimensional scaling. For both the mesocosm and field experiments, NMDS plots showed no significant differences between non-inoculated and inoculated treatments (Figure 2). In addition for the spring field experiment, we compared the AMF community of roots collected within the upper 20 cm of the soil with those collected below 30 cm. These communities showed little separation in the ordination space and their centroids were not significantly different ($p = 0.89$, data not shown).

Analysis of Seasonal Changes in the AMF Community

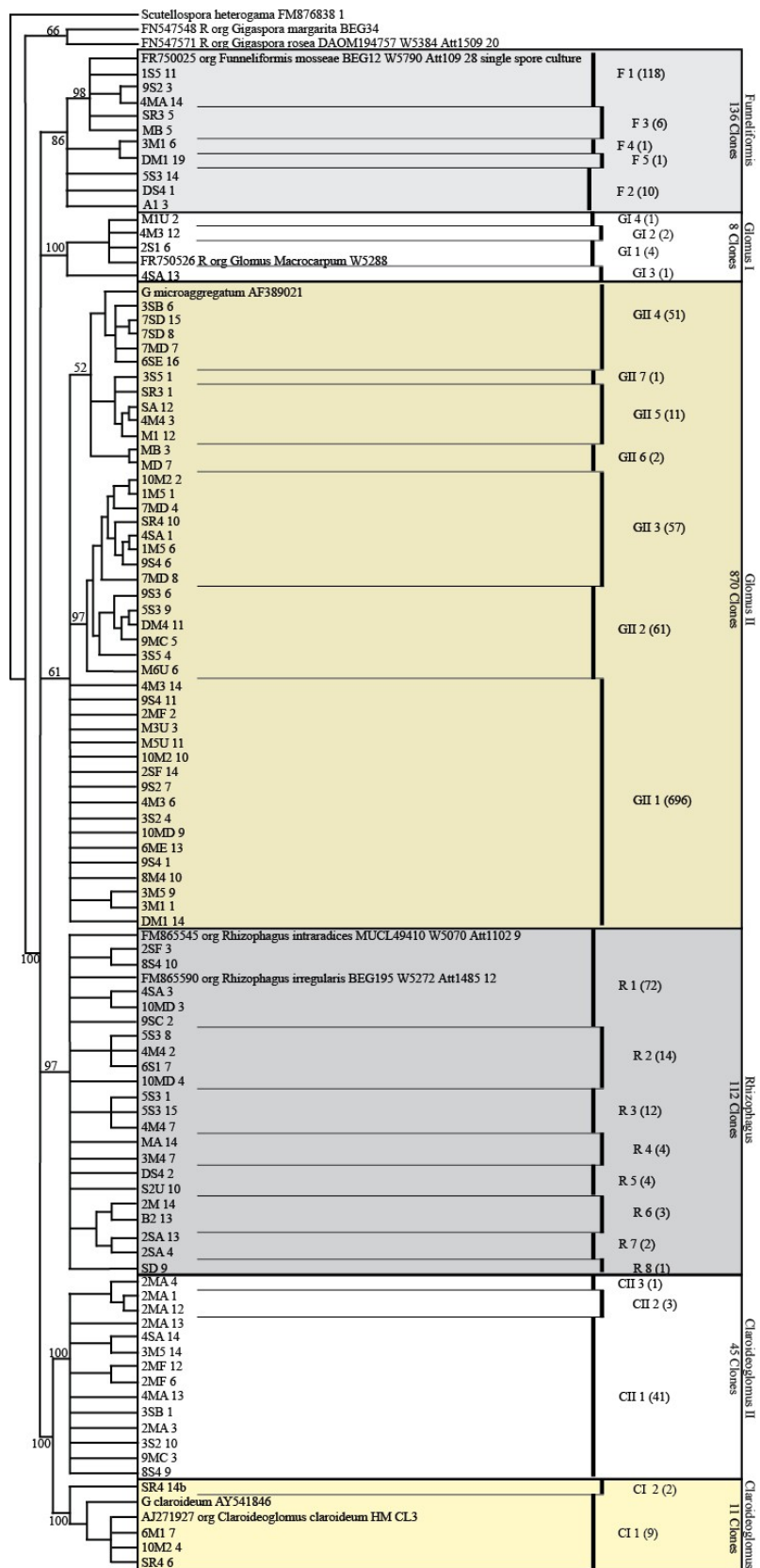
For the mesocosm and field experiments, we also compared the AMF communities of seedlings harvested during the summer (4 to 5 months after spring transplanting) to those harvested in early spring (7 to 8 months after fall transplanting). Seedlings from the mesocosm experiments showed more seasonal variation in their centroids than those from the field experiments (Figure 3, A and B). However, in both analyses the centroids were not significantly different with *p* values of 0.16 and 0.73 for the mesocosm and field experiments, respectively

Table 1. Richness (*S*) and Shannon-Wiener Diversity (*H'*) indices of AMF OTUs detected in roots of (*n*) individual sagebrush seedlings. Mean $\pm$ SE for each study. Within a particular experiment and transplanting time, values that differ significantly from the non-inoculated seedlings are indicated by an asterisk.

Experiment	Transplanting time	Treatment	n	Richness (<i>S</i>)	Diversity (<i>H'</i>)
Mesocosm	Spring	Non-inoculated	5	4.70 $\pm$ 1.20	1.21 $\pm$ 0.32
		Inoculated	5	5.00 $\pm$ 0.58	1.13 $\pm$ 0.09
	Fall	Non-inoculated	8	4.13 $\pm$ 0.72	0.95 $\pm$ 0.22
		Inoculated	8	3.40 $\pm$ 0.42	0.74 $\pm$ 0.14
Field	Spring	Non-inoculated	6	5.00 $\pm$ 0.52	0.96 $\pm$ 0.10
		Inoculated	6	3.83 $\pm$ 0.31	0.64 $\pm$ 0.07 *
	Fall	Non-inoculated	6	3.67 $\pm$ 0.56	0.82 $\pm$ 0.15
		Inoculated	6	2.83 $\pm$ 0.48	0.59 $\pm$ 0.17

The lack of significant differences in AMF communities between inoculation treatments, root depth, and seasons appeared to have been related to the predominance of certain OTUs. In all experiments and treatments, the most common OTU was *GII-1* (Figure 4). Overall this OTU was detected in 94% of the seedlings (Figure 4, E). Other OTUs that were present in relatively high frequency were *F1*, *GII-2*, and *R1*, which were detected in 54, 51, and 40% of the seedlings respectively. For these OTUs, similar patterns were in general observed in individual experiments (Figure 4, A-D). *Funneliformis 1* and *GII-2* were found in more than 50% of the seedlings in three of the four experiments, the exception was the fall 11 experiment, where only 18% and 31% of the seedlings had *F1* and *GII-2*, respectively. The fourth most abundant OTU, *R1*, showed more variation. In the mesocosm experiments (Figure 4, A and B), *R1* was found in at least half of the seedlings. In contrast, in the field experiments, *R1* was not detected in one of the treatments or it was found at low frequency on the other (Figure 4, C and D). Another major factor contributing to the dominance of certain OTUs over others was that several OTUs were only found in very few seedlings. Specifically, 15 of the 29 OTUs were detected in less than 5% of the seedlings and 10 of them in less than 2%. Thus, the overall contribution of these OTUs to the AMF community of sagebrush seedlings was probably nominal. Further work is needed to evaluate whether the differences in OTU abundance reflect preference by the host plant or differences in OTU frequencies within the soil.

Figure 1. Phylogenetic tree of representative Glomeromycota LSU-D2 rDNA sequences detected in this study with the FLR3/FLR4 primers and database sequences of known Glomeromycota. The values above the branches are bootstrap support values obtained by Maximum Parsimony analysis. Names on the right indicate the six phylotypes identified in the phylogenetic analysis. Smaller vertical lines within each phylotype indicate operational taxonomic units (OTUs) with a threshold level of 94% sequence similarity based on pairwise distance analysis.



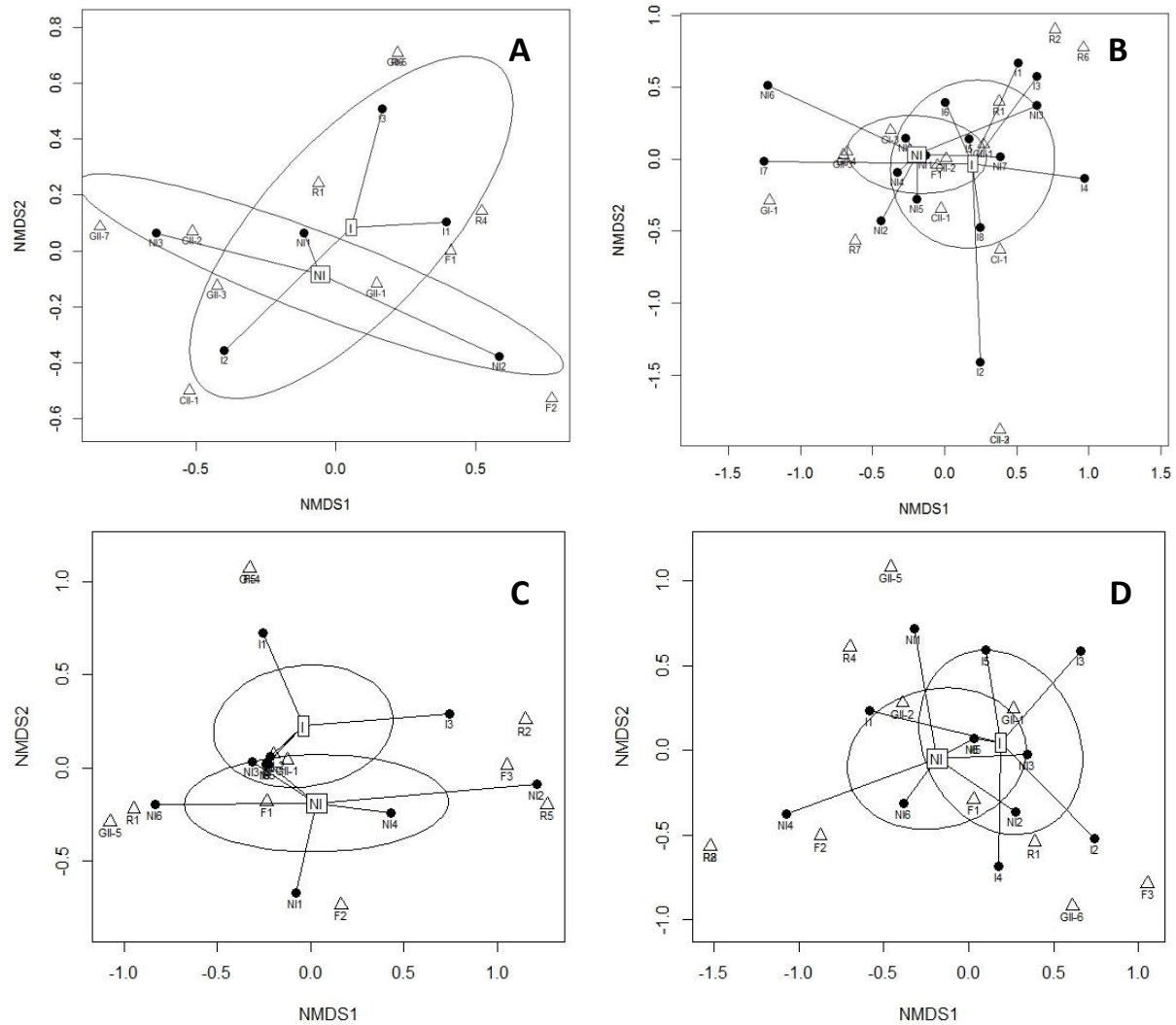


Figure 2. Comparison of arbuscular mycorrhizal communities of non-inoculated and inoculated seedlings by nonmetric multidimensional scaling. Samples of *Artemisia tridentata* seedlings were collected several months after transplanting in the spring (A) and fall (B) mesocosm experiments, and the spring (C) and fall (D) field experiments. OTUs are represented by open triangles and seedlings with filled circles. The centroids for the each treatment are labeled (NI, non-inoculated seedlings; I, inoculated seedlings) and linked to the samples that relate to them. Ellipses represent 95% confidence limits around the centroids of each variable. OTUs are labeled based on their phylotype (CI, *Claroideoglomus I*; CII, *Claroideoglomus II*; F, *Funnelformis*; GI, *Glomus I*; GII, *Glomus II*; R, *Rhizophagus*) and OTU number within its phylotype.

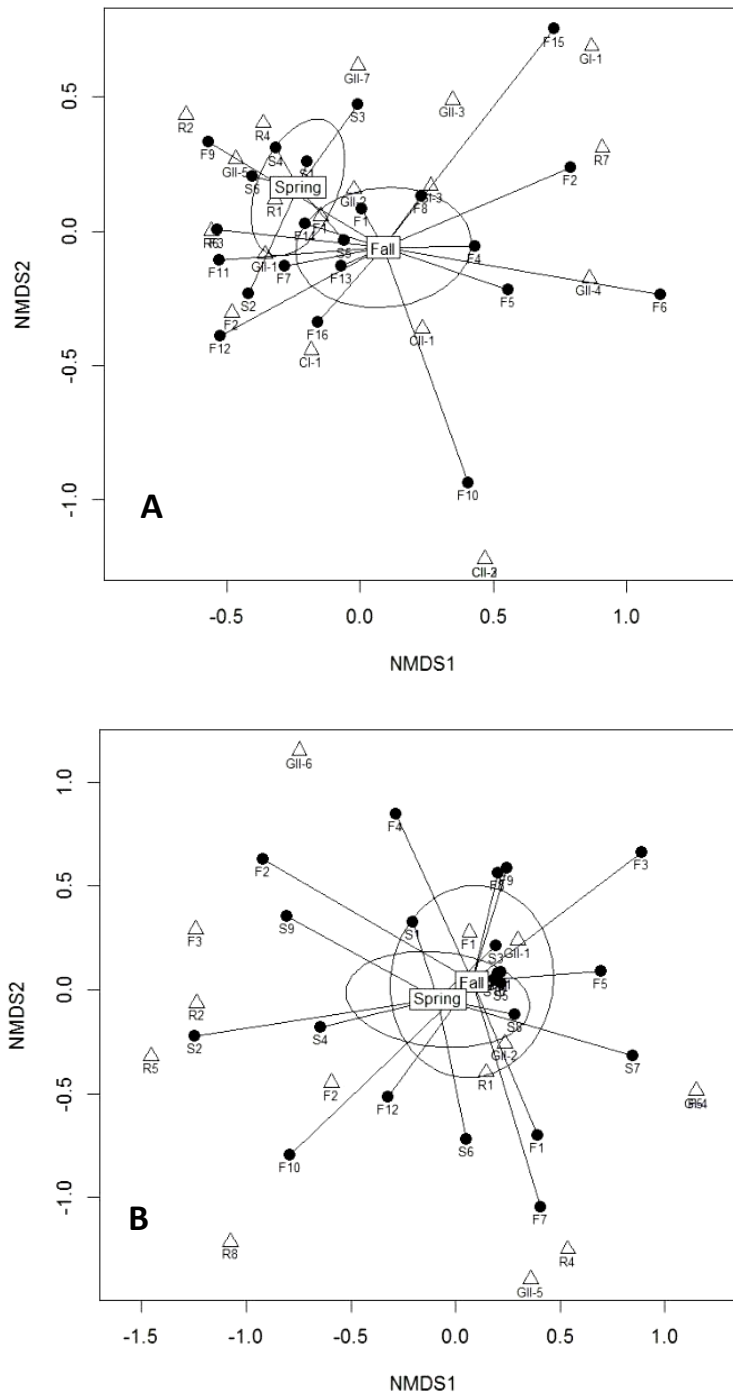


Figure 3. Analysis of seasonal changes in arbuscular mycorrhizal communities by nonmetric multidimensional scaling. (A) Mesocosm experiments, comparison of AMF communities in seedlings collected 5 and 8 months after spring and fall transplanting, respectively. (B) Field experiments, comparison of AMF communities in seedlings collected 4 and 8 months after spring and fall, respectively. OTUs are represented by open triangles and seedlings with filled circles. The centroids for each categorical variable are labeled and linked to the samples that relate to them. Ellipses represent 95% confident limits around the centroids of each variable.

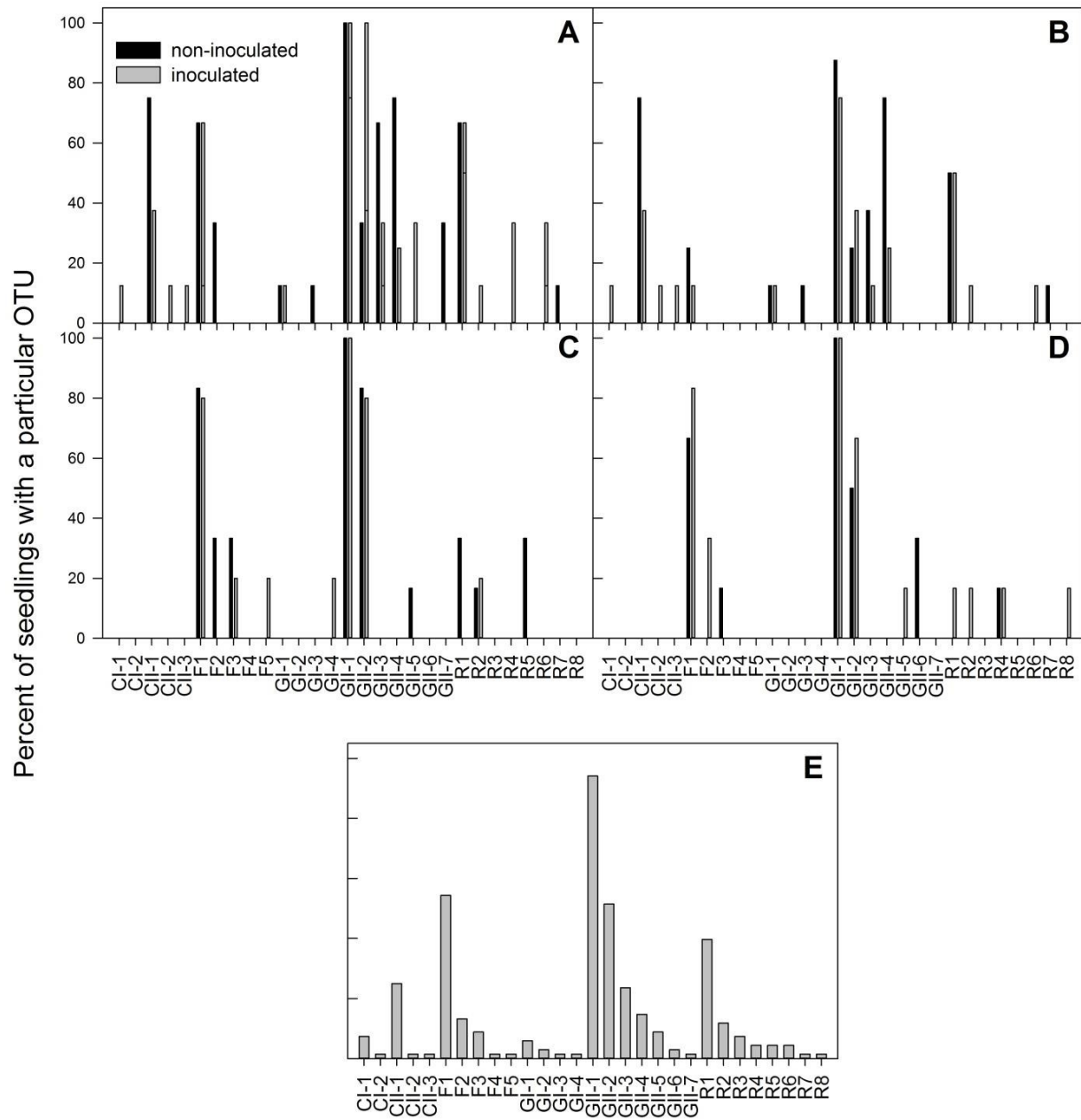


Figure 4. Percent of *Artemisia tridentata* seedlings colonized by different OTUs. Results from the spring (A) and fall (B) mesocosm experiments, and from the spring (C) and fall (D) field experiments. Overall frequencies observed after combining the results from all the seedlings analyzed (E).

Management Applications

Restoration projects often use seedlings that have been pre-inoculated with commercial and non-native mycorrhizae. This can alter the resident AMF community with potentially detrimental ecological consequences. In principle, alterations of the AMF community can also occur following inoculation with native AMF if the process of AMF multiplication favors certain taxa over others. The results obtained in this study indicate that a native AMF community was rather resilient to changes in composition during multiplication and subsequent inoculation. Consequently, this approach appears to be a feasible strategy for increasing AMF colonization of sagebrush seedlings without the risks associated with changing the AMF community. The dominance of a few taxa may also simplify the production of inoculum. Production of monospecific cultures of these taxa and subsequent mixing would allow the development of a more precise and uniform inoculum.

Acknowledgments

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Presentations

Serpe, M. D.; Davidson, B. E. Pre-inoculation of Wyoming big sagebrush seedlings with native arbuscular mycorrhizae: effects on mycorrhizal colonization and seedling survival after transplanting. Great Basin Native Plant Annual Meeting; 2014 March 17-18; Boise, ID.

Davidson, B. E.; Smith, J. F.; Serpe, M. D. Inoculation of *Artemisia tridentata* ssp. *wyomingensis* with arbuscular mycorrhizae: impacts on colonization and mycorrhizal composition of roots after transplanting. Botanical Society of America Conference; 2014 July 26-30; Boise, ID. Poster. .

Davidson, B. E.; Serpe, M. D. Inoculation of Wyoming big sagebrush seedlings with native arbuscular mycorrhizae: impacts on root colonization, mycorrhizal community composition, and seedling survival after transplanting. Society for Ecological Restoration Regional Conference, Northwest Great Basin Chapter. 2014; Redmond, OR.

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Project Title Smoke-induced Germination of Great Basin Native Forbs

Project Agreement No. 11-CR-11221632-005

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Project Description

Objectives

Determine responsiveness to smoke of several species native to the Great Basin and how that responsiveness varies by population.

Methods

Step one is to conduct a wide literature review of as many species as possible. Step two is to test as many species as possible to determine smoke response. Step three is to further investigate responsive species to determine whether smoke response varies by population by testing seeds from as many populations of the species in question as possible. Step four will be to develop seeding protocols for the most responsive species that include smoke treatments.

Results and Discussion

The literature review has been completed, and is now being organized by species. We are preparing portions of this literature review as a publication that will analyze seed/species characteristics as a method for predicting possible smoke response. We have now tested 19 species for smoke response, and are analyzing the results. Species tested are: *Achillea millefolium*, *Achnatherum hymenoides*, *Achnatherum thuberianum*, *Agoseris grandiflora*, *Artemisia tridentata*, *Atriplex canescens*, *Balsamorhiza hookeri*, *Balsamorhiza hirsutissima*, *Chrysothamnus nauseosus*, *Erigeron pumilus*, *Eriogonum heracleoides*, *Eriogonum umbellatum*, *Grayia spinosa*, *Lomatium dissectum*, *Lomatium grayi*, *Penstemon speciosus*, *Phacelia hastata*, *Poa secunda*, and *Pseudorognena spicata*.

Objectives

With this study we set out to improve our understanding of the impact of imazapic on forbs native to the sagebrush steppe ecosystem. Specifically we asked:

- How do different application rates (concentrations) affect forb performance?
- How does the timing of imazapic application relative to seeding of forbs impact forb performance?
- Does a fire-induced change in soil microbial activity mediate the impact of imazapic on soils?

Methods

To assess the impact of fire reduction treatments on the performance of native forb species, we conducted two greenhouse experiments in which we (1) applied a gradient of imazapic concentrations, and (2) varied the timing of application relative to seeding of *Astragalus filipes*, *Achillea millefolium*, and *Sphaeralcea grossularifolia* (Figure 1). Soils were collected in degraded-burned and unburned sagebrush ecosystems (0-10 cm depth) at the Morley Nelson Birds of Prey National Conservation Area. The soil was air-dried for 7 days, litter and roots were removed by using a 2mm sieve, and kept under dry conditions at 20-23°C until ready for planting.



Figure 1. Greenhouse experiment

A 15-day laboratory incubation with the soil was performed to confirm that the fire had altered microbial activity in the recently burned soil compared to the unburned soil. Soils from each treatment were placed in quart mason jars, then incubated in the dark for 15 days under controlled soil moisture (60% WHC) and temperature (20°C) conditions. Potential C decomposition rates were measured on days 1, 3, 5, 7 and 15 with a LI-7000 CO₂/H₂O analyzer (http://www.licor.com/env/products/gas_analysis/).

Both burned and unburned soils were transferred to pots (6.4 cm diameter and 12.7 cm depth) that were lined with a nylon sack (Figure 2). The nylon sack was filled with cleaned rocks and then sealed, after which the remainder of the pot was filled with 250g of soil. Soil was watered evenly to 60% water holding capacity.



Figure 2. Pot preparation

Imazapic Concentration Study

The imazapic concentration experiment was set up as a complete randomized block design (n=10) (Figure 4). Imazapic concentrations of 0, 2, 4 and 8 oz a. i. /acre were applied evenly to pots 2 weeks prior to planting forbs. Three sage-grouse preferred forbs *Achillea millefolium* (A. m.), *Astragalus filipes* (A. f), and *Sphaeralcea grossulariifolia* (S. g), were planted in pots for a controlled greenhouse experiment after the seeds were germinated according to their specific germination requirements

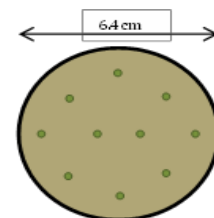


Figure 3. Seed spacing

(Table 1). The seeds were planted with equal spacing (Figure 3) and the pots were randomized every 3 weeks. Plants were grown at 15°C-25°C for 41 days. We measured height, maturity, emergence, and aboveground and belowground biomass on a biweekly basis. Data were analyzed using a Two-Way Analysis of Variance (ANOVA) in SPSS.

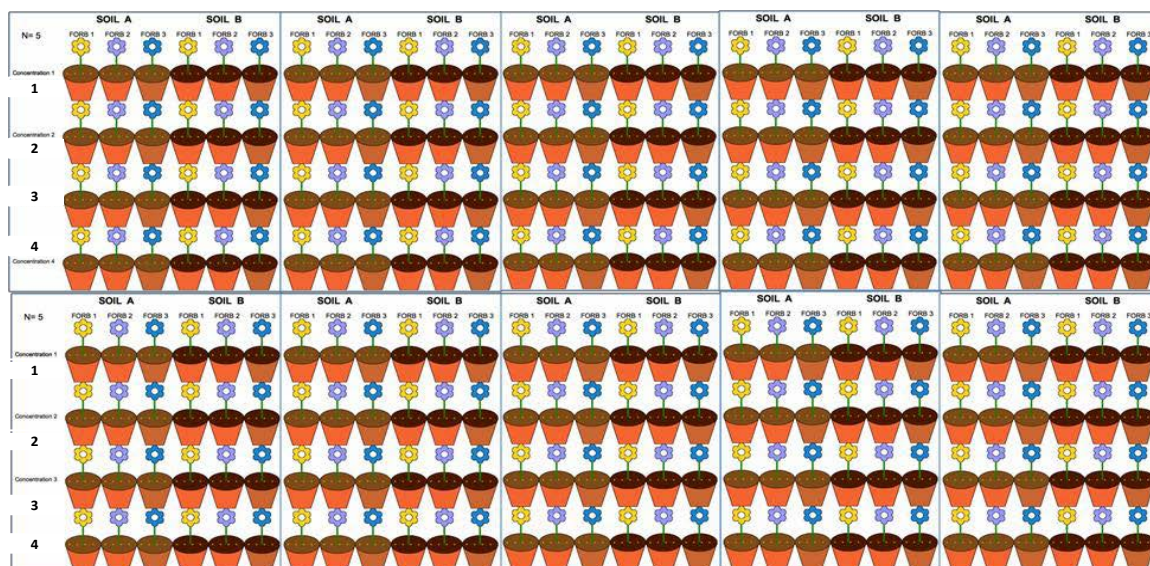


Figure 4. Complete randomized block design of imazapic impacts on forb performance greenhouse experiment. Soil A and B are unburned and burned soils, respectively. On each one of the soils, one of three forb species (*Astragalus filipes*, *Achillia millefolium*, *Sphaeralcea grossularifolia*) is planted. All are exposed to one of four imazapic concentrations (including a control treatment receiving water only).

Table 1. Germination protocol

Forb	Scarify	Stratify	Surface Sterilize	Plant depth
<i>Astragalus filipes</i>	220 grit sandpaper for 3 minutes (50 seeds X 8)	NO	NO	3. 5 mm
<i>Achillia millefolium</i>	NO	NO	NO	0 mm
<i>Sphaeralcea grossularifolia</i>	18 M H ₂ SO ₄ for 10 min (200 seeds X 4)	3/15/13- 4/29 Refrigerated (~5°C) in petri dishes on moist filter paper for 7 weeks	NO	6. 5 mm
<i>Bromus tectorum</i>	NO	NO	NO	Light dusting

Imazapic Application

The imazapic application timing experiment was a controlled greenhouse experiment. Burned and unburned soils were composited and transferred to pots in the above method. Imazapic

(4oz a. i. /acre) or water containing 1% mineral oil surfactant was added by spray to all of the pots. The above-mentioned forbs and *Bromus tectorum* (n=10) were then planted after 2, 4, 8, and 16 weeks in a pattern (represented in Figure 5). The plants were watered daily and kept at optimal conditions in the greenhouse. Soils waiting to be planted were maintained under the same conditions and watered three times weekly.

The plants grew for 41 days when the height was recorded and the foliage was then harvested for aboveground biomass. The plant matter was dried at 40°C for 24 hours and weighed to obtain aboveground biomass. The soils were frozen at -20°C until belowground biomass could be processed. At the time of processing the live roots were removed from the soil, washed and dried in the oven at 40°C for 24 hours. After drying, the roots were weighed to obtain belowground biomass. The differences were then analyzed using a Two-Way ANOVA in SPSS.

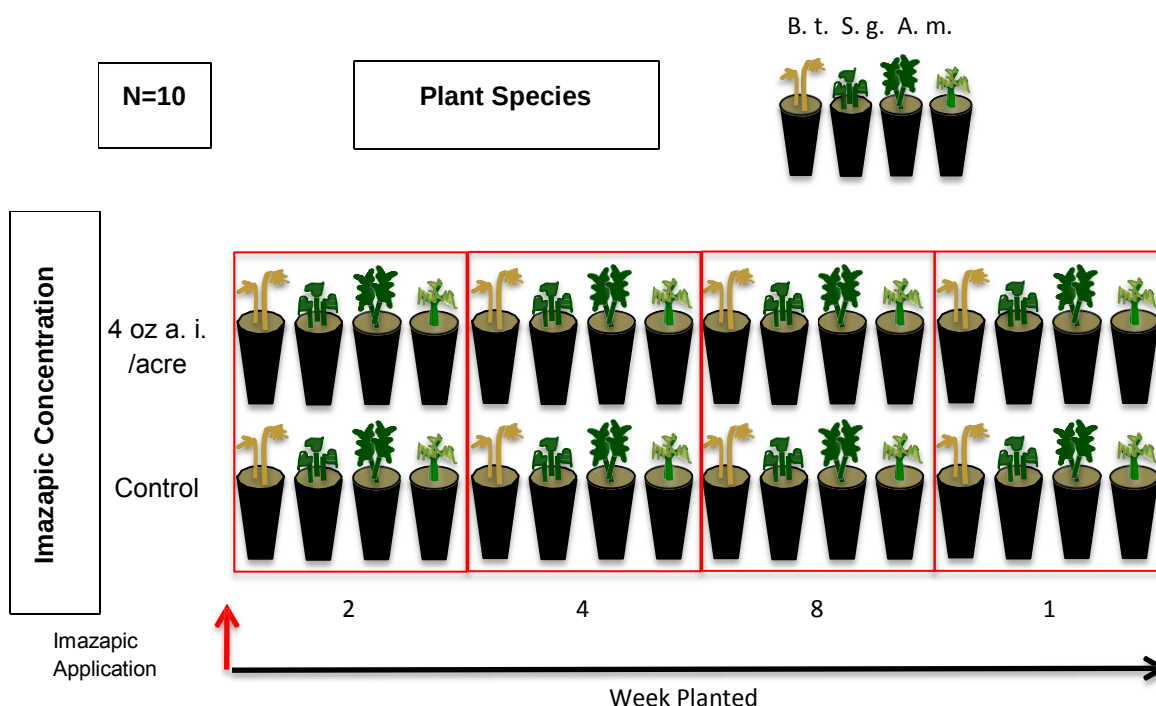


Figure 5. Experimental design for herbicide application timing impacts on forb performance.

Results and Discussion

Experiment 1: Impact of Herbicide Concentrations on Forb Performance

Burning significantly affected soil microbial activity ($p < 0.05$); recently burned soils had a greater content of labile C leading to greater resource availability for microbes and greater CO₂ respiration rates as compared to soils that were not burned (Figure 6). These data indicate that changes in the soil microbial community occurred following a fire and these changes may have altered decay rates of imazapic, hence its impact on forb performance. However, we found that imazapic application significantly suppressed biomass production for each of the species ($p < 0.05$, $n = 10$; Table 2), but that burning did not impact the response of forbs to imazapic applications.

The magnitude of the response to imazapic application differed among species. We calculated the response as the percent change in biomass production relative to the control (i.e. no imazapic application); where a greater response signifies a greater sensitivity of the forb to imazapic. The average response of above and belowground biomass production was significantly different ($p < 0.05$) across forb species ($n = 20$). Specifically, *Astragalus filipes* (A. f.) was affected by the herbicide the least ($n = 20$).

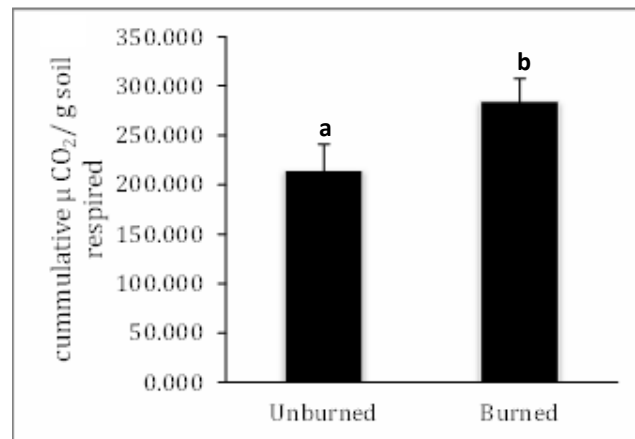


Figure 6. Impact of fire on soil microbial activity. Values are means + SE ($n = 5$). Different letters indicate significant differences in CO_2 respiration between burned and unburned soils.

Experiment 2: Impact of Timing of Imazapic Application Relative to Seeding on Forb Performance.

Since fire had no impact on imazapic effects on forb performance, we did not include the burned soils in the second greenhouse experiment. Instead, in this experiment we focused on the timing of imazapic application to forbs relative to seeding. In addition, we included cheatgrass to ascertain if any impacts of imazapic on forb performance also impact cheatgrass growth. For each one of the forbs, biomass production in soils not receiving imazapic was greater when plants were seeded into soil at a later date (Table 3). This results from the multiple irrigation events that promoted soil organic matter decomposition and the release of nutrients in soil over time. Our results further indicated that imazapic negatively impacted biomass production of forbs and cheatgrass regardless of application timing (Table 4).



Figure 8. Visual differences of forb species containing different concentrations of imazapic.

Interestingly, performance of *Astragalus filipes* was much less negatively impacted by imazapic across both experiments (Figure 8). *A. filipes* is a legume, whereas the others are not. These data indicate that legumes may be impacted less by imazapic applications than other plants functional types.

Conclusions

Imazapic significantly impacts forb performance, and burning did not mediate the impact of herbicide on forb performance. This suggests that imazapic is not specific to cheatgrass and that the use of imazapic could impact species diversity and essential sage-grouse preferred forbs. This information should be taken into account in future restoration projects.

Ongoing research funded by the Forest Service will assess whether imazapic impacted N mineralization in the soil. This may explain why performance of the legume was not affected by imazapic to the extent that the other forb species were.

Table 2. Total standing biomass (shoots + roots) at harvest for *Astragalus filipis*, *Achillea millefolium*, and *Sphaeralcea grossulariifolia*. Values are means + SE (n = 10). Significant differences within treatments are shown by different letters above the gaps ($p < 0.05$, $N = 10$).

Total Forb Biomass

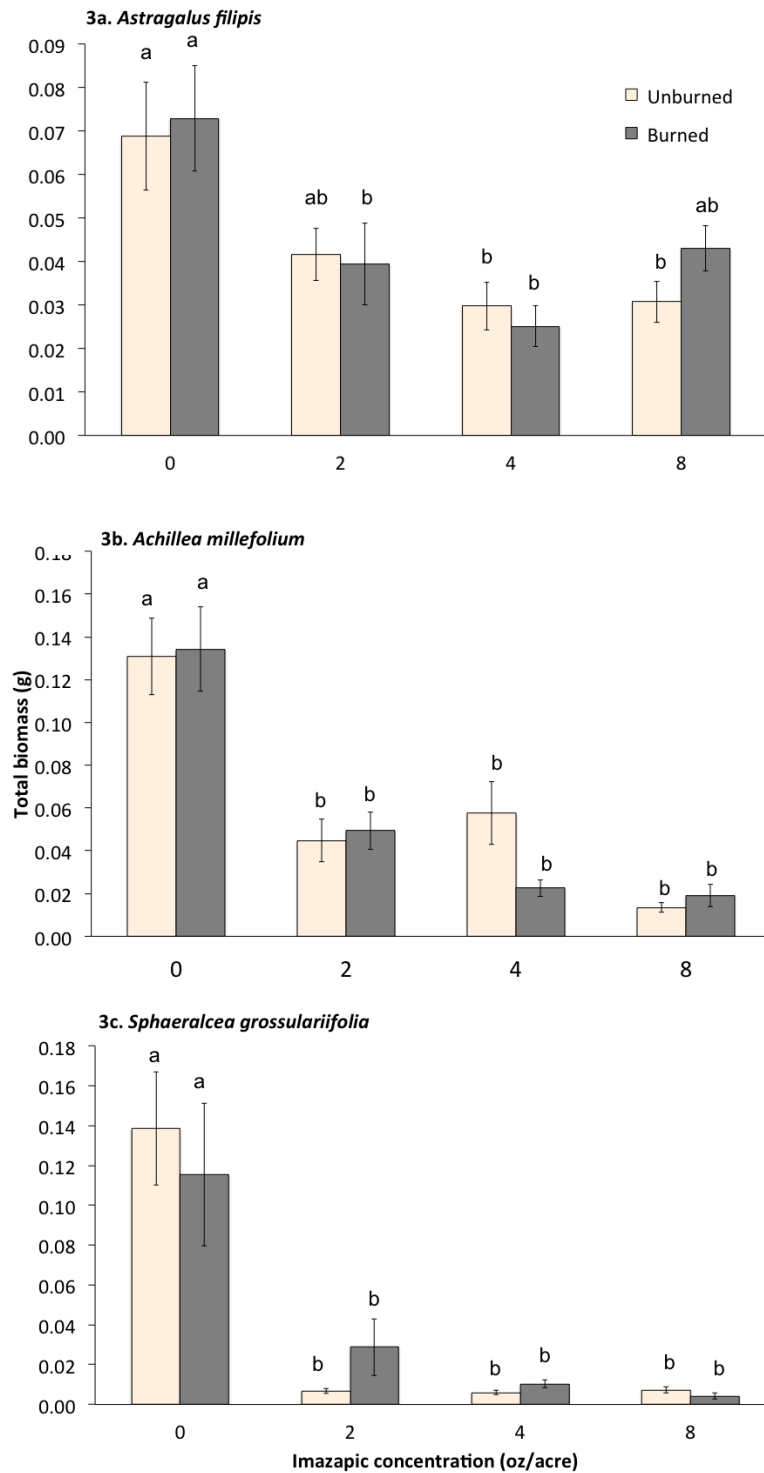


Table 3. Differences in the response to imazapic application among the three forbs. A. f. (*Astragalus filipes*), A. m. (*Achillea millefolium*), S. g. (*Sphaeralcea grossulariifolia*). Values are means + SE (n = 20). Different letters indicate significant differences in response to imazapic among forbs.

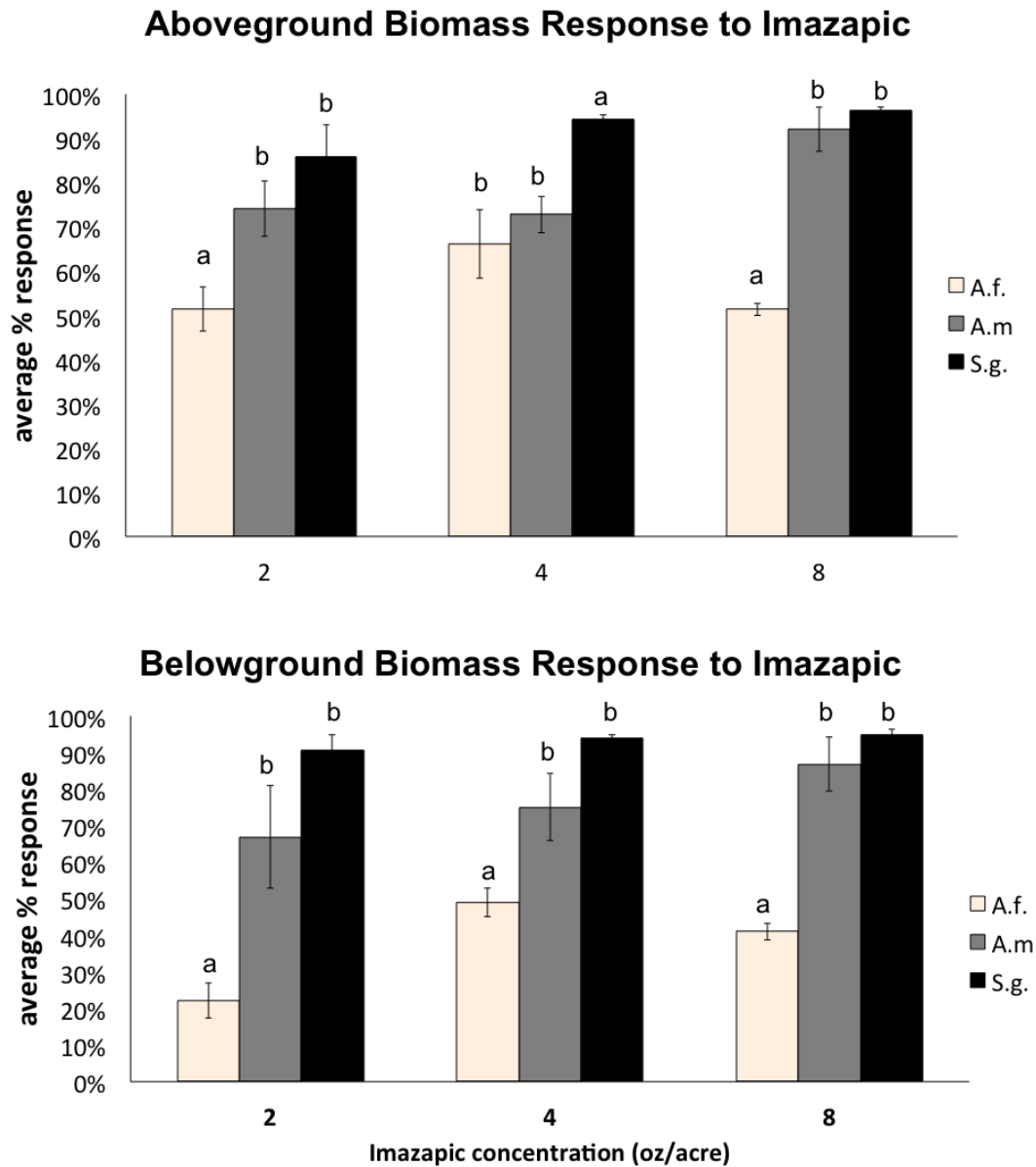
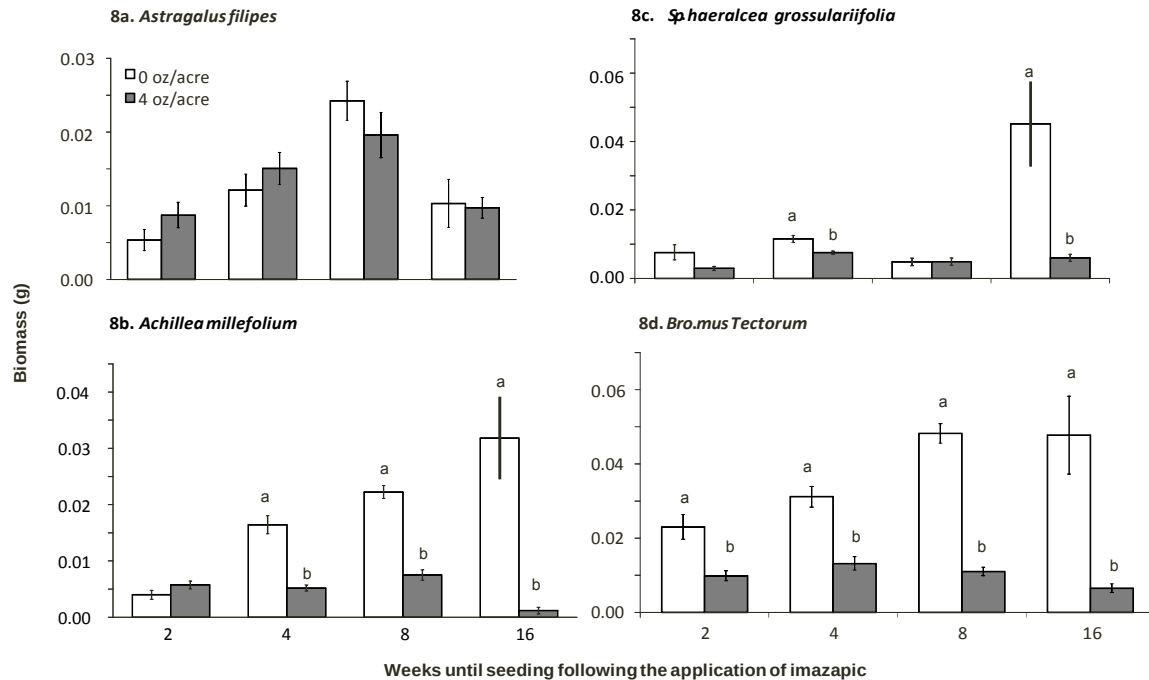


Table 4. Differences in the total biomass at different imazapic application times for *Astragalus filipes*, *Achillea millefolium*, *Sphaeralcea grossulariifolia*, and *Bromus tectorum*. Values are means + SE (n = 10). Different letters indicate significant differences in response to imazapic application between control and imazapic treatments.



Presentations

Johns, A.; de Graaff, M. A. Herbicide impacts on forb performance in degraded sagebrush steppe ecosystems. Society for Ecological Restoration Regional Conference, Northwest and Great Basin Chapters; 2014 October 6-10; Redmond, OR. Poster.

de Graaff, M. A. 2014. Herbicide impacts on forb performance in degraded sagebrush steppe ecosystems. Great Basin Native Plant Project Annual Meeting; 2014 March 17-18; Boise, ID.

Acknowledgements

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Project Title Increasing the Availability and Integration of Great Basin
Native Plant Project Tools for BLM Restoration
Practitioners

Project Agreement No. 13-IA-11221632-161

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Project Description

There is a critical need within the Bureau of Land Management (BLM) to step-up the integration and use of applied research tools and products that inform restoration of sagebrush-steppe systems. Key BLM and United States Forest Service (USFS) landscape planning efforts that are driving this immediate need include 1) the Greater Sage-Grouse Environmental Impact Statement (EIS) and commensurate plan amendments that will be required, and 2) the Fire and Invasive Assessment effort (FIAT) that identifies management strategies (Chambers et. al 2014) to reduce the habitat threats resulting from impacts of invasive annual grasses, wildfires and conifer expansion. In addition, in January 2015 Department of Interior Secretary, Sally Jewel, issued Secretarial Order 3336 (USDI 2015) that sets forth enhanced policies and strategies for preventing and suppressing rangeland fire and for restoring sagebrush landscapes impacted by fire across the West. One of the key sections of the order directs BLM to develop an enhanced fire prevention, suppression and restoration strategy. Sections germane to restoration include:

- Apply science and research to improve the identification and protection of resistant and resilient sagebrush-steppe landscapes and the development of biocontrols and other tools for cheatgrass control to improve capability for long-term restoration of sagebrush-steppe ecosystems.
- To the extent practicable, utilize locally-adapted seeds and native plant materials appropriate to the location, conditions, and management objectives for vegetation management and restoration activities, including strategic sourcing for acquiring, storing, and utilizing genetically appropriate seeds and other plant materials native to the sagebrush-steppe ecosystem.

For more than a decade, the Great Basin Native Plant Project has been at the forefront of addressing regionally relevant applied research questions that cover ecologically complex topics such as, genetics, climate change, native plant interactions, plant cultural practices, plant material development and restoration. To assist BLM in better integrating this knowledge and use of available tools we have been working with our partners and BLM Botanists and Natural Resource Specialists throughout Idaho, Oregon, Nevada, Utah and eastern California to work on acquisition and deployment of genetically appropriate native plant material for restoration.

Fundamental to this process is the increased coordination of Great Basin-wide seed collections to accelerate acquisition and production of seed stock for plant increase. We will be drawing on “lessons learned” from these efforts (Shaw et. al 2005; Youtie 2013). Via development of a “seed increase” technical team, we are integrating a systematic procedure to refine this work. Our goal is to identify species, and/or type of plant materials (seeds, plant container stock) and average quantity of each needed in each provisional (Bower et. al 2014) or empirical seed zone when available for the next 10 years. The first priority is development and refinement of specific plant material needs by these seed zones for workhorse species that are, or could be, increased in the agricultural market. This can be further refined by prioritizing seed zones and plant community types where restoration is a priority.

A commensurate task will be to develop seed management plans for each species that will include the following information:

- Average quantity of each species/year/seed zone
- Appropriate production and storage requirements and location for each species, e.g.,
 - speculative production or wildland collection
 - contract production or wildland collection
 - nursery stock production
 - seed storage location/capacity

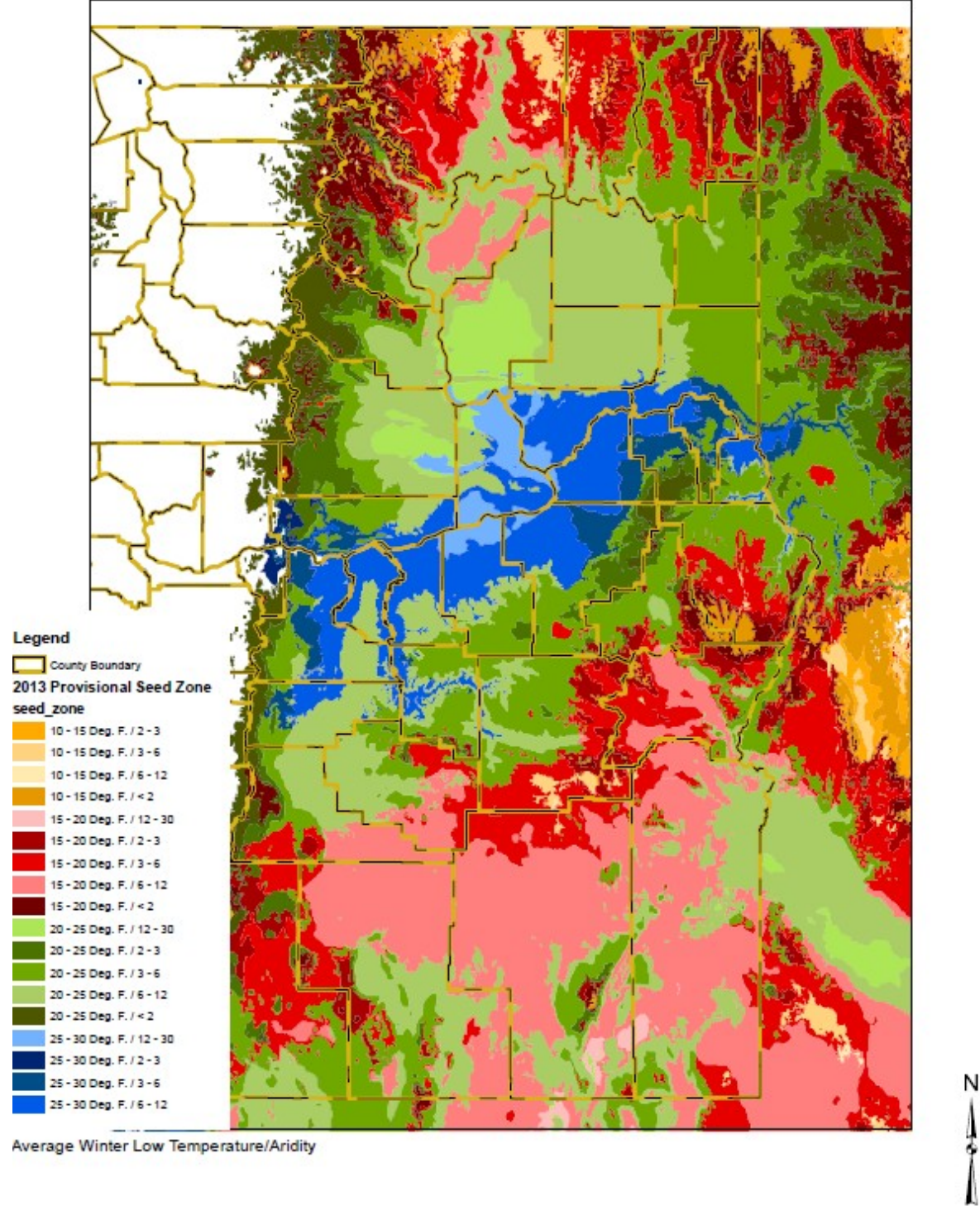
The technical team includes geneticists to help inform number of collections required, seed source pooling, and selection of sources in consideration of climate change, seed growers, agronomists, and nurserymen to review target species for production feasibility.

The final task will be to refine and provide the requisite contracting tools via already established BLM and USFS Oregon models (Erickson 2005; Ferriell 2015; Kendig 2015) including IDIQ (Indefinite-Delivery, Indefinite-Quantity) contracts with growers to expand Great Basin-wide coordinated plant increase.

To date the BLM Vale and Burns Districts are working with Eastern Oregon Stewardship Services to pilot this model for development of Greater Sage-Grouse habitat seed mixes (Figure 1). In addition, BLM and GBNPP have partnered with the Fire Science Delivery Exchange to develop a restoration webinar series titled “The Right Seed in the Right Place at the Right Time - Tools for Sustainable Restoration.” Series topics include seed zones, seed production, restoration equipment, seed mixes, climate, and use of plant container stock to augment wildland seedings.

The past, current, and future applied research that has been spearheaded by GBNPP researchers has set a critical foundation and example for the Draft National Seed Strategy, a multi-agency and partner effort that outlines the “coordinated federal, state, and non-governmental organizations’ response to the need to provide an adequate supply of appropriate seed and plant materials for ecosystem and land health conservation, restoration, and rehabilitation” (Draft BLM IM 2015). Via the GBNPP and on-going development of technical teams comprised of subject matter experts, an increased breadth, coordination, and deployment of native plant materials across the Great Basin can be achieved.

Figure 1. Vale BLM provisional seed zones for sage-grouse forb seed mix (Fritts 2015), based on Bower et al. (2014).



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Project Title Developing Protocols for Maximizing Establishment of Great Basin Legume Species

Project Agreement No. 11-IA-11221632-007

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Project Description

Rapid, uniform germination and initial stand establishment of legumes are frequently limited by hard-seededness. As part of this project, we previously conducted greenhouse experiments that determined how depth of planting and seed scarification treatments (soaking for 5 minutes in concentrated sulfuric acid or mechanical scarification by 120-grit sandpaper) affected germination and emergence of western prairie clover (*Dalea ornata*), basalt milkvetch (*Astragalus filipes*), and Searls' prairie clover (*Dalea searlsiae*). These studies showed substantial improvements in germination and seedling emergence of western prairie clover and Searls' prairie clover, but only marginal improvements for basalt milkvetch (Bushman et al., under review). For basalt milkvetch, recent experiments where seeds were imbibed, scarified seeds in moist sand resulted in over 90% germination within 7 days after seeding.

In a second study, we planted scarified and non-treated seeds of western prairie clover and basalt milkvetch at three dryland sites in Oregon. The purpose was to determine an optimal time and seed treatment for rangeland stand establishment of these species. Seeded plots were planted for 3 years, with each planting including a fall and spring seeding. The fall 2011/spring 2012 occurred at the USFS/OSU Powell Butte farm and the river bottoms at Clarno, Oregon. The fall 2012/spring 2013 plantings occurred at the Powell Butte farm, an upland site near Clarno, and the OSU Malheur Experiment Station in Ontario, OR. The third planting occurred at those same three sites during fall 2014, and soon to be spring 2015. These plantings are in coordination with Matt Horning of the USFS and Clinton Shock of Oregon State University.

Results from the first year of data from these studies indicated that early spring plantings of scarified western prairie clover seed were the most successful (Figure 1) while scarified basalt milkvetch seed established best in fall seedings (Figure 2). The second year of seeding resulted in no establishment due to a lack of precipitation from January through June of 2013; however both scarified and non-treated seed of basalt milkvetch established the following year at a low percentage.

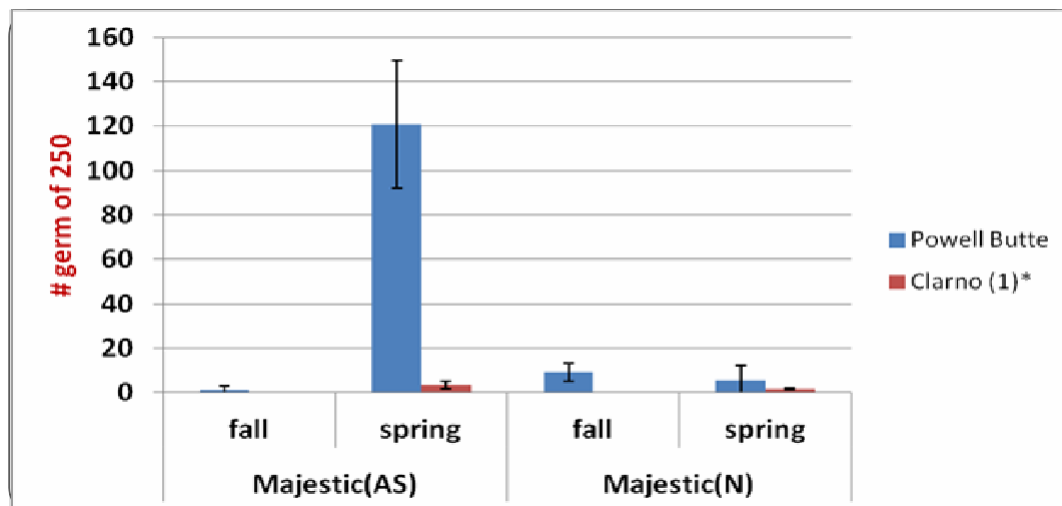


Figure 1. Seedling emergence and establishment at Powell Butte and *Clarno river bottom locations after the fall 2011/spring 2012 planting. Data collected July 2012. Majestic (AS) is acid-scarified seed of Majestic *D. ornata* germplasm, and Majestic(N) is non-treated seed.

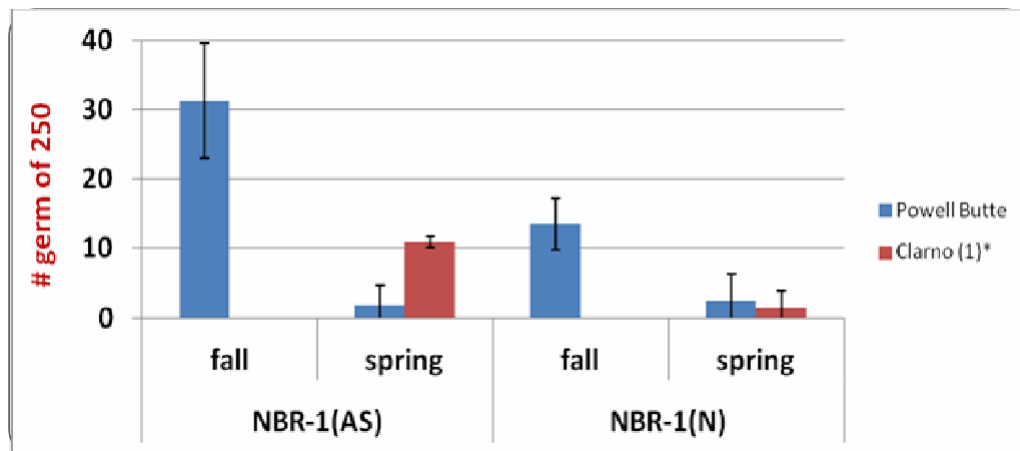


Figure 2. Seedling emergence and establishment at Powell Butte and Clarno river bottom locations after the fall 2011/spring 2012 planting. Data collected July 2012. NBR-1(AS) corresponds to acid scarified NBR-1 germplasm of basalt milkvetch. NBR-1(N) is non-treated seed of NBR-1.

Research with Utah trefoil (*Lotus utahensis*)

Seed collections were made of ecotypes of Utah trefoil (a Great Basin leguminous species) throughout its range of distribution in southern Utah, southern Nevada, and northern Arizona during 2012 and 2013. Forage samples are currently being analyzed for tannin content.

Replicated common gardens of 19 Utah trefoil collections were established at three sites in northern Utah and will be evaluated for various morphological and physiological characteristics during 2015. Jason Stettler (previous biologist with the Utah Division of Wildlife Resources at Ephraim, UT) is pursuing his M. S. degree on this project at Utah State University.

Publications

Bushman, B. S.; Johnson, D. A.; Connors, K. J.; Jones, T. A. Germination and seedling emergence of three western North American rangeland legumes. *Under Review*, Rangeland Ecology and Management.

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Presentations

Johnson, D. A.; Connors, K. J.; Bushman, B. S.; Jones, T. A. 2014. *Lotus utahensis*: Southern Great Basin legume for possible use in rangeland revegetation. Society for Range Management Annual Meeting; 2014 February; Orlando, FL.

Management Applications and Seed Production Guidelines

Seed producers will benefit by knowing how to obtain stands of these North American legume species for seed production. This information will provide land managers with information to diversify their rangeland revegetation projects.

Products

- Germplasm releases for basalt milkvetch, western prairie clover, and Searls' prairie clover.
- Seed production guidelines and planting guides.

Project Title Native Forb Increase and Research at the Great Basin Research Center

Project Agreement No. 12-JV-11221632-050 and 11-JV-11221632-009

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Project Description

Cushion buckwheat (*Eriogonum ovalifolium*) common garden study.

Objectives

Analyze seed production of multiple native collected accessions of cushion buckwheat (*Eriogonum ovalifolium*) and G1 production seed from those accessions to test if seed production is a heritable trait. Evaluate drought tolerance of the same accessions with a common garden planted on the Desert Experimental Range.

Methods

In the fall of 2013 a common garden of the top 11 producing accessions (Table 1) from a prior common garden study, along with the first generation daughter plants (G1) of the same accessions, were planted on our Ephraim, UT farm and the Desert Experimental Range (DER) located in Millard County, UT. Ten plants of each accession and generation were planted in randomized blocks replicated four times per site. Seedlings were planted into weed barrier fabric and thoroughly watered in at the time of transplanting to minimize the effects of transplanting. No supplemental water was given after the initial transplant. Mortality, seed production, seed size, and seed viability will be monitored on the Ephraim study site, and mortality will be measured on the DER site.

Table 1. Cushion buckwheat (*Eriogonum ovalifolium*) germplasm sources

Lot #	Site	Ecoregion
EROV-U11-2002	Sand Pass	13k Lahontan Sagebrush Slopes
EROV-U13-2002	Toano	13q Carbonate Woodland Zone
EROV-U20-2005	Crittenden Res.	13r Central Nevada High Valleys
EROV-U23-2005	Crittenden Res.	80a Dissected High Lava Plateau
EROV-U27-2005	Newcastle	13c Sagebrush Basins and Slopes
EROV-U28-2005	Jungo Road	13z Upper Lahontan Basin
EROV-U29-2005	Cobre	80a Dissected High Lava Plateau
EROV-U30-2004	Hwy 26 mm 280-281	12g Eastern Snake River Basalt Plains
EROV-U7-2002	Pequop Foothills	13p Carbonate Sagebrush Valleys
EROV-U8-2002	North Battle Mountain	13m Upper Humboldt Plains
EROV-U9-2002	Adobe Hill	13m Upper Humboldt Plains

Future Plans

Measurements will continue to be taken through the 2015 growing season. Analysis and publication are anticipated in 2016.

Project Description

Lupine species iron deficiency chlorosis (IDC) study.

Objectives

Identify a practical and effective method of treating iron deficiency chlorosis (IDC) for improved establishment and seed production in multiple lupine species.

Methods

In the fall of 2011 two common gardens (randomized complete block design) were planted at our Fountain Green and Snow Field Station research farms to study the effects of iron fertilizer treatments. The treatments of EDDHA chelated iron fertilizer were: seed applied iron, foliar applied iron, a combined treatment of seed and foliar applied iron, and a control group without any fertilizer application. These were applied to three lupine species: longspur lupine (*L. arbustus*), hairy bigleaf lupine (*L. prunophilus*), and silky lupine (*L. sericeus*). Measurements of emergence, establishment, chlorophyll content, plant height, and seed production were collected in 2012 and 2013, and plant height and seed production were collected in 2014.

Results and Discussion

Results from 2012 and 2013 were published in Kilkenny et al. (2014). Preliminary results from the 2014 data collection are presented here. Seed was only harvested on the Snow Field Station in 2014 due to an insect infestation on the Fountain Green farm that destroyed the seed inside the pods. Seed yield of silky lupine was significantly lower in 2014 than prior years on the Snow Field Station. This too may have been due to predation from insects. There remained no significant difference in yield of silky lupine among the treatments* (Figure 1). There was no

significant difference in plant height between treatments or treatment*farm in 2014. Similar to seed yield, plant height was significantly smaller in 2014 than in 2013 (Figure 2). Preliminary results indicate that iron treatments had limited impact on seed production and vegetation response.

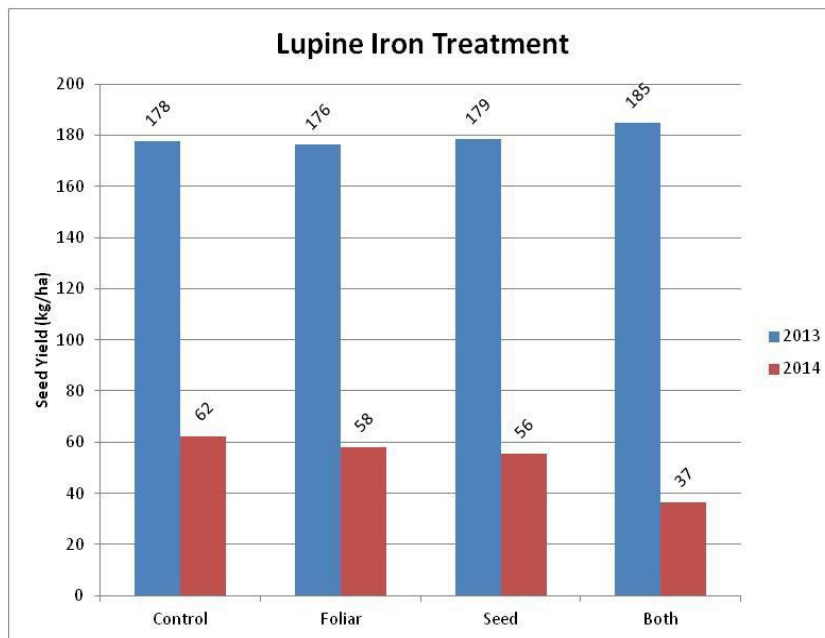


Figure 1. Seed yield of silky lupine (*Lupinus sericeus*) on now Field Station by treatment for 2013 and 2014.

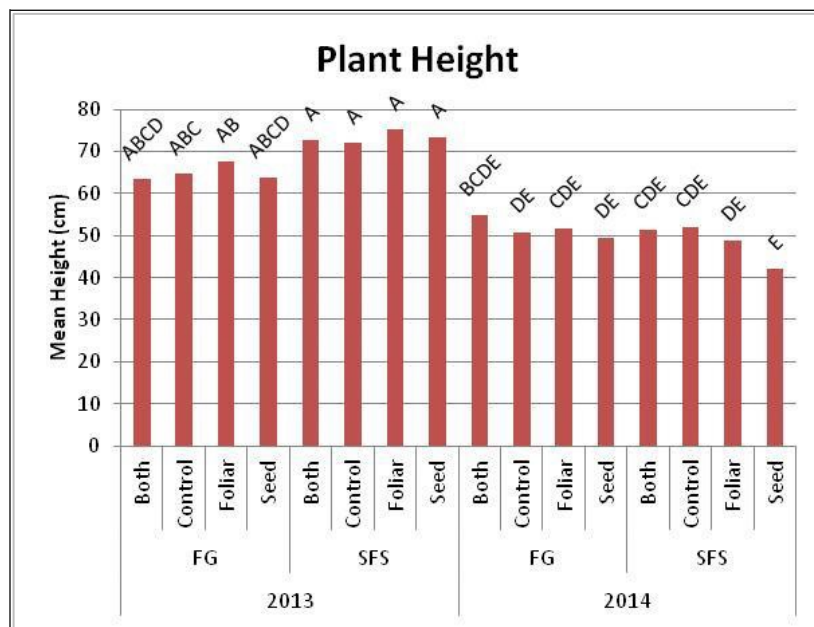


Figure 2. Mean plant height of four lupine species on the Fountain Green (FG) and Snow Field Station (SFS) for 2013 and 2014.

Future Plans

Final analysis and publication are anticipated in 2015.

Project Description

Wildland collection native seed increase.

Objectives

Increase seed from wildland collections to support further research and increase distribution of native seed to commercial growers. Develop and test methods to increase germination and establishment in agronomic settings.

Methods

Work will be done in conjunction with the Provo Shrub Sciences Lab wildland seed collection project. Selected species and accessions of wildland collected seed will be planted on Utah Division of Wildlife Resources (UDWR) farms in Fountain Green, UT or Ephraim, UT for the purpose of seed increase. Seed will be either direct seeded into fields or propagated in the greenhouse for plug transplanting depending on the amount of seed available.

Production fields will be maintained and harvested to maximize seed production of native species. When opportunities arise, development of propagation protocols and research for increased establishment and production will be conducted.

Results

Seed from 12 species with 58 accessions were harvested on the UDWR farms in 2014 (Table 2). Two species with 10 accessions were direct seeded into new increase beds in the fall of 2014, and a further 14 accessions of those same species will be propagated in the greenhouse and seedlings transplanted in the spring of 2015 (Table 3).

Table 2. Seeded species harvested from UDWR farms in 2014.

Code	Species	# of Accessions	Location
ASFI	<i>Astragalus filipes</i>	1	Ephraim
CRAC2	<i>Crepis acuminata</i>	3	Ft. Green
CRIN4	<i>Crepis intermedia</i>	3	Ft. Green
CRYPT	<i>Cryptantha</i> sp.	1	Ft. Green
DAOR2	<i>Dalea ornata</i>	1	Ephraim
ENNUN	<i>Enceliopsis nudicaulis</i>	3	Ft. Green
IPAG	<i>Ipomopsis aggregata</i>	3	Ft. Green
LECI4	<i>Leymus cinereus</i>	31*	Ephraim
LILE3	<i>Linum lewisii</i>	6	Ephraim
LUAR6	<i>Lupinus arbustus</i>	1	Ephraim
LUSES2	<i>Lupinus sericeus</i>	1	Ephraim
PEPA6	<i>Penstemon pachyphyllus</i>	4	Ft. Green

*Foundation source of UDWR Tetra Great Basin Wildrye selected release.
Accessions are pooled when harvested.

Table 3. Species sown on UDWR farms in 2014-2015.

Code	Species	# of Accessions	Location
HEMUN	<i>Heliomeris multiflora nevadensis</i>	5	Ft. Green
PEPA6	<i>Penstemon pachyphyllus</i>	19	Ft. Green

Future Plans

Maintenance, harvest and distribution of seed from established increase plots will continue. Expansion of increase plots will proceed with the addition of new species and accessions as deemed necessary. Development of propagation protocols and research for increased establishment and production will be conducted as the opportunity arises.

Project Description

N-sulate® Fabric assessment on germination and establishment study.

Objectives

Determine the effects of N-sulate® fabric on germination and establishment of native forb species in a wildland setting.

Methods

This study was implemented in 2009 and 2010. Four sites were selected in Utah, two in Tooele County, one in Sanpete County, and one in Carbon County. Each study site consists of two years replication with five randomized complete blocks of treatments in each year. Treatments are two seed mixes (Table 4) and two mulch treatments covered with N-sulate® fabric, and an uncovered control. The study sites were prepared by mechanically removing sagebrush and other vegetation with two passes of a pipe harrow. The seed mixes were sown with rice hulls using a hand-operated seed broadcaster at a rate of 20-25 seeds ft², depending on the species. The plots were then compacted with a Brillion packer wheel (Brillion Farm Equipment, Brillion, WI) to ensure good seed to soil contact. Germination and establishment data were recorded one, two, and five years post treatment.

Results and Discussion

The five year data has not been collected for the 2010 planting yet, so only results from the first two years are reported here. When looking at total mean density of seeded species across all four study sites, we see differing responses over time. Germination was higher for species in both mixes in the covered treatment in the first growing season, but establishment of species by the second growing season of both seed mixes was much lower and there was no substantial difference of mean density in covered and uncovered treatments (Figure 3).

When response is looked at across study sites, germination is higher than the unseeded control for both mixes on all sites. Density is higher in the covered treatments for both mixes across the treatment types, but this is most pronounced in the lower precipitation sites of Hatch Ranch and Lookout Pass (Figure 4).

Table 4. Forb island study seed mixes.

Seed Mix 1			
USDA Plant Code	Scientific Name	Accession No.	Seeded Rate (g)
BASA3	<i>Balsamorhiza sagittata</i>	Basa-I-UT-R2	17
CLSE	<i>Cleome serrulata</i>	CSE-107	2. 8
HEBO	<i>Hedysarum boreale</i>	2008. 0366	21. 3
LIPE2	<i>Linum perenne</i> ‘Appar’	NBS-RR8-APP-2	3. 12
LUAR3	<i>Lupinus argenteus</i>	122	63. 8
PEPA6	<i>Penstemon pachyphyllus</i>	PEPA6-B5-2009	4. 3
POFE	<i>Poa fendleriana</i>	2006. 04. 08	1. 1
SPGR2	<i>Sphaeralcea grossulariifolia</i>	287	2. 3

Seed Mix 2			
USDA Plant Code	Scientific Name	Accession No.	Seeded Rate (g)
AGGR2	<i>Agoseris grandiflora</i>	AGGLG 28080 LPN	4. 5
AGHE2	<i>Agoseris heterophylla</i>	SI-1	1. 9
ARMU	<i>Argemone munita</i>	ARMU-U1-2009	8. 7
HEMUN	<i>Helioomeris multiflora nevadensis</i>	HEMUN-B4-2009	1. 9
LONU2	<i>Lomatium nudicaule</i>	Big Butte source	28. 4
NIAT	<i>Nicotiana attenuata</i>	Mud Springs source	0. 4
THMI5	<i>Thelypodium milleflorum</i>	THMI5-P2-2009	0. 4

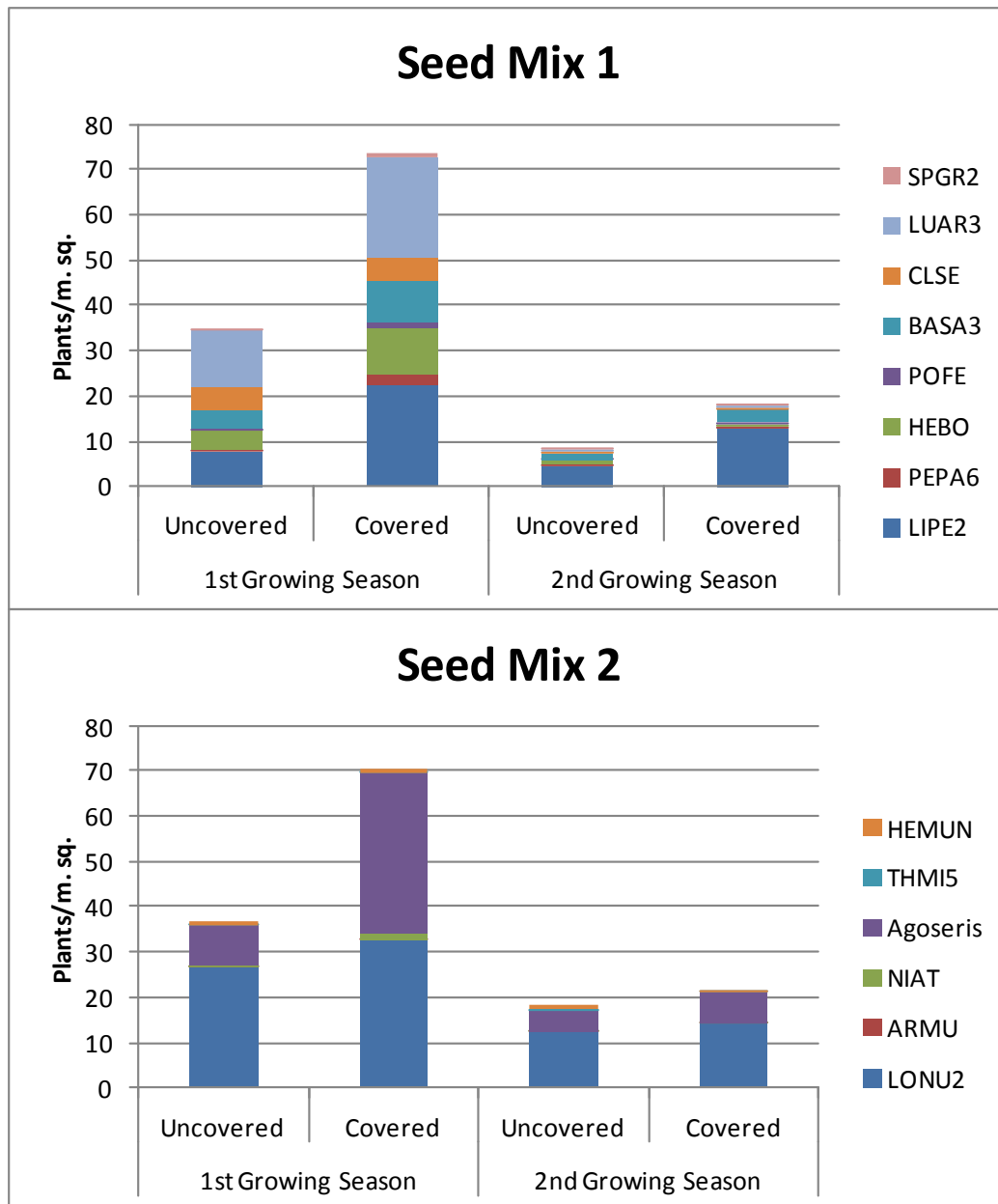


Figure 3. Total density across sites of seeded species for the first and second growing season.

Future Plans

Data collection will occur one more time in the summer of 2015 to assess the 2010 treatment for the full 5 years. After data collection is complete, analysis and publication is anticipated for 2016.

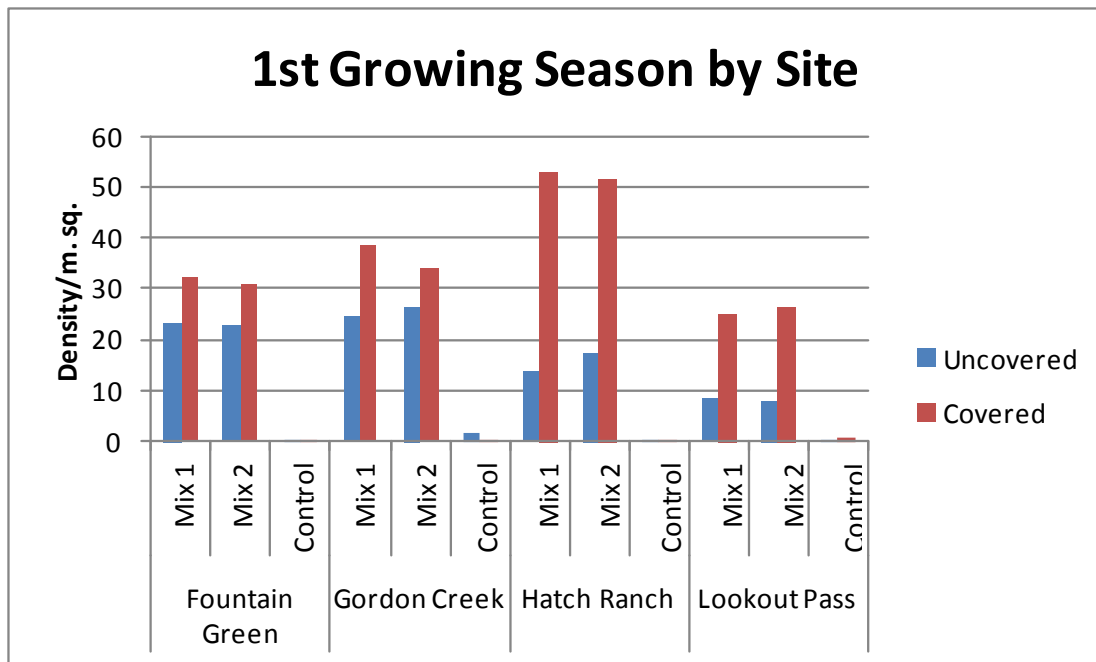


Figure 4. Density of perennial species by treatment type and study location.

Project Description

Forb seeding method study using Truax drill, Lawson aerator, Dixie pipe harrow and Ely chain.

Objectives

Currently, seed mixes used for restoration generally do not include native forb species, mainly due to their high cost. Because these species have not been included in past restoration efforts there is a lack of information about planting and establishing native forbs in wildland settings. As these native forbs become more available on the market, the lower costs will facilitate land manager's ability to include these species in seed mixes used for restoration. This creates a need to determine the best methods of establishing native forbs in wildland settings. The main objective of this study is to evaluate native forb establishment in Wyoming big sagebrush communities using four different pieces of planting equipment: Truax drill, Lawson aerator, Dixie pipe harrow, and Ely chain.

Methods

This study was established on two sites (referred to as North and South) in Tooele County, Utah. Treatments occurred in the fall of 2008 and 2009. The seed mix used for the study consisted of only native forbs (Table 5). Each study site consists of two years replication with two randomized complete blocks of disturbance treatments in each year. Cover was collected for all species and density for perennial species. Measurements were done in post treatment years one, two, and six.

Future Plans

Results from 2009 and 2010 were published in Shaw and Pellant (2011). Final sampling will occur in the summer of 2015. Final analysis and publication are anticipated in 2016.

Table 5. Seed mix used on the project.

Species	Bulk lbs/acre)	PLS lbs/acre	Seeds/ft²
Munro Globemallow (<i>Sphaeralcea munroana</i>)	0.5	0.38	4.32
Blue Flax (<i>Linum lewisii</i>)	1.0	0.90	6.04
Northern Sweetvetch (<i>Hedysarum boreale</i>)	1.0	0.77	0.60
Silvery Lupine (<i>Lupinus argenteus</i>)	1.5	0.55	0.27
Palmer Penstemon (<i>Penstemon palmeri</i>)	0.5	0.39	4.86
Utah Milkvetch (<i>Astragalus utahensis</i>)	0.6	0.39	2.03
Arrowleaf Balsamroot (<i>Balsamorhiza sagittata</i>)	2.0	1.81	2.28
Firecracker Penstemon (<i>Penstemon eatonii</i>)	0.29	0.23	3.18
Tapertip Hawksbeard (<i>Crepis acuminata</i>)	0.16	0.10	0.48
Total	7.55	6.02	24.04

Presentations

Stettler, J. 2014. Lupine cultivation and ecological niche modeling. Great Basin Native Plant Project Annual Meeting; 2014 March 17-18; Boise, ID.

References

Kilkenny, Francis; Shaw, Nancy; Gucker, Corey. 2014. Great Basin Native Plant Project: 2013 Progress Report. Boise, ID: U. S. Department of Agriculture Forest Service, Rocky Mountain Research Station: 74-93.

Shaw, Nancy; Pellant, Mike. 2011. Great Basin Native Plant Selection and Increase Project: 2010 Progress Report. Boise, ID: U. S. Department of Agriculture Forest Service, Rocky Mountain Research Station: 167-172.

Project Title Plant Material Work at the Provo Shrub Sciences Lab

Project Agreement No. 13-IA-11221632-161

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Project Descriptions

Wildland Seed Collection

Seed collection efforts in 2014 (Table 1) were focused on identifying and harvesting new populations of thistleleaf penstemon (*Penstemon pachyphyllus*) and recollecting basin wildrye (*Leymus cinereus*) for an ongoing study. A cheatgrass (*Bromus tectorum*) die-off afforded an opportunity for a bulk collection of Nevada bluegrass (*Poa secunda*).

Table 1. Species and number of sources collected in 2013.

Family	Name	Common Name	2014 Collections
Poaceae	<i>Poa secunda</i>	Nevada bluegrass	1
Poaceae	<i>Leymus cinereus</i>	Basin wildrye	27
Scrophulariaceae	<i>Penstemon pachyphyllus</i>	thistleleaf penstemon	17

Seed Distributions for Stock Seed and Commercial Seed Production

In cooperation with the Utah Division of Wildlife Resources and the Great Basin Research Center (GBRC), 19 sources of thistleleaf penstemon from provisional seed zone 15 - 20 Deg. F./ 3 – 6 (Bower et al. 2014) and five sources of Nevada showy goldeneye (*Heliomeris multiflora* var. *nevadensis*) from provisional seed zone 15 - 20 Deg. F./ 6 – 12 (Bower et al. 2014) were either direct seeded or seeded into plugs for grow out and transplant at the Fountain Green farm facility (Table 2). Future seed harvests from these beds will serve as stock seed for these species/zone combinations for distribution to commercial producers.

A small number of private industry seed producers continue to show interest in commercial production of Great Basin native forbs and grasses. In 2014, eight species representing stock seed for 12 species/zone combinations were distributed to private commercial seed producers (Table 3).

Table 2. Species and sources planted for stock seed production at Fountain Green, Utah.

Species	# Sources	Method	Provisional Seed Zone
<i>Penstemon pachyphyllus</i>	7	S	15 - 20 Deg. F. / 3 - 6
<i>Penstemon pachyphyllus</i>	12	P	15 - 20 Deg. F. / 3 - 6
<i>Heliomeris multiflora</i> var. <i>nevadensis</i>	3	S	15 - 20 Deg. F. / 6 - 12
<i>Heliomeris multiflora</i> var. <i>nevadensis</i>	2	P	15 - 20 Deg. F. / 6 - 12
Totals	2	24	2
S - Direct seed, P - Transplant plugs			

Table 3. Lots distributed to private industry for commercial production.

Species	# Sources	Lots	Weight (lbs)	Provisional Seed Zone
<i>Heliomeris multiflora</i> var. <i>nevadensis</i>	3	15	14.6	15 - 20 Deg. F. / 6 - 12
<i>Heliomeris multiflora</i> var. <i>nevadensis</i>	2	2	2.1	20 - 25 Deg. F. / 6 - 12
<i>Lomatium nudicaule</i>	1	1	6.25	15 - 20 Deg. F. / 6 - 12
<i>Agoseris grandiflora</i>	1	2	3.39	20 - 25 Deg. F. / 3 - 6
<i>Erigeron speciosus</i>	1	1	0.1	15 - 20 Deg. F. / 3 - 6
<i>Cleome lutea</i>	1	1	0.79	15 - 20 Deg. F. / 6 - 12
<i>Sphaeralcea grossulariifolia</i>	1	1	7.5	15 - 20 Deg. F. / 6 - 12
<i>Sphaeralcea munroana</i>	1	1	0.21	10 - 15 Deg. F. / 6 - 12
<i>Leymus cinereus</i>	9	9	9	10 - 15 Deg. F. / 6 - 12
<i>Leymus cinereus</i>	5	5	2	15 - 20 Deg. F. / 3 - 6
<i>Leymus cinereus</i>	8	8	11.47	15 - 20 Deg. F. / 6 - 12
<i>Leymus cinereus</i>	5	5	3.33	20 - 25 Deg. F. / 6 - 12
Totals	8	38	51	60.74
				6

Evaluating Emergence from Increasing Planting Depth for 20 Native Forbs

Objectives

Evaluate the effect of planting depth on seedling emergence for 20 native forb species (Table 4) planted in loam-textured soils at three locations.

Methods

In Fall 2013 and 2014 each species was sown at four depths in a randomized block design with 10 blocks per site. Seeding rates were adjusted for viability and purity to 25 PLS/ft. Five blocks were covered with N-sulate fabric and five were left uncovered. The study was replicated at three sites, Orovada Nevada; Wells, Nevada; and Fountain Green, Utah. Emergence and short term persistence data will be collected 2014 - 2016.

Table 4. Forbs seeded to evaluate planting depth on seedling emergence.

Family	Name	Common Name
Asteraceae	<i>Achillea millefolium</i>	Common yarrow
Asteraceae	<i>Agoseris grandiflora</i>	Bigflower agoseris
Asteraceae	<i>Agoseris heterophylla</i>	Annual agoseris
Caryophyllaceae	<i>Arenaria macradenia</i> ssp. <i>ferrisiae</i>	Ferris' sandwort
Fabaceae	<i>Astragalus filipes</i>	Basalt milk-vetch
Asteraceae	<i>Balsamorhiza hookeri</i>	Hooker's balsamroot
Asteraceae	<i>Enceliopsis nudicaulis</i>	Nakedstem sunray
Polygonaceae	<i>Eriogonum umbellatum</i>	Sulphur-flower buckwheat
Asteraceae	<i>Heliomeris multiflora</i> var. <i>nevadensis</i>	Nevada showy goldeneye
Polemoniaceae	<i>Ipomopsis aggregata</i>	Scarlet gilia
Apiaceae	<i>Lomatium nudicaule</i>	Barestem biscuitroot
Fabaceae	<i>Lupinus argenteus</i>	Silvery lupine
Fabaceae	<i>Lupinus prunophilus</i>	Hairy big leaf lupine
Asteraceae	<i>Machaeranthera canescens</i>	Hoary tansy-aster
Scrophulariaceae	<i>Penstemon acuminatus</i>	Sharpleaf penstemon
Scrophulariaceae	<i>Penstemon pachyphyllus</i>	Thickleaf penstemon
Scrophulariaceae	<i>Penstemon speciosus</i>	Royal penstemon
Malvaceae	<i>Sphaeralcea grossulariifolia</i>	Gooseberryleaf globemallow
Malvaceae	<i>Sphaeralcea munroana</i>	Munro's globemallow
Brassicaceae	<i>Stanleya pinnata</i> var. <i>integrifolia</i>	Golden prince's-plume

Evaluating Methods of Pairing Seed Sources to Restoration Sites Using Basin Wildrye (Leymus cinereus)

Objectives

Basin wildrye is a common grass native to western North America. Its distribution extends from New Mexico on the south, to Saskatchewan on the north, then west across all states and provinces to the Pacific Coast. Across its distribution is an enormous array of climatic and ecological variation that has likely led to the development of localized adaptations between spatially divergent populations. In recent years plant material development strategies have

emphasized methods that focus on local adaptation or matching adaptive variation to climate. The products of these genecological studies are maps that display similarities in plant performance metrics and climate parameters across a species distribution.

For a number of important restoration species genecological work is underway. However, this type of work may continue for decades and will likely never be completed for many species. Data must be developed on a species by species basis requiring several years of study adding to expenses. Where genecological work is lacking, surrogate approaches have been suggested.

In this study we evaluate generalized provisional seed zones (GPSZ) as a method of matching seed sources to restoration sites. Because this locally adapted approach of matching seed supplies to restoration sites is relatively new in large scale restoration efforts and in direct competition with the common cultivar model, we include basin wildrye cultivars in the trial. This permits a comparison of establishment success between primary and secondary restoration gene pool materials at sites with varying degrees of divergence from historic norms.

Methods

In excess of 105 known populations of basin wildrye were mapped by GPSZ. Approximately 90% of these populations fell within four provisional seed zones and none of the poorly represented zones had a proportional occurrence of more than 5%. Next we located test sites in each of the four well represented zones at Fountain Green, Utah; Spanish Fork, Utah; Nephi, Utah; and Orovada, Nevada. Seed from four basin wildrye cultivars Magnar, Trailhead, Continental and Tetra was procured through local vendors and 27 wildland sources representing four provisional seed zones were collected from native stands in 2013 and 2014. Individual sources were sampled for seed weight, viability, and ploidy; then seeded at 25 PLS/ft in a randomized block design with ten blocks per site. Five blocks were covered with N-sulate fabric and five blocks were left uncovered. Plots were seeded in 2013 and 2014. Emergence and persistence data will be collected 2014 - 2016.

References

Bower, A. D.; St. Clair, J. B.; Erickson, V. 2014. Generalized provisional seed zones for native plants. *Ecological Applications* 24(5): 913-919.

Project Title Aberdeen Plant Materials Center Report of Activities

Project Agreement No. 11-1A-11221632-004

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Project Description

The Aberdeen Plant Materials Center (PMC) is involved with plant collection, selection and development, and seed and plant production for improving degraded or disturbed lands. The Aberdeen PMC also transfers garnered plant species production, establishment, and management knowledge to others.

Plant Guides

The Aberdeen PMC is gathering information on selected plant species to create Natural Resources Conservation Service (NRCS) plant guides. Plant guides offer the most recent information on plant establishment, management and seed and plant production information. General information for the species can also be found in our plant guides including information on potential uses, ethnobotanical significance, adaptation, pests, and potential problems. In 2014 plant guides were completed or revised for Rocky Mountain Penstemon (*Penstemon strictus*) and Hoary tansyaster (*Machaeranthera canescens*). Plant guides are available at the PLANTS database, www.plants.usda.gov, and at the Aberdeen Plant Materials Center website: www.id.nrcs.usda.gov/programs/plant.html.

Plant Materials Development

Hoary tansyaster

Nine accessions of hoary tansyaster (*Machaeranthera canescens*) were evaluated from 2009 through 2011 for establishment, plant growth, and seed production. Accession 9076670 had the best establishment and stands for 2009 and 2010. It also had the best rated vigor in 2010 and the tallest plants in the overall study. The population for 9076670 is located near the St. Anthony Sand Dunes in Fremont County, Idaho at 5,000 ft. elevation. The site has sandy soils and supports a bitterbrush, Indian ricegrass, rabbitbrush, and scurfpea plant community. The location receives between 10 and 15 inches of mean annual precipitation. In 2014, accession 9076670 was officially released as Amethyst Germplasm hoary tansyaster.

G1 and G2 seed of Amethyst Germplasm hoary tansyaster will be maintained by the USDA Natural Resources Conservation Service, Aberdeen Plant Materials Center. Seed through the G5 generation will be eligible for certification. G1 and G2 seed will be made available to commercial growers for distribution by the University of Idaho Foundation Seed Program and Utah Crop Improvement Association. Small quantities of seed will be provided to researchers by request to the Plant Materials Center.

Wyeth or whorled buckwheat

Thirty-nine accessions of Wyeth and sulphur-flower buckwheat (*Eriogonum heracleoides* and *E. umbellatum*) were compared in a common garden study from 2007 through 2011. Accession 9076546 Wyeth buckwheat showed good establishment, seed production, and longevity compared with the other accessions.

Initial seed increase of accession 9076546 is ongoing. Release documentation is being developed, and official release will occur once the Aberdeen PMC has produced a sufficient amount of early generation seed.

Publications

St. John, Loren (editor). 2014. Plant Guide for Rocky Mountain penstemon (*Penstemon strictus*). Aberdeen, ID: U. S. Department of Agriculture, Natural Resources Conservation Service, Aberdeen Plant Materials Center. Revised January, 2014.

Tilley, Derek; Ogle, Dan; St. John, Loren. 2014. Plant Guide for hoary tansyaster (*Machaeranthera canescens*). Aberdeen, ID: U. S. Department of Agriculture, Natural Resources Conservation Service, Aberdeen Plant Materials Center. 4 p.

Tilley, Derek. 2014. Release Brochure for Amethyst Germplasm Hoary Tansyaster (*Machaeranthera canescens*). Aberdeen, ID: U. S. Department of Agriculture, Natural Resources Conservation Service, Aberdeen Plant Materials Center. 2 p.

Products

- Revised Plant Guides are available for Rocky Mountain penstemon and hoary tansyaster.
- Early generation certified seed of hoary tansyaster is in production, and allocations have been made to Utah Crop Improvement and Idaho Foundation Seed Program.
- Early generation certified seed of Wyeth buckwheat is being produced and will be available through Utah Crop Improvement and University of Idaho Foundation Seed Program when release is approved.

Project Title Bee Pollination and Breeding Biology Studies

Project Agreement No. 11-IA-11221632-010

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Project Description

Successful reproduction by flowering plants requires the confluence of several favorable factors. Some are intrinsic to the plant (e.g. age, nutritional status); others are external, either abiotic (e.g. rainfall, fire) or biotic (e.g. pollinators). The survival and performance of perennial sagebrush-steppe forbs after fire is an unknown with potentially great ramifications for pollinators (floral resources for reproduction). Seed choices (e.g. alfalfa) and management tactics may be needed to retain remnant pollinator communities while awaiting establishment of new seedlings of their floral hosts.

Methods

Native Bees in the Aftermath of Wildfire in the Great Basin

Opportunities are few to sample bee faunas in the weeks and months following large wildfires. In the aftermath of the huge Long Butte wildfire near Twin Falls (440 sq miles), we sampled native bee faunas at scattered remnant stands of sunflowers growing in ditches along gravel roads that served as fire lines some 7 miles from the burn perimeter. Comparable quantitative samples of bees were taken at coflowering sunflowers outside the burn. All but two of the bee species were non-social and soil nesting. These sunflower bee faunas largely survived the fire intact (but for one surface-nesting species). Females even continued to collect pollen for their nests. The fire had passed the sample sites at night, a time when female bees are in their nest (and thus safe underground). A manuscript has been submitted to the journal *Biological Conservation* entitled: "Direct effects of wildfire on a bee community: nesting habitus determines persistence."

Fire Impact on Forb Survival

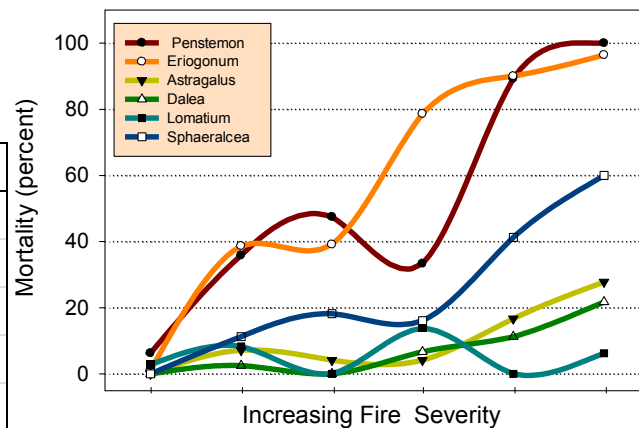
Changes in the frequency and intensity of fire in the sagebrush steppe have become key factors in degrading native plant communities in basin and foothill habitats. We know that many of the dominant Great Basin shrubs are consumed by fire and do not resprout well. Some forbs clearly survive some wildfires to thrive and bloom thereafter, but the observations are anecdotal and not related to fire attributes. Hence, we do not know which native forb species survive fires of a particular intensity.

To examine the individual plant's response to wildfire, six common Great Basin perennial forb species were experimentally burned in 2012 at increasing intensities using a custom portable propane burner designed to mimic wildfire attributes. Six propane-fueled prescription treatments were used to mimic wildfire conditions, varying heat intensity and duration (Table 1). Survival data were collected along with a number of characteristics thought to be indicators important for bees in a post-fire environment (e.g. numbers of flowers, of flowering stalks and/or the lengths of racemes. Analyses are completed and manuscript writing is underway.

To reinforce our conclusions with field data, we sampled densities of perennial blooming *Penstemon*, *Lupine*, *Lomatium* and *Balsamorhiza* plants 8 months after the State Line Fire in the Samaria Mountains of southern Idaho. Obviously, these plants had to be survivors and not seedling recruits. Plants were larger, more vigorous and equally numerous within the fire perimeter compared with outside the edge in comparable soils, slopes and aspects. The general prediction from our forb burning treatment was upheld, that many Great Basin perennial forbs can and do survive wildfire to flower the following spring.

Table 1. Propane burn treatments used on native plants to mimic wildfires of increasing severity, and mortality of select burned forbs.

Category	Prescription	Heat attained (°C)
Control	No fuel applied	Ambient
Very Low	7.5 psi, 25 sec	100
Low	7.5 psi, 50 sec	200
Medium	15 psi, 65 sec	300
High	15 psi, 175 sec	500
Very High	15 psi, 240 sec	600



Future plans

1) This year we expect to finish writing and submit manuscripts for the forb burning study and for the design, manufacture and use of the burner built for this application. A final manuscript will report analyses of the native bee faunas systematically sampled in and out of a chronosequence of large wildfires in the Great Basin sage steppe.

2) Manual pollination proved to be an intractable method for documenting the breeding biology of silverleaf phacelia (*Phacelia hastata*). We therefore grew plants from seed in containers. We have transplanted these to six separate locations in and around Logan. At each site, we transplanted one isolated *P. hastata* plant and, at a distance, a close-set trio of plants. The former should be primarily selfed by resident bees, whereas the trio should have considerable outcrossing. Mortality varied among sites. Dead plants were replaced, a few others flowered in

this, their first year. In 2015, we will collect seeds per umbel of counted flowers to evaluate seed production with these naturally pollinated plants.

3) My colleagues and I in the Great basin Native Plant Project will be submitting a proposal to support a research project that will compare two methods for improved forb seedling establishment. We will enhance shallow soil moisture in early spring either by: 1) directed snowdrift accretion using custom snow fences, or 2) reduced spring evapotranspiration using floating row cover fabric. If successful, the technique could be used to establish replicate islands of mixed forbs at burn sites.

4) We will replicate our quantitative samples of native bees at wild stands of blue flax and western yarrow to evaluate a preliminary impression that these two workhorse forbs of sage-steppe restoration are relatively unattractive to native bees. Results will guide our recommendation about the value of these two easily grown forbs for bee conservation.

Publications

Cane, J. H.; Dunne, R. 2014. Generalist bees pollinate red-flowered *Penstemon eatonii*: refining the hummingbird pollination syndrome. *American Midland Naturalist* 171: 365-370.

Cane, J. H. 2014. The oligolectic bee *Osmia brevis* sonicates *Penstemon* flowers for pollen; a newly documented behavior for the Megachilidae. *Apidologie* 45: 675-684.

Presentations

Cane, J. Wild bees for Wyoming's wild flowers. Wyoming Native Plant Society; 2014 June 21; Lander, WY. Invited keynote.

Cane, J. Floral guilds of native bees endure wildfire in the Great Basin. North America Congress for Conservation Biology; 2014, July 13-16; Missoula, MT.

Cane, J. Pollinators and agricultural seed production, consideration of pollinators in management and restoration planning. Society for Ecological Restoration Northwest/Great Basin Meeting; 2014, October 6-11; Bend, OR. Invited symposium.

Management Applications and Seed Production Guidelines

A number of the common perennial forbs in sage steppe will survive late summer wildfires. Knowing what species were on a landscape prior to fire can guide forb seed selection for post-fire seedings. Emphasis should be given to those forb species expected at the location but absent owing to earlier extirpation and not the recent fire.

Project Title Seed Production of Great Basin Native Forbs

Project No. 12-JV-11221632-066

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Project Description

A five part study regarding seed production of Great Basin native forbs using subsurface drip irrigation (SDI) for stable, efficient native forb seed production using small amounts of supplemental irrigation water, weed control, and seeding practices.

A. Direct Surface Seeding Strategies for Emergence of Native Plants in 2014

Clinton Shock, Erik Feibert, Alicia Rivera, and Lamont Saunders, Malheur Experiment Station, Oregon State University, Ontario, OR

Francis Kilkenny and Nancy Shaw, U.S. Forest Service, Rocky Mountain Research Station, Boise, ID

Introduction

Seed of native plants is needed to restore rangelands of the Intermountain West. Reliable commercial seed production is desirable to make seed readily available. Direct seeding of native range plants has been generally problematic, especially for certain species. Fall planting is important for many species, because their seed requires a period of cold to break dormancy (vernalization). Fall planting of native seed has resulted in poor stands in some years at the Malheur Experiment Station. Loss of soil moisture, soil crusting, and bird damage are some detrimental factors hindering emergence of fall planted seed. Previous trials at the Malheur Experiment Station have examined seed pelleting, planting depth, and soil anti-crustants (Shock et al. 2010). Planting at depth with soil anti-crustant led to improved emergence compared to surface planting. Seed pelleting did not improve emergence. Despite some positive results, emergence was extremely poor for all treatments, due to soil crusting and bird damage.

In established native perennial fields at the Malheur Experiment Station and in rangeland areas we have observed prolific natural emergence from seed that falls on the soil surface and is covered by thin layers of organic debris. In 2011, 2012, and 2013, trials tested the effect of seven planting systems on surface planted seed (Table 1; Shock et al. 2012, 2013, 2014).

Row cover can be a protective barrier against soil desiccation and bird damage. Sawdust can mimic the protective effect of organic debris. Sand can help hold the seed in place. Seed treatment can protect the emerging seed from fungal pathogens that might cause seed decomposition or seedling damping off. Hydroseeding mulch could be a low cost replacement for row cover. The treatments did not test all possible combinations of factors, but tested combinations that might be likely to result in adequate stand establishment. In 2014, the seven planting systems were tested for emergence of 8 important species, 7 of which are native to Malheur County and surrounding rangelands and forestlands.

Materials and Methods

Seven species for which stand establishment has been problematic were chosen. An eighth species (*Penstemon speciosus*) was chosen as a check, because it has reliably produced good stands at Ontario. Seed weights for all species were determined. A portion of the seed was treated with a liquid mix of the fungicides Thiram[®] and Captan (10g Thiram, 10g Captan in 0.5 liter of water). Seed weights of the treated seeds were determined after treatment. The seed weights of untreated and treated seed were used to make seed packets containing approximately 300 seeds each. The seed packets were assigned to one of seven treatments (Table 1). The trial was planted manually on November 26, 2013. The experimental design was a randomized

complete block with six replicates. Plots were 30-inch-wide by 5-ft-long beds. Two seed rows were planted on each bed.

Tetrazolium tests were conducted to determine seed viability of each species (Table 2). The tetrazolium results were used to correct the emergence data to emergence of viable seed.

After planting, the sawdust was applied in a narrow band over the seed row at 0.26 oz/ft of row (558 lb/acre). For the treatments receiving both sawdust and sand, the sand was applied at 0.65 oz/ft of row (1,404 lb/acre) as a narrow band over the sawdust. Following planting, sawdust and sand applications, some of the beds were covered with row cover. The row cover (N-sulate, DeWitt Co. Inc., Sikeston, MO) covered four rows (two beds) and was applied with a mechanical plastic mulch layer.

For the hydro seeding mulch treatments, 12 lb of hydro seeding paper mulch (Premium Hydro seeding Mulch, Applegate Mulch, <http://applegatemulch.com>) was mixed in 50 gallons of water in a jet-agitated 50-gallon hydro seeder (Turbo Turf Technologies, Beaver Falls, PA). The mulch was applied with the hydro seeder in a 3-cm band over the seed row.

On April 15 2014, the row cover was removed and emergence counts were made in each plot. Data were analyzed using analysis of variance (General Linear Models Procedure, NCSS, Kaysville, UT). Means separation was determined using a protected Fisher's least significant difference test at the 5 percent probability level, LSD (0.05).

Results and Discussion

Overall, emergence in the trial was poor. December of 2013 and January of 2014 had precipitation that was about 50% lower than normal and could have contributed to the poor emergence. Emergence and stand of *Phacelia linearis*, *Ligusticum porteri*, and *Ligusticum canbyi* was poor at 10% or less (Table 3). Emergence and stand of *Phacelia hastata*, *Heliomeris multiflora*, and *Penstemon speciosus* was fair at 20% or less. There was no significant difference in stand between treatments for *Phacelia linearis*, *Phacelia hastata*, *Heliomeris multiflora*, and *Ligusticum canbyi*.

The row cover with sawdust and seed treatment resulted in higher stands than no row cover (bare ground) with sawdust and seed treatment for *Machaeranthera canescens* and *Ligusticum porteri* (Table 3). Sawdust added to the row cover and seed treatment only improved stands of *Ligusticum porteri*. Adding seed treatment to sawdust and row cover did not improve stands of any species. Adding sand to sawdust, seed treatment, and row cover increased stand for *Penstemon speciosus*.

The hydroseed mulch applicator is designed to have the seed mixed in the tank with the mulch and then the mixture is sprayed on the soil surface. Since it was not practical to mix the seed with the mulch, the application pressure had to be reduced enough to not displace the previously planted seed on the soil surface. The resulting mulch application was too thick and when dry resembled paper mâché, which was probably too hard of a barrier for seed emergence. Future adjustments of the thickness of the mulch mix and spray nozzle might allow for the application of mulch of the right consistency. Stand with hydroseed mulch and seed treatment was lower

than with row cover and seed treatment for *Machaeranthera canescens*. For *Chaenactis douglasii*, stand with hydroseed mulch and seed treatment was not different from stand with row cover and seed treatment. Stand for the other species was too poor to draw conclusions.

In 2013 (Shock et al. 2014), the same trial was conducted with 15 species and included all of the species in the 2014 trial. In 2013, systems including row cover improved stand of 6 of the species including *Chaenactis douglasii*, *Machaeranthera canescens*, and *Penstemon speciosus*. In 2013, seed treatment only improved stand of *Penstemon speciosus* and reduced stand of *Phacelia hastata*. In 2013, sand improved stand of *Chaenactis douglasii* and *Heliomeris multiflora*.

Systems including row cover have been the most consistent factor for improving stand establishment over the years of trials at the Malheur Experiment Station (Shock et al. 2011, 2012, and 2013). Seed treatment, sawdust, and sand are factors that for some species in some trials have shown value in improving stand, but their performance has not been consistent.

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Table 1. Planting systems evaluated for emergence of eight native plant species in 2014. Mouse bait packs were scattered over the trial area. Malheur Experiment Station, Oregon State University, Ontario, OR.

No.	Row cover	Seed treatment*	Sawdust	Sand	Mulch
1	yes	yes	yes	no	no
2	yes	yes	no	no	no
3	yes	no	yes	no	no
4	no	yes	yes	no	no
5	yes	yes	yes	yes	no
6	no	yes	no	no	yes
7	no	no	no	no	no

*Mixture of Captan and Thiram fungicides for prevention of seed decomposition and seedling damping off.

Table 2. Seed weights and tetrazolium test (seed viability) for seed submitted to emergence treatments in fall 2013 and evaluated in spring 2014. Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	Common name	Untreated seed weight	Tetrazolium test
		seeds/g	%
<i>Chaenactis douglasii</i>	Douglas' dustymaiden	787	71.0
<i>Machaeranthera canescens</i>	hoary tansyaster	2,321	84.0
<i>Phacelia hastata</i>	silverleaf phacelia	1,471	98.0
<i>Phacelia linearis</i>	threadleaf phacelia	2,843	98.0
<i>Heliomeris multiflora</i>	showy goldeneye	1,700	83.0
<i>Ligusticum porteri</i>	Porter's licorice-root	158	77.0
<i>Ligusticum canbyi</i>	Canby's licorice-root	238	54.0
<i>Penstemon speciosus</i>	showy penstemon	710	89.0

Table 3. Plant stands of eight native plant species on April 18, 2014 in response to seven planting systems used in 2013. Emergence for each species was corrected to the percent emergence of viable seed. Oregon State University, Malheur Experiment Station, Ontario, OR.

Species	Row cover, seed treatment, sawdust	Row cover, seed treatment	Row cover, sawdust	Seed treatment, sawdust	Row cover, seed treatment, sawdust, sand	Seed treatment, mulch	Untreated check	LSD (0. 05)
	-----% Stand-----							
<i>Chaenactis douglasii</i>	36.0	34.7	49.9	15.8	57.0	33.1	11.3	26.8
<i>Machaeranthera canescens</i>	67.3	63.0	76.4	28.4	70.2	8.6	26.4	31.6
<i>Phacelia hastata</i>	11.5	15.0	11.3	4.1	7.7	15.0	3.9	NS
<i>Phacelia linearis</i>	2.6	2.7	9.0	0.5	0.6	1.2	1.6	NS
<i>Heliomeris multiflora</i>	13.5	16.4	19.9	4.2	13.7	0.5	8.8	NS
<i>Ligusticum porteri</i>	1.1	0.4	0.9	0.0	0.9	0.2	0.0	0.7
<i>Ligusticum canbyi</i>	1.3	0.5	2.7	1.5	1.9	0.0	0.0	NS
<i>Penstemon speciosus</i>	5.4	1.7	1.9	1.9	12.2	1.9	0.7	6.1

B. Forb Response to Post-emergence Herbicides

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Introduction

Weed control methods are needed for the production of native wildflower seeds. Herbicides were tested for post emergence weed control. The methods and products reported here are not registered for use and do not construe recommendations. Growers should always carefully follow product labels.

Materials and Methods

Seed of 12 wildflower species were planted on the soil surface during fall 2013 (Table 1). After planting, a protective ground cover was immediately placed on each bed. The protective ground cover was removed on April 2, 2014.

Before planting, drip tape (T-Tape TSX 515-16-340) was buried at 12-inch depth midway between each pair of 30-inch rows. The flow rate for the drip tape was 0.34 gal/min/100ft at 8 psi with emitters spaced 16 inches apart, resulting in a water application rate of 0.066 inch/hour. Treatments to evaluate forb species tolerance to various herbicides were applied post emergence on April 16 (early) or May 14, 2014 (late). The treatments were broadcast using a CO₂ sprayer with 8002 nozzles at 30 psi applying 20 gal/acre. The study had a randomized complete block design with four replications. Each plot consisted of 12 single rows (one row/wildflower species) and 7.33 ft wide. Herbicides were sprayed perpendicular to the rows, with all 12 species/plot sprayed in a single pass. Subjective plant damage ratings were taken in each plot on June 16, 2014.

Results and Discussion

Eight species had good stand (Table 2). *Lomatium dissectum* (fernleaf biscuitroot), *Phacelia linearis* (threadleaf phacelia), *Ligusticum porteri* (Porter's licorice-root), and *Ligusticum canbyi* (Canby's licorice-root) did not emerge.

Evaluations on June 14 indicated very high injury for the plants that were sprayed on April 16, 2014 (data not shown). All annual plant species were killed and perennial species were severely stunted. Evaluations indicated some level of herbicide tolerance for plants sprayed on May 14, 2014 (Table 2). *Sphaeralcea grossulariifolia*, *Eriogonum umbellatum*, *Penstemon speciosus*, and *Achillea millefolium* suffered injury ranging from 24 to 95% across the herbicide treatments. The injury was characterized by stunting and reduced flowering. Injury for *Machaeranthera canescens*, *Heliomeris multiflora*, *Chaenactis douglasii*, and *Phacelia hastata* ranged from 4 to 58%.

These results suggest that these wildflower species may be very sensitive to the herbicides evaluated, especially when applied early after removing the ground cover. However, it is possible that directed sprays between rows using protective shields (though not tested in this study) could be an option for weed control in forbs. These treatments will be applied in the same plots in 2015 to evaluate the response of perennial species that will have well-established root systems.

Table 1. Wildflower species planted in the fall of 2013 for the herbicide trial at the Malheur Experiment Station, Oregon State University, Ontario, OR.

	Species	Common name
1	<i>Lomatium dissectum</i>	fernleaf biscuitroot
2	<i>Sphaeralcea grossulariifolia</i>	gooseberryleaf globemallow
3	<i>Eriogonum umbellatum</i>	sulphur-flower buckwheat
4	<i>Penstemon speciosus</i>	royal penstemon, sagebrush penstemon
5	<i>Achillea millefolium</i>	yarrow
6	<i>Machaeranthera canescens</i>	hoary tansyaster
7	<i>Heliomeris multiflora</i>	showy goldeneye
8	<i>Chaenactis douglasii</i>	Douglas' dustymaiden
9	<i>Phacelia hastata</i>	silverleaf phacelia
10	<i>Phacelia linearis</i>	threadleaf phacelia
11	<i>Ligusticum porteri</i>	Porter's licorice-root
12	<i>Ligusticum canbyi</i>	Canby's licorice-root

Table 2. Response of eight forbs to post emergence herbicides for weed control in 2014. Malheur Experiment Station, Ontario, OR.

Treatment	Rate	Unit	Product rate	Injury ^a								
				<i>Sphaeralcea grossulariifolia</i>	<i>Eriogonum umbellatum</i>	<i>Penstemon speciosus</i>	<i>Achillea millefolium</i>	<i>Machaeranthera canescens</i>	<i>Heliomeris multiflora</i>	<i>Chaenactis douglasii</i>	<i>Phacelia hastata</i>	
				----- % -----								
1 Untreated					0c	0b	0b	0c	0d	0a	0b	0b
2 Buctril	0.125	lb ai/a	0.5 pt/a		73a	30b	11b	24bc	21ab	11a	5b	58a
Prowl H2O	0.95	lb ai/a	2 pt/a									
3 GoalTender	0.25	lb ai/a	0.5 pt/a		23bc	31b	39ab	24bc	14bc	6a	4b	48ab
Prowl H2O	0.95	lb ai/a	2 pt/a									
4 Buctril	0.125	lb ai/a	0.5 pt/a		83a	31b	43ab	40ab	31a	11a	23ab	35ab
GoalTender	0.25	lb ai/a	0.5 pt/a									
Prowl H2O	0.95	lb ai/a	2 pt/a									
5 Valor (Chateau)	0.128	lb ai/a	4 oz/a		74a	21b	79a	31ab	8cd	11a	13b	35ab
Prowl H2O	0.95	lb ai/a	2 pt/a									
6 Basagran	1.125	lb ai/a	2.25 pt/a		65ab	30b	53ab	58a	23ab	6a	8b	14ab
Prowl H2O	0.95	lb ai/a	2 pt/a									
7 Linex	1	lb ai/a	2 pt/a		55ab	91a	73a	38ab	14bc	11a	40a	16ab
Prowl H2O	0.95	lb ai/a	2 pt/a									
8 Raptor	0.0156	lb ae/a	0.125 pt/a		95a	33b	46ab	35ab	18bc	1a	5b	54a
Basagran	1.125	lb ai/a	2.25 pt/a									
Prowl H2O	0.95	lb ai/a	2 pt/a									
LSD (P=0.05)					49	33	53	28	13	14	23	48

^a Means within a column followed by same letter do not significantly differ (P=0.05, LSD)

C. Irrigation Requirements for Native Perennial Wildflower Seed Production in a Semi-arid Environment

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Introduction

Native wildflower seed is needed to restore rangelands of the Intermountain West. Commercial seed production is necessary to provide the quantity of seed needed for restoration efforts. A major limitation to economically viable commercial production of native wildflower (forb) seed is stable and consistent seed productivity over years.

In native rangelands, the natural variations in spring rainfall and soil moisture result in highly unpredictable water stress at flowering, seed set, and seed development, which for other seed crops is known to compromise seed yield and quality.

Native wildflower plants are not well adapted to croplands. They often are not competitive with crop weeds in cultivated fields. Poor competitiveness with weeds could also limit wildflower seed production. Both sprinkler and furrow irrigation could provide supplemental water for seed production, but these irrigation systems risk further encouraging weeds. Also, sprinkler and furrow irrigation can lead to the loss of plant stand and seed production due to fungal pathogens. By burying drip tapes at 12-inch depth and avoiding wetting the soil surface, we hoped to assure flowering and seed set without undue encouragement of weeds or opportunistic diseases. The trials reported here tested the effects of three low rates of irrigation on the seed yield of 13 native wildflower species.

Materials and Methods

Plant Establishment

Seed of seven Intermountain West wildflower species (the first seven species in Table 1) was received in late November in 2004 from the Rocky Mountain Research Station (Boise, ID). The plan was to plant the seed in the fall of 2004, but due to excessive rainfall in October, the ground preparation was not completed and planting was postponed to early 2005. To try to ensure germination, the seed was submitted to cold stratification. The seed was soaked overnight in distilled water on January 26, 2005, after which the water was drained and the seed soaked for 20 min in a 10 percent by volume solution of 13 percent bleach in distilled water. The water was drained and the seed was placed in thin layers in plastic containers. The plastic containers had lids with holes drilled in them to allow air movement. These containers were placed in a cooler set at approximately 34°F. Every few days the seed was mixed and, if necessary, distilled water added to maintain seed moisture. In late February, seed of *Lomatium grayi* and *L. triternatum* (see Table 1 for common names) had started to sprout.

In late February 2005, drip tape (T-Tape TSX 515-16-340) was buried at 12-inch depth between two 30-inch rows of a Nyssa silt loam with a pH of 8.3 and 1.1 percent organic matter. The drip tape was buried in alternating inter-row spaces (5 ft apart). The flow rate for the drip tape was

0. 34 gal/min/100ft at 8 psi with emitters spaced 16 inches apart, resulting in a water application rate of 0.066 inch/hour.

On March 3, seed of the first seven species in Table 1 was planted in 30-inch rows using a custom-made plot grain drill with disc openers. All seed was planted at 20-30 seeds/ft. of row. The *Eriogonum umbellatum* and the *Penstemon* spp. were planted at 0.25-inch depth and the *Lomatium* spp. at 0.5-inch depth. The trial was irrigated with a minisprinkler system (R10 Turbo Rotator, Nelson Irrigation Corp., Walla Walla, WA) for even stand establishment from March 4 to April 29. Risers were spaced 25 ft apart along the flexible polyethylene hose laterals that were spaced 30 ft apart and the water application rate was 0.10 inch/hour. A total of 1.72 inches of water was applied with the minisprinkler system. *Eriogonum umbellatum*, *Lomatium triternatum*, and *L. grayi* started emerging on March 29. All other species except *L. dissectum* emerged by late April. Starting June 24, the field was irrigated with the drip system. A total of 3.73 inches of water was applied with the drip system from June 24 to July 7. The field was not irrigated further in 2005.

Plant stands for *Eriogonum umbellatum*, *Penstemon* spp., *Lomatium triternatum*, and *L. grayi* were uneven. *Lomatium dissectum* did not emerge. None of the species flowered in 2005. In early October, 2005, more seed was received from the Rocky Mountain Research Station for replanting. The empty lengths of row were replanted by hand in the *E. umbellatum* and *Penstemon* spp. plots. The *Lomatium* spp. plots had the entire row lengths replanted using the planter. The seed was replanted on October 26, 2005. In the spring of 2006, the plant stands of the replanted species were excellent, except for *P. deustus*.

On April 11, 2006, seed of three globemallow species (*Sphaeralcea parvifolia*, *S. grossulariifolia*, *S. coccinea*), two prairie clover species (*Dalea searlsiae*, *D. ornata*), and basalt milkvetch (*Astragalus filipes*) was planted at 30 seeds/ft of row. The field was sprinkler irrigated until emergence. Emergence was poor. In late August of 2006, seed of the three globemallow species was harvested by hand. On November 9, 2006, the six wildflowers that were planted in 2006 were mechanically flailed and on November 10, they were replanted. On November 11, the *Penstemon deustus* plots were also replanted at 30 seeds/ft of row.

Table 1. Wildflower species planted in the drip irrigation trials at the Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	Common names
<i>Eriogonum umbellatum</i>	Sulphur-flower buckwheat
<i>Penstemon acuminatus</i>	Sharpleaf penstemon, sand-dune penstemon
<i>Penstemon deustus</i>	Scabland penstemon, hotrock penstemon
<i>Penstemon speciosus</i>	Royal penstemon, sagebrush penstemon
<i>Lomatium dissectum</i>	Fernleaf biscuitroot
<i>Lomatium triternatum</i>	Nineleaf biscuitroot, nineleaf desert parsley
<i>Lomatium grayi</i>	Gray's biscuitroot, Gray's lomatium
<i>Sphaeralcea parvifolia</i>	Smallflower globemallow
<i>Sphaeralcea grossulariifolia</i>	Gooseberryleaf globemallow
<i>Sphaeralcea coccinea</i>	Scarlet globemallow, red globemallow

Irrigation for Seed Production

In April, 2006 each planted strip of each wildflower species was divided into plots 30 ft long. Each plot contained four rows of each species. The experimental designs were randomized complete blocks with four replicates. The three treatments were a non-irrigated check, 1 inch of water applied per irrigation, and 2 inches of water applied per irrigation. Each treatment received 4 irrigations that were applied approximately every 2 weeks starting with flowering of the wildflowers. The amount of water applied to each treatment was calculated by the length of time necessary to deliver 1 or 2 inches through the drip system. Irrigations were regulated with a controller and solenoid valves. After each irrigation the amount of water applied was read on a water meter and recorded to ensure correct water applications.

In March of 2007, the drip-irrigation system was modified to allow separate irrigation of the species due to different timings of flowering. The three *Lomatium* spp. were irrigated together and *Penstemon deustus* and *P. speciosus* were irrigated together, but separately from the others. *Penstemon acuminatus* and *Eriogonum umbellatum* were irrigated individually. In early April, 2007 the three globemallow species, two prairie clover species, and basalt milkvetch were divided into plots with a drip-irrigation system to allow the same irrigation treatments that were received by the other wildflowers.

Irrigation dates are found in Table 2. In 2007, irrigation treatments were inadvertently continued after the fourth irrigation. Irrigation treatments for all species were continued until the last irrigation on June 24, 2007.

Soil volumetric water content was measured by neutron probe. The neutron probe was calibrated by taking soil samples and probe readings at 8-, 20-, and 32-inch depths during installation of the access tubes. The soil water content was determined volumetrically from the soil samples and regressed against the neutron probe readings separately for each soil depth. Regression equations were then used to transform the neutron probe readings into volumetric soil water content.

Flowering, Harvesting, and Seed Cleaning

Flowering dates for each species were recorded (Table 2). The *Eriogonum umbellatum* and *Penstemon* spp. plots produced seed in 2006, in part because they had emerged in the spring of 2005. Each year, the middle two rows of each plot were harvested when seed of each species was mature (Table 2), using the methods listed in Table 3. The plant stand for *P. deustus* was too poor to result in reliable seed yield estimates. Replanting *P. deustus* in fall 2006 did not result in adequate plant stand in the spring of 2007.

Eriogonum umbellatum seeds did not separate from the flowering structures in the combine; the unthreshed seed was taken to the U. S. Forest Service Lucky Peak Nursery (Boise, ID) and run through a dewinger to separate seed. The seed was further cleaned in a small clipper seed cleaner.

Penstemon deustus seed pods were too hard to be opened in the combine; the unthreshed seed was precleaned in a small clipper seed cleaner and then seed pods were broken manually by rubbing the pods on a ribbed rubber mat. The seed was then cleaned again in the small clipper seed cleaner.

Penstemon acuminatus and *P. speciosus* were threshed in the combine and the seed was further cleaned using a small clipper seed cleaner.

Cultural Practices in 2006

On October 27, 2006, 50 lb. phosphorus (P)/acre and 2 lb. zinc (Zn)/acre were injected through the drip tape to all plots of *Eriogonum umbellatum*, *Penstemon* spp., and *Lomatium* spp. On November 11, 100 lb. nitrogen (N)/acre as urea was broadcast to all *Lomatium* spp. plots. On November 17, all plots of *Eriogonum umbellatum*, *Penstemon* spp. (except *P. deustus*), and *Lomatium* spp. had Prowl® at 1 lb. ai/acre broadcast on the soil surface. Irrigations for all species were initiated on May 19 and terminated on June 30. Harvesting and seed cleaning methods for each species are listed in Table 3.

Cultural Practices in 2007

Penstemon acuminatus and *P. speciosus* were sprayed with Aza-Direct® at 0.0062 lb. ai/acre on May 14 and 29 for lygus bug control. Irrigations for each species were initiated and terminated on different dates (Table 2). Harvesting and seed cleaning methods for each species are listed in Table 3. All plots of the *Sphaeralcea* spp. were flailed on November 8, 2007.

Cultural Practices in 2008

On November 9, 2007 and on April 15, 2008, Prowl® at 1 lb. ai/acre was broadcast on all plots for weed control. Capture® 2EC at 0.1 lb. ai/acre was sprayed on all plots of *Penstemon acuminatus* and *P. speciosus* on May 20 for lygus bug control. Irrigations for each species were initiated and terminated on different dates (Table 2). Harvesting and seed cleaning methods for each species are listed in Table 3.

Cultural Practices in 2009

On March 18, Prowl® at 1 lb. ai/acre and Volunteer® at 8 oz/acre were broadcast on all plots for weed control. On April 9, 50 lb. N/acre and 10 lb. P/acre were applied through the drip irrigation system to the three *Lomatium* spp.

The flowering, irrigation timing, and harvest timing were recorded for each species (Table 2). Harvesting and seed cleaning methods for each species are listed in Table 3. On December 4, 2009, Prowl at 1 lb. ai/acre was broadcast for weed control on all plots.

Cultural Practices in 2010

The flowering, irrigation, and harvest timing of the established wildflowers were recorded for each species (Table 2). Harvesting and seed cleaning methods for each species are listed in Table 3. On November 17, Prowl® at 1 lb. ai/acre was broadcast on all plots for weed control.

Cultural Practices in 2011

On May 3, 2011, 50 lb. N/acre was applied to all *Lomatium* spp. plots as Uran (urea ammonium nitrate) injected through the drip tape. The timing of flowering, irrigations, and harvests varied by species (Table 2). Harvesting and seed cleaning methods for each species are listed in Table 3. On November 9, Prowl® at 1 lb. ai/acre was broadcast on all plots for weed control.

Cultural Practices in 2012

The soil volumetric water content was very low in 2012 prior to the onset of irrigation for each species. Iron deficiency symptoms were prevalent in 2012. On April 13, 50 lb. N/acre, 10 lb. P/acre, and 0.3 lb. iron (Fe)/acre was applied to all *Lomatium* spp. plots as liquid fertilizer injected through the drip tape. On November 7, Prowl[®] at 1 lb. ai/acre was broadcast on all plots of *Eriogonum umbellatum*, *Lomatium grayi*, *Lomatium dissectum*, and *Lomatium triternatum* for weed control.

Cultural Practices in 2013

On March 29, 20 lb. N/acre, 25 lb. P/acre, and 0.3 lb. Fe/acre were applied through the drip tape to all plots of *Lomatium grayi*, *Lomatium dissectum*, and *Lomatium triternatum*. On April 3, Select Max at 32 oz/acre was broadcast for grass weed control on all plots of *Eriogonum umbellatum*, *Lomatium grayi*, *Lomatium dissectum*, *Lomatium triternatum*, and *Penstemon speciosus*.

Cultural Practices in 2014

On February 26, Prowl[®] at 1 lb. ai/acre and Select Max at 32 oz/acre were broadcast on all plots of *Eriogonum umbellatum*, *Lomatium grayi*, *Lomatium dissectum*, and *Lomatium triternatum* for weed control. On April 2, 20 lb. N/acre, 25 lb. P/acre, and 0.3 lb. Fe/acre were applied through the drip tape to all plots of *Lomatium grayi*, *Lomatium dissectum*, and *Lomatium triternatum*. On April 18, Orthene at 8 oz/acre was broadcast to all plots of *Penstemon speciosus* for lygus bug control. On April 29, 5 lb. Fe/acre was applied through the drip tape to all plots of *Penstemon speciosus*.

Table 2, continued on next pages. Native wildflower flowering, irrigation, and seed harvest dates by species in 2006-2014, Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	Flowering			Irrigation		Harvest
	Start	Peak	End	Start	End	
2006						
<i>Eriogonum umbellatum</i>	19-May		20-Jul	19-May	30-Jun	3-Aug
<i>Penstemon acuminatus</i>	2-May	10-May	19-May	19-May	30-Jun	7-Jul
<i>Penstemon deustus</i>	10-May	19-May	30-May	19-May	30-Jun	4-Aug
<i>Penstemon speciosus</i>	10-May	19-May	30-May	19-May	30-Jun	13-Jul
<i>Lomatium dissectum</i>				19-May	30-Jun	
<i>Lomatium triternatum</i>				19-May	30-Jun	
<i>Lomatium grayi</i>				19-May	30-Jun	
<i>Sphaeralcea parvifolia</i>						
<i>S. grossulariifolia</i>						
<i>Sphaeralcea coccinea</i>						
2007						
<i>Eriogonum umbellatum</i>	25-May		25-Jul	2-May	24-Jun	31-Jul
<i>Penstemon acuminatus</i>	19-Apr		25-May	19-Apr	24-Jun	9-Jul
<i>Penstemon deustus</i>	5-May	25-May	25-Jun	19-Apr	24-Jun	
<i>Penstemon speciosus</i>	5-May	25-May	25-Jun	19-Apr	24-Jun	23-Jul
<i>Lomatium dissectum</i>				5-Apr	24-Jun	
<i>Lomatium triternatum</i>	25-Apr		1-Jun	5-Apr	24-Jun	29-Jun, 16-Jul
<i>Lomatium grayi</i>	5-Apr		10-May	5-Apr	24-Jun	30-May, 29-Jun
<i>Sphaeralcea parvifolia</i>	5-May	25-May		16-May	24-Jun	20-Jun, 10-Jul, 13-Aug
<i>S. grossulariifolia</i>	5-May	25-May		16-May	24-Jun	20-Jun, 10-Jul, 13-Aug
<i>Sphaeralcea coccinea</i>	5-May	25-May		16-May	24-Jun	20-Jun, 10-Jul, 13-Aug
2008						
<i>Eriogonum umbellatum</i>	5-Jun	19-Jun	20-Jul	15-May	24-Jun	24-Jul
<i>Penstemon acuminatus</i>	29-Apr		5-Jun	29-Apr	11-Jun	11-Jul
<i>Penstemon deustus</i>	5-May		20-Jun	29-Apr	11-Jun	
<i>Penstemon speciosus</i>	5-May		20-Jun	29-Apr	11-Jun	17-Jul
<i>Lomatium dissectum</i>				10-Apr	29-May	
<i>Lomatium triternatum</i>	25-Apr		5-Jun	10-Apr	29-May	3-Jul
<i>Lomatium grayi</i>	25-Mar		15-May	10-Apr	29-May	30-May, 19-Jun
<i>Sphaeralcea parvifolia</i>	5-May		15-Jun	15-May	24-Jun	21-Jul
<i>S. grossulariifolia</i>	5-May		15-Jun	15-May	24-Jun	21-Jul
<i>Sphaeralcea coccinea</i>	5-May		15-Jun	15-May	24-Jun	21-Jul

Table 2, continued. Native wildflower flowering, irrigation, and seed harvest dates by species in 2006-2014. Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	Flowering			Irrigation		Harvest
	start	peak	end	start	end	
2009						
<i>Eriogonum umbellatum</i>	31-May		15-Jul	19-May	24-Jun	28-Jul
<i>Penstemon acuminatus</i>	2-May		10-Jun	8-May	12-Jun	10-Jul
<i>Penstemon deustus</i>				19-May	24-Jun	
<i>Penstemon speciosus</i>	14-May		20-Jun	19-May	24-Jun	10-Jul
<i>Lomatium dissectum</i>	10-Apr		7-May	20-Apr	28-May	16-Jun
<i>Lomatium triternatum</i>	10-Apr	7-May	1-Jun	20-Apr	28-May	26-Jun
<i>Lomatium grayi</i>	10-Mar		7-May	20-Apr	28-May	16-Jun
<i>Sphaeralcea parvifolia</i>	1-May		10-Jun	22-May	24-Jun	14-Jul
<i>Sphaeralcea grossulariifolia</i>	1-May		10-Jun	22-May	24-Jun	14-Jul
<i>Sphaeralcea coccinea</i>	1-May		10-Jun	22-May	24-Jun	14-Jul
2010						
<i>Eriogonum umbellatum</i>	4-Jun	12-19 Jun	15-Jul	28-May	8-Jul	27-Jul
<i>Penstemon speciosus</i>	14-May		20-Jun	12-May	22-Jun	22-Jul
<i>Lomatium dissectum</i>	25-Apr		20-May	15-Apr	28-May	21-Jun
<i>Lomatium triternatum</i>	25-Apr		15-Jun	15-Apr	28-May	22-Jul
<i>Lomatium grayi</i>	15-Mar		15-May	15-Apr	28-May	22-Jun
<i>Sphaeralcea parvifolia</i>	10-May	4-Jun	25-Jun	28-May	8-Jul	20-Jul
<i>Sphaeralcea grossulariifolia</i>	10-May	4-Jun	25-Jun	28-May	8-Jul	20-Jul
<i>Sphaeralcea coccinea</i>	10-May	4-Jun	25-Jun	28-May	8-Jul	20-Jul
2011						
<i>Eriogonum umbellatum</i>	8-Jun	30-Jun	20-Jul	20-May	5-Jul	1-Aug
<i>Penstemon speciosus</i>	25-May	30-May	30-Jun	20-May	5-Jul	29-Jul
<i>Lomatium dissectum</i>	8-Apr	25-Apr	10-May	21-Apr	7-Jun	20-Jun
<i>Lomatium triternatum</i>	30-Apr	23-May	15-Jun	21-Apr	7-Jun	26-Jul
<i>Lomatium grayi</i>	1-Apr	25-Apr	13-May	21-Apr	7-Jun	22-Jun
<i>Sphaeralcea parvifolia</i>	26-May	15-Jun	14-Jul	20-May	5-Jul	29-Jul
<i>Sphaeralcea grossulariifolia</i>	26-May	15-Jun	14-Jul	20-May	5-Jul	29-Jul
<i>Sphaeralcea coccinea</i>	26-May	15-Jun	14-Jul	20-May	5-Jul	29-Jul

Table 2, continued. Native wildflower flowering, irrigation, and seed harvest dates by species in 2006-2014. Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	Flowering			Irrigation		Harvest
	start	peak	end	start	end	
2012						
<i>Eriogonum umbellatum</i>	30-May	20-Jun	4-Jul	30-May	11-Jul	24-Jul
<i>Penstemon speciosus</i>	2-May	20-May	25-Jun	2-May	13-Jun	13-Jul
<i>Lomatium dissectum</i>	9-Apr	16-Apr	16-May	13-Apr	24-May	4-Jun
<i>Lomatium triternatum</i>	12-Apr	17-May	6-Jun	13-Apr	24-May	21-Jun
<i>Lomatium grayi</i>	15-Mar	25-Apr	16-May	13-Apr	24-May	14-Jun
2013						
<i>Eriogonum umbellatum</i>	8-May	27-May	27-Jun	8-May	19-Jun	9-Jul
<i>Penstemon speciosus</i>	2-May	10-May	20-Jun	2-May	12-Jun	11-Jul
<i>Lomatium dissectum</i>	10-Apr		25-Apr	4-Apr	16-May	4-Jun
<i>Lomatium triternatum</i>	18-Apr		10-May	4-Apr	16-May	4-Jun
<i>Lomatium grayi</i>	15-Mar		30-Apr	4-Apr	16-May	10-Jun
2014						
<i>Eriogonum umbellatum</i>	20-May	4-Jun	1-Jul	13-May	24-Jun	10-Jul
<i>Penstemon speciosus</i>	29-Apr	13-May	9-Jun	29-Apr	10-Jun	11-Jul
<i>Lomatium dissectum</i>	28-Mar		21-Apr	7-Apr	20-May	2-Jun
<i>Lomatium triternatum</i>	7-Apr	29-Apr	May 2	7-Apr	20-May	4-Jun
<i>Lomatium grayi</i>	28-Mar		May 2	7-Apr	20-May	10-Jun

Table 3. Native wildflower seed harvest and cleaning by species, Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	Number of harvests/year	Harvest method	Pre-cleaning	Threshing method	Cleaning method
<i>Eriogonum umbellatum</i>	1	combine ^a	none	dewinger ^b	mechanical ^c
<i>Penstemon acuminatus</i>	1	combine ^d	none	combine	mechanical ^c
<i>Penstemon deustus</i>	1	combine ^a	mechanical ^c	hand ^c	mechanical ^c
<i>Penstemon speciosus</i> ^f	1	combine ^d	none	combine	mechanical ^c
<i>Lomatium dissectum</i>	1	hand	hand	none	mechanical ^c
<i>Lomatium triternatum</i>	1–2	hand	hand	none	mechanical ^c
<i>Lomatium grayi</i>	1–2	hand	hand	none	mechanical ^c
<i>Sphaeralcea parvifolia</i>	1–3	hand or combine ^d	none	combine	none
<i>Sphaeralcea grossulariifolia</i>	1–3	hand or combine ^d	none	combine	none
<i>Sphaeralcea coccinea</i>	1–3	hand or combine ^d	none	combine	none
<i>Dalea searlsiae</i>	0 or 2	hand	none	dewinger	mechanical ^c
<i>Dalea ornate</i>	0 or 2	hand	none	dewinger	mechanical ^c

^a Wintersteiger Nurserymaster small-plot combine with dry bean concave.

^b Specialized seed threshing machine at USDA Lucky Peak Nursery used in 2006. Thereafter an adjustable hand-driven corn grinder was used to thresh seed.

^c Clipper seed cleaner.

^d Wintersteiger Nurserymaster small-plot combine with alfalfa seed concave. For the *Sphaeralcea* spp., flailing in the fall of 2007 resulted in more compact growth and one combine harvest in 2008, 2009, and 2010.

^e Hard seed pods were broken by rubbing against a ribbed rubber mat.

^f Harvested by hand in 2007 and 2009 due to poor seed set.

Results and Discussion

Precipitation from January through June in 2014 was 5.1 inches, close to the average of 5.8 inches (Table 4). The accumulated growing degree-days (50–86°F) from January through June in 2014 were higher than average (Table 4, Figure 1 and 2).

Flowering and Seed Set

Penstemon acuminatus and *P. speciosus* had poor seed set in 2007, partly due to a heavy lygus bug infestation that was not adequately controlled by the applied insecticides. In the Treasure Valley, the first hatch of lygus bugs occurs when 250 degree-days (52°F base) are accumulated. Data collected by an AgriMet weather station adjacent to the field indicated that the first lygus bug hatch occurred on May 14, 2006; May 1, 2007; May 18, 2008; May 19, 2009; and May 29, 2010. The average (1995–2010) lygus bug hatch date was May 18. *Penstemon acuminatus* and *P. speciosus* start flowering in early May. The earlier lygus bug hatch in 2007 probably resulted in harmful levels of lygus bugs present during a larger part of the *Penstemon* spp. flowering period than normal. Poor seed set for *P. acuminatus* and *P. speciosus* in 2007 also was related to poor vegetative growth compared to 2006 and 2008. In 2009 all plots of *P. acuminatus* and *P. speciosus* again showed poor vegetative growth and seed set. Root rot affected all plots of *P. acuminatus* in 2009, killing all plants in two of the four plots of the wettest treatment (2 inches

per irrigation). Root rot affected the wetter plots of *P. speciosus* in 2009, but the stand partially recovered due to natural reseeding.

The three *Sphaeralcea* spp. showed a long flowering period (early May through September) in 2007. Multiple manual harvests were necessary because the seed falls out of the capsules once they are mature. The flailing of the three *Sphaeralcea* spp. starting in the fall of 2007 was done annually to induce a more concentrated flowering, allowing only one mechanical harvest. Precipitation in June of 2009 (2.27 inches) and 2010 (1.95 inches) was substantially higher than average (0.76 inches). Rust (*Puccinia sherardiana*) infected all three *Sphaeralcea* spp. in June of 2009 and 2010, causing substantial leaf loss and reduced vegetative growth. Stand of all three *Sphaeralcea* spp. deteriorated in 2011 and the plots were disked out in 2012.

Eriogonum umbellatum

In 2006, seed yield of *Eriogonum umbellatum* increased with increasing water application, up to 8 inches, the highest amount tested (Tables 5 and 7). In 2007-2009 seed yield showed a quadratic response to irrigation rate (Tables 6 and 7). Seed yields were maximized by 8.1 inches, 7.2 inches, and 6.9 inches of water applied in 2007, 2008, and 2009, respectively. In 2010, there was no significant difference in yield between treatments. In 2011, seed yield was highest with no irrigation. The 2010 and 2011 seasons had unusually cool (Table 4, Figure 2) and wet weather (Figure 2). The accumulated precipitation in April through June of 2010 and 2011 was the highest over the years of the trial (Table 4). The relatively high seed yield of *E. umbellatum* in the non-irrigated treatment in 2010 and 2011 seemed to be related to the high spring precipitation. The negative effect of irrigation on seed yield in 2011 might have been related to the presence of rust. Irrigation could have exacerbated the rust and resulted in lower yields. In 2012, seed yield of *Eriogonum umbellatum* increased with increasing water application, up to 8 inches, the highest amount tested (Tables 6 and 7). In 2013 and 2014, seed yields showed quadratic responses to irrigation rate. Seed yield was maximized by 5.7 inches and by 5.3 inches of water applied in 2013 and 2014, respectively. Averaged over 9 years, seed yield of *E. umbellatum* showed a quadratic response to irrigation rate with the highest yield achieved with 6.9 inches of water applied.

Penstemon acuminatus

There was no significant difference in seed yield between irrigation treatments for *P. acuminatus* in 2006 (Table 5). Precipitation from March through June was 6.4 inches in 2006. The 64-year-average precipitation from March through June is 3.6 inches. The wet weather in 2006 could have attenuated the effects of the irrigation treatments. In 2007 seed yield showed a quadratic response to irrigation rate. Seed yields were maximized by 4.0 inches of water applied in 2007. In 2008, seed yield showed a linear response to applied water. In 2009 there was no significant difference in seed yield between treatments (Table 7). However, due to root rot affecting all plots in 2009, the seed yield results were compromised. By 2010, substantial lengths of row contained only dead plants. Measurements in each plot showed that plant death increased with increasing irrigation rate. The stand loss was 51.3, 63.9, and 88.5 percent for the 0-, 4-, and 8-inch irrigation treatments, respectively. The trial area was disked out in 2010. Following the 2005 planting, seed yields were substantial in 2006 and moderate in 2008. *P. acuminatus* performed as a short-lived perennial.

Penstemon speciosus

In 2006-2009 seed yield of *P. speciosus* showed a quadratic response to irrigation rate (Tables 5, 6, and 7). Seed yields were maximized by 4.3, 4.2, 5.0, and 4.3 inches of water applied in 2006, 2007, 2008, and 2009, respectively. In 2010, 2011, and 2012 there was no difference in seed yield between treatments. Seed yield was low in 2007 due to lygus bug damage, as discussed previously. Seed yield in 2009 was low due to stand loss from root rot. The plant stand recovered somewhat in 2010 and 2011, due in part to natural reseeding, especially in the non-irrigated plots. In 2013, seed yield increased with increasing water application, up to 8 inches, the highest amount tested. In 2014 seed yield of *P. speciosus* showed a quadratic response to irrigation rate with the calculated optimum of 276 lb. /acre at 5.2 inches of irrigation water. Averaged over 9 years, seed yield was maximized by 5.0 inches of water applied.

Lomatium triternatum

Lomatium triternatum showed a trend for increasing seed yield with increasing irrigation rate in 2007 (Table 5). The highest irrigation rate resulted in significantly higher seed yield than the non-irrigated check in seven of the last 8 years. Seed yields of *L. triternatum* were substantially higher in 2008-2011 (Tables 6 and 7). In 2008-2011 seed yields of *L. triternatum* showed a quadratic response to irrigation rate. Seed yields were estimated to be maximized by 8.4, 5.4, 7.8, and 4.1 inches of water applied in 2008, 2009, 2010, and 2011, respectively. In 2012, 2013, and 2014 seed yield increased linearly with increasing water applied up to the highest amount of water applied, 8 inches. Over 8 years, seed yield of *L. triternatum* was estimated to be maximized at 1328 lb. /acre/year at 6.9 inches of applied water (Table 7).

Lomatium grayi

Lomatium grayi showed a trend for increasing seed yield with increasing irrigation rate in 2007 (Table 5). The highest irrigation rate resulted in significantly higher seed yield than the non-irrigated check in six of the last eight years. Seed yields of *L. grayi* were substantially higher in 2008 and 2009. In 2008, seed yields of *L. grayi* showed a quadratic response to irrigation rate. Seed yields were estimated to be maximized by 6.9 inches of water applied in 2008. In 2009, seed yield showed a linear response to irrigation rate (Tables 6 and 7). Seed yield with the 4-inch irrigation rate was significantly higher than in the non-irrigated check, but the 8-inch irrigation rate did not result in a significant increase above the 4-inch rate.

In 2010, seed yield was not responsive to irrigation, possibly caused by the unusually wet spring of 2010. A further complicating factor in 2010 that compromised seed yields was rodent damage. Extensive rodent (vole) damage occurred over the 2009-2010 winter. The affected areas were transplanted with 3-year-old *L. grayi* plants from an adjacent area in the spring of 2010. To reduce their attractiveness to voles, the plants were mowed after becoming dormant in early fall of 2010 and in each subsequent year. In 2011 seed yield again did not respond to irrigation. The spring of 2011 was unusually cool and wet. In 2012 seed yields of *L. grayi* showed a quadratic response to irrigation rate, with a maximum seed yield at 5.5 inches of applied water. In 2013 seed yield increased linearly with increasing water application, up to 8 inches, the highest amount applied. In 2014 seed yields of *L. grayi* showed a quadratic response to irrigation rate, with a calculated maximum seed yield of 1477 lb. /acre at 5.3 inches of applied water. Over 8 years, seed yield of *L. grayi* was estimated to be maximized at 827 lb. /acre/year by 5.4 inches of

applied water. Most appropriately, irrigation probably should be variable according to precipitation.

Lomatium dissectum

Lomatium dissectum had very little vegetative growth during 2006-2008, and produced only very few flowers in 2008. All the *Lomatium* species tested were affected by *Alternaria* fungus, but the infection was greatest on the *L. dissectum* selection planted in this trial. This infection delayed *L. dissectum* plant development. In 2009, vegetative growth and flowering for *L. dissectum* were improved.

Seed yield of *L. dissectum* showed a linear response to irrigation rate in 2009 (Figure 14). Seed yield with the 4-inch irrigation rate was significantly higher than with the non-irrigated check, but the 8-inch irrigation rate did not result in a significant increase above the 4-inch rate. In 2010 and 2011 seed yields of *L. dissectum* showed a quadratic response to irrigation rate. Seed yields were estimated to be maximized by 5.4 and 5.1 inches of applied water in 2010 and 2011 respectively. In 2012, seed yields of *L. dissectum* were not responsive to irrigation rate. In 2013 and 2014, seed yield increased linearly with increasing irrigation rate up to 8 inches, the highest amount applied. Over the 5 years, seed yield showed a quadratic response to irrigation rate and was estimated to be maximized at 869 lb./acre/year by applying 6.1 inches of applied water.

Sphaeralcea spp.

In 2007-2011, there were no significant differences in seed yield among irrigation treatments for the three *Sphaeralcea* spp. (Tables 5 and 6). Stand of the three *Sphaeralcea* species was poor in 2012 and the plantings were eliminated.

Conclusions

Subsurface drip irrigation systems were tested for native seed production because they have two potential strategic advantages: a) low water use, and b) the buried drip tape provides water to the plants at depth, precluding most irrigation induced stimulation of weed seed germination on the soil surface and keeping water away from native plant tissues that are not adapted to a wet environment.

Due to the arid environment, supplemental irrigation may often be required for successful flowering and seed set because soil water reserves may be exhausted before seed formation. The total irrigation requirements for these arid-land species were low and varied by species (Table 7). The *Sphaeralcea* spp. and *Penstemon acuminatus* did not respond to irrigation in these trials. Natural rainfall was sufficient to maximize seed production in the absence of weed competition.

Lomatium dissectum required approximately 6 inches of irrigation. *Lomatium grayi*, *L. triternatum*, and *Eriogonum umbellatum* responded quadratically to irrigation with the optimum varying by year. *Penstemon deustus* had insufficient plant stands to reliably evaluate its response to irrigation over multiple years.

Table 4. Early season precipitation and growing degree-days at the Malheur Experiment Station, Ontario, OR, 2006-2014.

Year	Precipitation (inches)		Growing degree-days (50-86°F)
	Jan-June	April-June	Jan-June
2006	9.0	3.1	1120
2007	3.1	1.9	1208
2008	2.9	1.2	936
2009	5.8	3.9	1028
2010	8.3	4.3	779
2011	8.3	3.9	671
2012	5.8	2.3	979
2013	2.6	1.4	1118
2014	5.1	1.6	1109
70-year average	5.8	2.7	1010 ^a

^a24-year average.

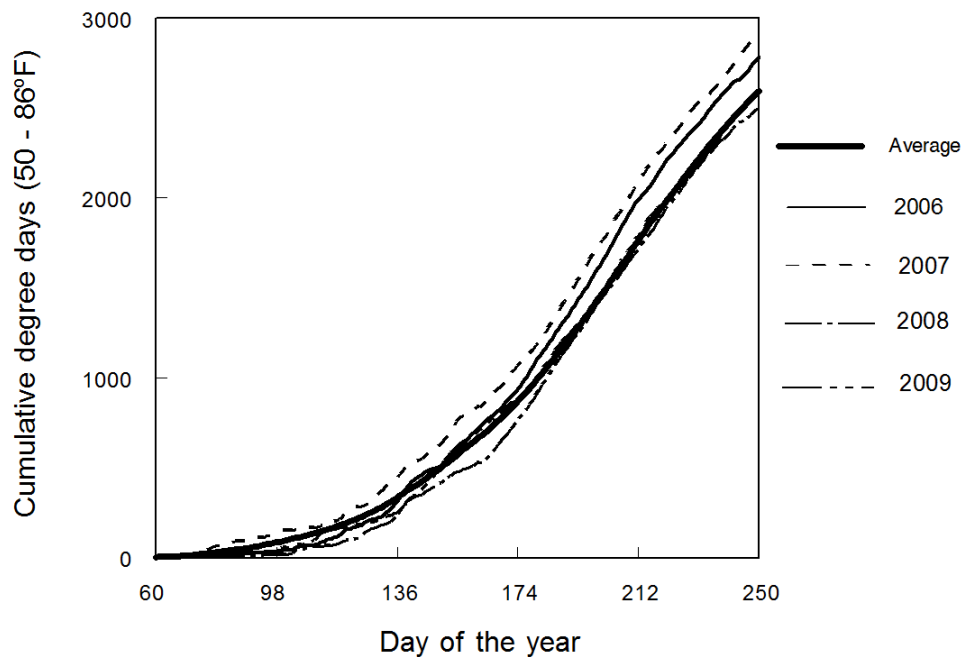


Figure 1. Growing degree days (50 – 86 °F) for 2006 through 2009 and 24-year average. Malheur Experiment Station, Oregon State University, 2014.

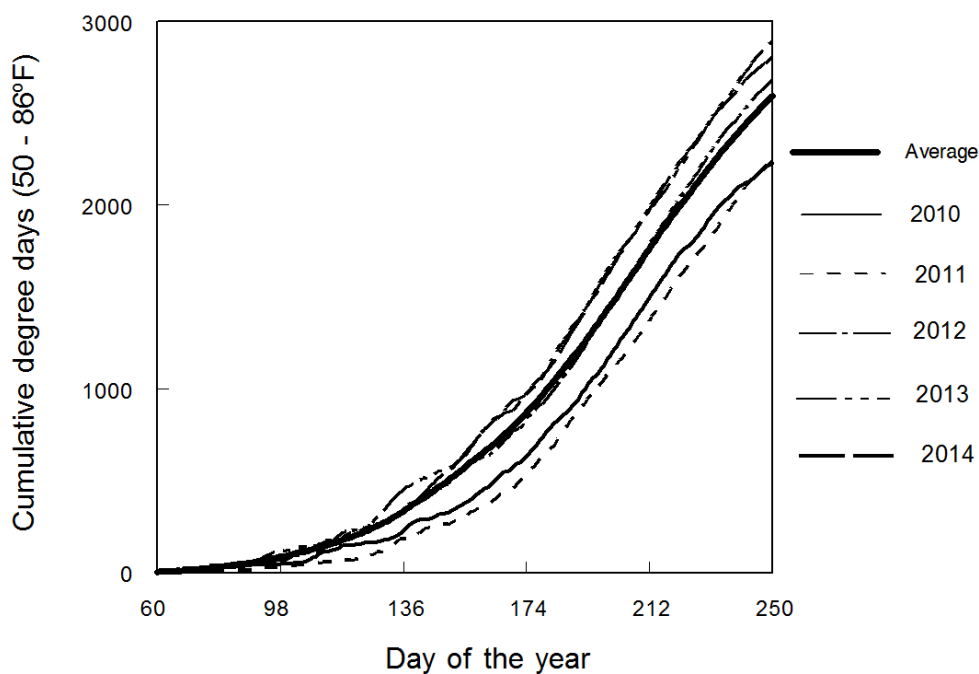


Figure 2. Growing degree days (50 – 86 °F) for 2010 through 2014 and 24-year average. Malheur Experiment Station, Oregon State University, 2014.

Table 5. Native wildflower seed yield response to irrigation rate (inches/season) in 2006 through 2011. Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	2006				2007				2008			
	0 inch	4 inch	8 inch	LSD (0.05)	0 inch	4 inch	8 inch	LSD (0.05)	0 inch	4 inch	8 inch	LSD (0.05)
----- lb/acre -----												
<i>Eriogonum umbellatum</i> ^a	155.3	214.4	371.6	92.9	79.6	164.8	193.8	79.8	121.3	221.5	245.2	51.7
<i>Penstemon acuminatus</i> ^a	538.4	611.1	544.0	NS	19.3	50.1	19.1	25.5 ^b	56.2	150.7	187.1	79.0
<i>Penstemon deustus</i> ^c	1246	1201	1069	NS	120.3	187.7	148.3	NS	--- very poor stand ---			
<i>Penstemon speciosus</i> ^a	163.5	346.2	213.6	134.3	2.5	9.3	5.3	4.7 ^b	94.0	367.0	276.5	179.6
<i>Lomatium dissectum</i> ^d	---- no flowering ----				--- no flowering ---				- very little flowering -			
<i>Lomatium triternatum</i> ^d	---- no flowering ----				2.3	17.5	26.7	16.9 ^b	195.3	1061	1387	410.0
<i>Lomatium grayi</i> ^d	---- no flowering ----				36.1	88.3	131.9	77.7 ^b	393.3	1287	1445	141.0
<i>Sphaeralcea parvifolia</i> ^e					1063	850.7	957.9	NS	436.2	569.1	544.7	NS
<i>Sphaeralcea grossulariifolia</i> ^e					442.6	324.8	351.9	NS	275.3	183.3	178.7	NS
<i>Sphaeralcea coccinea</i> ^e					279.8	262.1	310.3	NS	298.7	304.1	205.2	NS
Species	2009				2010				2011			
	0 inch	4 inch	8 inch	LSD (0.05)	0 inch	4 inch	8 inch	LSD (0.05)	0 inch	4 inch	8 inch	LSD (0.05)
----- lb/acre -----												
<i>Eriogonum umbellatum</i> ^a	132.3	223	240.1	67.4	252.9	260.3	208.8	NS	248.7	136.9	121.0	90.9
<i>Penstemon acuminatus</i> ^a	20.7	12.5	11.6	NS	-- Stand disked out --							
<i>Penstemon speciosus</i> ^a	6.8	16.1	9.0	6.0 ^b	147.2	74.3	69.7	NS	371.1	328.2	348.6	NS
<i>Lomatium dissectum</i> ^d	50.6	320.5	327.8	196.4 ^b	265.8	543.8	499.6	199.6	567.5	1342.8	1113.8	180.9
<i>Lomatium triternatum</i> ^d	181.6	780.1	676.1	177	1637	2830	3195	309.4	1983	2625	2028	502.3 ^b
<i>Lomatium grayi</i> ^d	359.9	579.8	686.5	208.4	1036	1144	704.8	NS	570.3	572.7	347.6	NS
<i>Sphaeralcea parvifolia</i> ^e	285.9	406.1	433.3	NS	245.3	327.3	257.3	NS	81.6	142.5	141.2	NS
<i>Sphaeralcea grossulariifolia</i> ^e	270.7	298.9	327.0	NS	310.5	351	346.6	NS	224.0	261.9	148.1	NS
<i>Sphaeralcea coccinea</i> ^e	332.2	172.1	263.3	NS	385.7	282.6	372.5	NS	89.6	199.6	60.5	NS

^aplanted March, 2005, areas of low stand replanted by hand in October 2005. ^bLSD (0.10).

^cplanted March, 2005, areas of low stand replanted by hand in October 2005 and whole area replanted in October 2006. Yields in 2006 are based on small areas with adequate stand. Yields in 2007 are based on whole area of very poor and uneven stand.

^dplanted March, 2005, whole area replanted in October 2005.

^eplanted spring 2006, whole area replanted in November 2006.

Table 6. Native wildflower seed yield in response to irrigation rate (inches/season) in 2012 - 2014 and 2- to 9-year yield averages. Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	2012				2013				2014			
	0 inch	4 inch	8 inch	LSD (0.05)	0 inch	4 inch	8 inch	LSD (0.05)	0 inch	4 inch	8 inch	LSD (0.05)
<i>Eriogonum umbellatum</i> ^a	61.2	153.2	185.4	84.4	113.2	230.1	219.8	77.5	257.0	441.8	402.7	82.9
<i>Penstemon speciosus</i> ^a	103.8	141.1	99.1	NS	8.7	80.7	138.6	63.7	76.9	265.6	215.1	76.7
<i>Lomatium dissectum</i> ^d	388.1	460.3	444.4	NS	527.8	959.8	1167	282.4	353.4	978.9	1368	353.9
<i>Lomatium triternatum</i> ^d	238.7	603.0	733.2	323.9	153.7	734.4	1051	425.0	240.6	897.1	1497	157.0
<i>Lomatium grayi</i> ^d	231.9	404.4	377.3	107.4	596.7	933.4	1036	NS	533.1	1418	1241	672.0

	2- to 9-year averages			
	0 inches	4 inches	8 inches	LSD (0.05)
<i>Eriogonum umbellatum</i> ^a	161.4	228.0	239.7	24.9
<i>Penstemon speciosus</i> ^a	108.5	174.4	152.7	36.1
<i>Lomatium dissectum</i> ^d	358.9	807.9	820.1	142.7
<i>Lomatium triternatum</i> ^d	579.0	1193	1311	150.2
<i>Lomatium grayi</i> ^d	469.6	803.4	746.3	248.3

^bLSD (0.10)

Table 7, continued on next page. Regression analysis for native wildflower seed yield response to irrigation rate (inches/season) in 2006- 2014, and 2- to 9-year averages. For the quadratic equations, the amount of irrigation that resulted in maximum yield was calculated using the formula: $-b/2c$, where b is the linear parameter and c is the quadratic parameter. Malheur Experiment Station, Oregon State University, Ontario, OR.

<i>Eriogonum umbellatum</i>							Maximum yield	Water applied for maximum yield
Year	intercept	linear	quadratic	R ²	P		lb/acre	inches/season
2006	137.9	27.8		0.68	0.01		360.3	8.0
2007	79.6	28.3	-1.8	0.69	0.05		194.0	8.1
2008	121.3	34.6	-2.4	0.73	0.01		246.0	7.2
2009	132.3	31.9	-2.3	0.60	0.05		242.9	6.9
2010	252.9	9.2	-1.8	0.08	NS			
2011	232.7	-16.0		0.58	0.01		232.7	0.0
2012	71.2	15.5		0.61	0.01		195.2	8.0
2013	113.2	45.2	-4.0	0.62	0.05		241.3	5.7
2014	257.0	74.2	-7.0	0.76	0.01		453.7	5.3
Average	161.4	23.5	-1.7	0.82	0.001		241.9	6.9
<i>Penstemon speciosus</i>							Maximum yield	Water applied for maximum yield
Year	intercept	linear	quadratic	R ²	P		lb/acre	inches/season
2006	163.5	85.1	-9.9	0.66	0.05		346.4	4.3
2007	2.5	3.2	-0.4	0.48	0.10		9.2	4.2
2008	94.1	113.7	-11.4	0.56	0.05		377.6	5.0
2009	6.8	4.4	-0.5	0.54	0.05		16.1	4.2
2010	147.2	29.8	-2.1	0.35	NS			
2011	360.6	-2.8		0.01	NS			
2012	103.8	19.3	-2.5	0.30	NS			
2013	11.0	16.2		0.77	0.001		141.0	8.0
2014	76.9	77.1	-7.5	0.62	0.05		275.5	5.2
Average	108.5	27.5	-2.7	0.55	0.05		177.2	5.0

^a not significant. There was no statistically significant difference in yield between the non-irrigated plots and the plots receiving 4 or 8 inches of water.

Table 7, continued. Regression analysis for native wildflower seed yield response to irrigation rate (inches/season) in 2006 - 2014, and 2- to 9-year averages. Malheur Experiment Station, Oregon State University, Ontario, OR.

<i>Lomatium triternatum</i>						Maximum	Water applied for maximum
Year	intercept	linear	quadratic	R ²	P	yield	yield
						lb/acre	inches/season
2007	3.3	3.1		0.52	0.01	27.7	8.0
2008	195.3	283.9	-16.9	0.77	0.01	1387.6	8.4
2009	181.6	237.4	-22.0	0.83	0.001	822.0	5.4
2010	1637.2	401.5	-25.9	0.83	0.001	3193.2	7.8
2011	1982.9	315.1	-38.7	0.45	0.10	2624.3	4.1
2012	277.8	61.8		0.49	0.05	772.2	8.0
2013	197.7	112.2		0.66	0.01	1095.0	8.0
2014	249.6	157.4		0.97	0.001	1508.6	8.0
Average	579.0	215.7	-15.5	0.84	0.001	1328.2	6.9
<i>Lomatium dissectum</i>						Maximum	Water applied for maximum
Year	intercept	linear	quadratic	R ²	P	yield	yield
						lb/acre	inches/season
2009	86.4	34.6		0.31	0.10	363.2	8.0
2010	265.8	109.8	-10.1	0.68	0.01	564.2	5.4
2011	567.5	319.3	-31.4	0.86	0.001	1379.2	5.1
2012	402.7	7.0		0.04	NS ^a		
2013	565.3	79.9		0.65	0.01	1204.2	8.0
2014	392.7	126.9		0.82	0.001	1407.9	8.0
Average	358.9	166.9	-13.7	0.91	0.001	869.1	6.1
<i>Lomatium grayi</i>						Maximum	Water applied for maximum
Year	intercept	linear	quadratic	R ²	P	yield	yield
						lb/acre	inches/season
2007	37.5	12.0		0.26	0.10	133.5	8.0
2008	393.3	315.4	-23.0	0.93	0.001	1474.6	6.9
2009	378.7	40.8		0.38	0.05	705.1	8.0
2010	1035.7	95.3	-17.1	0.22	NS		
2011	608.2	-27.8		0.07	NS		
2012	231.9	68.1	-6.2	0.66	0.01	418.9	5.5
2013	635.6	55.0		0.25	0.10	1075.3	8.0
2014	533.1	354.0	-33.2	0.64	0.05	1477.1	5.3
Average	469.6	132.3	-12.2	0.55	0.05	827.9	5.4

^a not significant. There was no statistically significant difference in yield between the non-irrigated plots and the plots receiving 4 or 8 inches of water.

Table 8. Amount of irrigation water for maximum native wildflower seed yield, years to seed set, and life span. A summary of multi-year research findings, Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	Optimum amount of irrigation	Years to first	
		seed set	Life span
	inches/season	from fall planting	years
<i>Eriogonum umbellatum</i>	0 in wet years, 5 to 8 in dry years	1	8+
<i>Lomatium dissectum</i>	5 in wet years, 8 in dry years	4	8+
<i>Lomatium grayi</i>	0 in wet years, 5 to 8 in dry years	2	8+
<i>Lomatium triternatum</i>	average of 6.9 inches over 8 years	2	8+
<i>Penstemon acuminatus</i>	no response	1	3
<i>Penstemon speciosus</i>	0 in wet years, 4 in dry years	1	3
<i>Sphaeralcea coccinea</i>	no response	1	5
<i>Sphaeralcea grossulariifolia</i>	no response	1	5
<i>Sphaeralcea parvifolia</i>	no response	1	5

D. Irrigation Requirements for Native Wildflower Seed Production for the Second Set of Species Planted in the Fall of 2009

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Experiment Station, Oregon State University, Ontario, OR, 2014

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Introduction

Native wildflower seed is needed to restore rangelands of the Intermountain West as described above. The trials reported here tested the effects of three low rates of irrigation on the seed yield of a second set of 11 native wildflower species (Table 1) started with initial plantings in 2009.

Materials and Methods

Plant Establishment

Each wildflower species was planted in four rows 30 inches apart (a 10-foot wide strip) about 450 feet long on Nyssa silt loam at the OSU Malheur Experiment Station, Ontario, Oregon. The soil had a pH of 8.3 and 1.1 percent organic matter. In October 2012, two drip tapes 5 feet apart (T-Tape TSX 515-16-340) were buried at 12-inch depth to irrigate the four rows in the plot. Each drip tape irrigated two rows of plants. The flow rate for the drip tape was 0.34 gal/min/100ft at 8 psi with emitters spaced 16 inches apart, resulting in a water application rate of 0.066 inch/hour.

On November 25, 2009 seed of nine perennial species (Table 1) was planted in 30-inch rows using a custom-made plot grain drill with disk openers. All seed was planted on the soil surface at 20-30 seeds/ft of row. After planting, sawdust was applied in a narrow band over the seed row at 0.26 oz/ft of row (558 lb/acre). Following planting and sawdust application, the beds were covered with row cover. The row cover (N-sulate, DeWitt Co., Inc., Sikeston, MO) covered four rows (two beds) and was applied with a mechanical plastic mulch layer. The field was irrigated for 24 hours on December 2, 2009 due to very dry soil conditions.

Cultural Practices in 2010

After the newly planted wildflowers had emerged, the row cover was removed in April. The irrigation treatments were not applied to these wildflowers in 2010. Stands of *Penstemon cyaneus*, *P. pachyphyllus*, and *Eriogonum heracleoides* were not adequate for yield estimates.

Gaps in the rows were replanted by hand on November 5. The replanted seed was covered with a thin layer of a mixture of 50 percent sawdust and 50 percent hydro seeding mulch (Hydrostraw LLC, Manteno, IL) by volume. The mulch mixture was sprayed with water using a backpack sprayer. On November 18, 2010, seed of *Cleome serrulata* was planted as previously described.

Cultural Practices in 2011

Seed from the middle two rows in each plot of *Penstemon deustus* and *Eriogonum heracleoides* was harvested with a small plot combine. Seed from the middle two rows in each plot of the other species was harvested manually.

On November 11, 2011, seed of *Cleome serrulata* was planted as previously described. On December 5, 2011, seed of *C. lutea* was planted as previously described. The *Cleome* species are annuals so they were replanted in new strips of land.

Cultural Practices in 2012

Many areas of the wildflower seed production were suffering from severe iron deficiency early in the spring of 2012. On April 13, 2012, 50 lb. nitrogen/acre, 10 lb. phosphorus/acre, and 0.3 lb. iron (Fe)/acre was applied to all plots of *Lomatium nudicaule*, *Cymopterus bipinnatus*, *Penstemon deustus*, *P. cyaneus*, and *P. pachyphyllus* as liquid fertilizer injected through the drip tape. On April 23, 2012, 0.3 lb. Fe/acre was applied to all plots of *P. deustus*, *P. cyaneus*, *P. pachyphyllus*, *Eriogonum heracleoides*, *Dalea searlsiae*, *D. ornata*, and *Astragalus filipes* as liquid fertilizer injected through the drip tape.

Flea beetles were observed feeding on leaves of *Cleome serrulata* and *C. lutea* in April. On April 29, all plots of *C. serrulata* and *C. lutea* were sprayed with Capture® at 5 oz/acre to control flea beetles. On June 11, *C. serrulata* was again sprayed with Capture at 5 oz/acre to control a re-infestation of flea beetles.

A substantial amount of plant death occurred in the *Penstemon deustus* plots during the winter and spring of 2011/2012. For *P. deustus*, only the undamaged parts in each plot were harvested. Seed of all species was harvested and cleaned manually. On October 26, dead *P. deustus* plants were removed and the empty row lengths were replanted by hand at 20-30 seeds/ft. of row. After planting, sawdust was applied in a narrow band over the seed row. Following planting and sawdust application, the beds were covered with row cover.

On November 1, seed of *Cleome serrulata* and *Cleome lutea* was planted on the soil surface at 20-30 seeds/ft of row. After planting, sawdust was applied in a narrow band over the seed row. Following planting and sawdust application, the beds were covered with row cover.

Cultural Practices in 2013

On March 27, row cover was removed and bird netting placed over the *Cleome serrulata* and *Cleome lutea* plots to protect seedlings from bird feeding. The bird netting was placed over No. 9 galvanized wire hoops. Bird netting was also placed over *Cymopterus bipinnatus* on March 29 to protect new shoots.

Seed of *Penstemon deustus* and *Eriogonum heracleoides* was harvested with a small plot combine. Seed of the other species was harvested manually. Weeds were controlled by hand weeding as necessary.

Seed of *Cleome serrulata* was planted on October 31 and seed of *Cleome lutea* was planted on November 15. Seed of both species was planted on the soil surface at 20-30 seeds/ft of row. After planting, sawdust was applied in a narrow band over the seed row. Following planting and sawdust application, the beds were covered with row cover.

Cultural Practices in 2014

On March 27, row cover was removed and bird netting placed over the *Cleome serrulata* and *Cleome lutea* plots to protect seedlings from bird feeding. The bird netting was placed over No. 9 galvanized wire hoops. Bird netting was also placed over *Cymopterus bipinnatus* and *Lomatium nudicaule* on March 29 to protect new shoots. On April 29, 0.3 lb Fe/acre was applied through the drip tape to all plots of *Penstemon deustus*, *P. cyaneus*, *P. pachyphyllus*, *Eriogonum heracleoides*, and *Astragalus filipes*.

Seed of *Penstemon deustus* and *Eriogonum heracleoides* was harvested with a small plot combine. Seed of the other species was harvested manually.

Table 1. Wildflower species planted in the fall of 2009 at the Malheur Experiment Station, Oregon State University, Ontario, OR. All species are perennial except *Cleome serrulata* and *Cleome lutea*.

Species	Common names	Growth Habit
<i>Penstemon deustus</i>	Scabland penstemon, hotrock penstemon	Perennial
<i>Penstemon cyaneus</i>	Blue penstemon	Perennial
<i>Penstemon pachyphyllus</i>	Thickleaf beardtongue	Perennial
<i>Eriogonum heracleoides</i>	Parsnipflower buckwheat	Perennial
<i>Dalea searlsiae</i>	Searls' prairie clover	Perennial
<i>Dalea ornata</i>	Western prairie clover, Blue Mountain prairie clover	Perennial
<i>Astragalus filipes</i>	Basalt milkvetch	Perennial
<i>Cleome serrulata</i>	Rocky Mountain beeplant	Annual
<i>Cleome lutea</i>	Yellow beeplant	Annual
<i>Lomatium nudicaule</i>	Barestem biscuitroot, Barestem lomatium	Perennial
<i>Cymopterus bipinnatus</i> ^a	Hayden's cymopterus	Perennial

^a recently classified as *Cymopterus nivalis* S. Watson "snowline springparsley."

Irrigation for Seed Production

In April, 2011, each strip of each wildflower species was divided into twelve 30-ft plots. Each plot contained four rows of each species. The experimental design for each species was a randomized complete block with four replicates. The three treatments were a non-irrigated check, 1 inch of water applied per irrigation, and 2 inches of water applied per irrigation. Each treatment received 4 irrigations that were applied approximately every 2 weeks starting with flowering of the wildflowers. The amount of water applied to each treatment was calculated by the length of time necessary to deliver 1 or 2 inches through the drip system. Irrigations were regulated with a controller and solenoid valves. After each irrigation the amount of water applied was read on a water meter and recorded to ensure correct water applications.

The drip-irrigation system was designed to allow separate irrigation of the species due to different timings of flowering and seed formation. The three *Penstemon* spp. were irrigated together and the two *Dalea* spp. were irrigated together. *Eriogonum heracleoides* and *Astragalus filipes* were irrigated individually. Flowering, irrigation, and harvest dates were recorded (Table 2). *Lomatium nudicaule* flowered in 2012; irrigation treatments were applied and seed was harvested. *Cymopterus bipinnatus* had not flowered as of 2012, but differential irrigation treatments were applied to *Cymopterus bipinnatus* starting in 2012. In 2014, after the 4 bi-weekly irrigations ended, *Cleome serrulata* and *Cleome lutea* received an additional 3 bi-weekly

irrigations starting on August 12 in an attempt to extend the flowering and seed production period. On August 12, 50 lb N/acre, 30 lb P/acre, and 0.2 lb Fe/acre were applied through the drip tape to all plots of *Cleome serrulata* and *Cleome lutea*.

Table 2, continued on next page. Native wildflower flowering, irrigation, and seed harvest dates by species. Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	Flowering			Irrigation		Harvest
	start	peak	end	start	end	
2011						
<i>Penstemon cyaneus</i>	23-May	15-Jun	8-Jul	13-May	23-Jun	18-Jul
<i>Penstemon pachyphyllus</i>	10-May	30-May	20-Jun	13-May	23-Jun	15-Jul
<i>Penstemon deustus</i>	23-May	20-Jun	14-Jul	13-May	23-Jun	16-Aug
<i>Eriogonum heracleoides</i>	26-May	10-Jun	8-Jul	27-May	6-Jul	1-Aug
<i>Dalea searlsiae</i>	8-Jun	20-Jun	20-Jul	27-May	6-Jul	21-Jul
<i>Dalea ornata</i>	8-Jun	20-Jun	20-Jul	27-May	6-Jul	22-Jul
<i>Astragalus filipes</i>	20-May	26-May	30-Jun	13-May	23-Jun	18-Jul
<i>Cleome serrulata</i>	25-Jun	30-Jul	15-Aug	21-Jun	2-Aug	26-Sep
<i>Lomatium nudicaule</i>		No flowering				
<i>Cymopterus bipinnatus</i>		No flowering				
2012						
<i>Penstemon cyaneus</i>	16-May	30-May	10-Jun	27-Apr	7-Jun	27-Jun
<i>Penstemon pachyphyllus</i>	23-Apr	2-May	10-Jun	27-Apr	7-Jun	26-Jun
<i>Penstemon deustus</i>	16-May	30-May	4-Jul	27-Apr	7-Jun	7-Aug
<i>Eriogonum heracleoides</i>	23-May	30-May	25-Jun	11-May	21-Jun	16-Jul
<i>Dalea searlsiae</i>	23-May	10-Jun	30-Jun	11-May	21-Jun	10-Jul
<i>Dalea ornata</i>	23-May	10-Jun	30-Jun	11-May	21-Jun	11-Jul
<i>Astragalus filipes</i>	28-Apr	23-May	19-Jun	11-May	21-Jun	5-Jul
<i>Cleome serrulata</i>	12-Jun	30-Jun	30-Jul	13-Jun	25-Jul	24-Jul to 30-Aug
<i>Cleome lutea</i>	16-May	15-Jun	30-Jul	2-May	13-Jun	12-Jul to 30-Aug
<i>Lomatium nudicaule</i>	12-Apr	1-May	30-May	18-Apr	30-May	22-Jun
<i>Cymopterus bipinnatus</i>		No flowering				

Table 2, continued. Native wildflower flowering, irrigation, and seed harvest dates by species. Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	Flowering			Irrigation		Harvest
	start	peak	end	start	end	
	2013					
<i>Penstemon cyaneus</i>	3-May	21-May	5-Jun	24-Apr	5-Jun	11-Jul
<i>Penstemon pachyphyllus</i>	26-Apr		21-May	24-Apr	5-Jun	8-Jul
<i>Penstemon deustus</i>	3-May	18-May	15-Jun	24-Apr	5-Jun	
<i>Eriogonum heracleoides</i>	29-Apr	13-May	10-Jun	24-Apr	5-Jun	1-Jul
<i>Dalea searlsiae</i>	13-May		15-Jun	8-May	19-Jun	29-Jun
<i>Dalea ornata</i>	13-May	21-May	15-Jun	8-May	19-Jun	28-Jun
<i>Astragalus filipes</i>	3-May	10-May	25-May	8-May	19-Jun	28-Jun
<i>Lomatium nudicaule</i>	11-Apr		20-May	12-Apr	22-May	10-Jun
<i>Cymopterus bipinnatus</i>	5-Apr		15-May	12-Apr	22-May	10-Jun
	2014					
<i>Penstemon cyaneus</i>	5-May	13-May	8-Jun	29-Apr	10-Jun	14-Jul
<i>Penstemon pachyphyllus</i>	22-Apr	5-May	4-Jun	29-Apr	10-Jun	13-Jul
<i>Penstemon deustus</i>	10-May	20-May	19-Jun	29-Apr	10-Jun	21-Jul
<i>Eriogonum heracleoides</i>	1-May	20-May	12-Jun	29-Apr	10-Jun	3-Jul
<i>Dalea searlsiae</i>	15-May	4-Jun	24-Jun	6-May	17-Jun	1-Jul
<i>Dalea ornata</i>	15-May	4-Jun	24-Jun	6-May	17-Jun	1-Jul
<i>Astragalus filipes</i>	5-May	13-May	28-May	29-Apr	10-Jun	24-Jun
<i>Cleome serrulata</i>	4-Jun	24-Jun	22-Jul	20-May	1-Jul	11-Jul to 30-Jul
<i>Cleome lutea</i>	29-Apr	4-Jun	22-Jul	23-Apr	3-Jun	23-Jun to 30-Jul
<i>Lomatium nudicaule</i>	7-Apr		13-May	7-Apr	20-May	16-Jun
<i>Cymopterus bipinnatus</i>	7-Apr		29-Apr	7-Apr	20-May	16-Jun

Results and Discussion

Precipitation from January through July was higher than average in 2011, close to average in 2012 and 2014, and lower than average in 2013 (Figure 1). The accumulation of growing degree days (50 to 86°F) was below average in 2011, close to average in 2012, and higher than average in 2013 and 2014 (Figure 2).

In 2012, a flea beetle infestation on the two *Cleome* species occurred in April and was controlled by insecticide application. Flea beetle feeding occurred earlier in 2013 than in 2012. Upon removal of the row cover in March of 2013, the flea beetle damage to the seedlings of *Cleome serrulata* and *C. lutea* was extensive resulting in full stand loss. Flea beetles were not observed on either *Cleome* species in 2014. Harvested seed pods of *Dalea ornata*, *D. searlsiae*, and

Astragalus filipes had extensive damage from feeding by seed beetles in 2013 and 2014, indicating that control measures during and following flowering will be necessary to maintain seed yields.

Penstemon cyaneus

Seed yields did not respond to irrigation in 2011 and 2014 (Tables 3 and 4). In 2012, seed yields increased with increasing irrigation up to the highest tested rate of 8 inches. In 2013, seed yields showed a quadratic response to irrigation with a maximum seed yield at 4 inches of water applied.

Penstemon pachyphyllus

Seed yields did not respond to irrigation in 2011, 2012, and 2014. In 2013, seed yields increased with increasing irrigation up to the highest tested of 8 inches.

Eriogonum heracleoides

Seed yields did not respond to irrigation in 2011, 2012, and 2014. In 2013, seed yields showed a quadratic response to irrigation with a maximum seed yield at 4.9 inches of water applied.

Dalea searlsiae

In 2011, seed yields were highest with no irrigation. In 2012 and 2014, seed yields showed a quadratic response to irrigation. Maximum seed yields were achieved with 6.6 and 8.9 inches of water applied in 2012 and 2014, respectively. In 2013, seed yields increased with increasing irrigation rate up to the highest tested of 8 inches. Averaged over the 4 years, seed yield showed a quadratic response to irrigation with a maximum seed yield at 7 inches of water applied.

Dalea ornata

Seed yields did not respond to irrigation in 2011. Seed yields showed a quadratic response to irrigation in 2012, 2013, and 2014 with a maximum seed yield at 7.7, 8.1, and 6.9 inches of water applied, respectively. Averaged over the 4 years, seed yield showed a quadratic response to irrigation with a maximum seed yield at 6.7 inches of water applied.

Astragalus filipes

Seed yields only responded to irrigation in 2013, when 4 inches of applied water was among the irrigation rates resulting in the highest yield (Table 3).

Lomatium nudicaule

Seed yields did not respond to irrigation in the 3 years of testing.

Cymopterus bipinnatus

Seed yields did not respond to irrigation in 2013. In 2014, seed yields increased with increasing irrigation rate up to the highest tested of 8 inches.

Cleome serrulata

In 2011, seed yields increased with increasing irrigation up to the highest tested of 8 inches. Seed yields did not respond to irrigation in 2012 or 2014. There was no plant stand in 2013 due to early severe flea beetle damage. The additional irrigations applied starting on August 12 in 2014 did result in an extension/resumption of flowering, but seed harvested in mid-October was not mature.

Cleome lutea

Seed yields did not respond to irrigation in 2012 or 2014. There was no plant stand in 2013. Early attention to flea beetle control is essential for *Cleome* seed production. The additional irrigations applied starting on August 12 did not result in an extension or resumption of flowering.

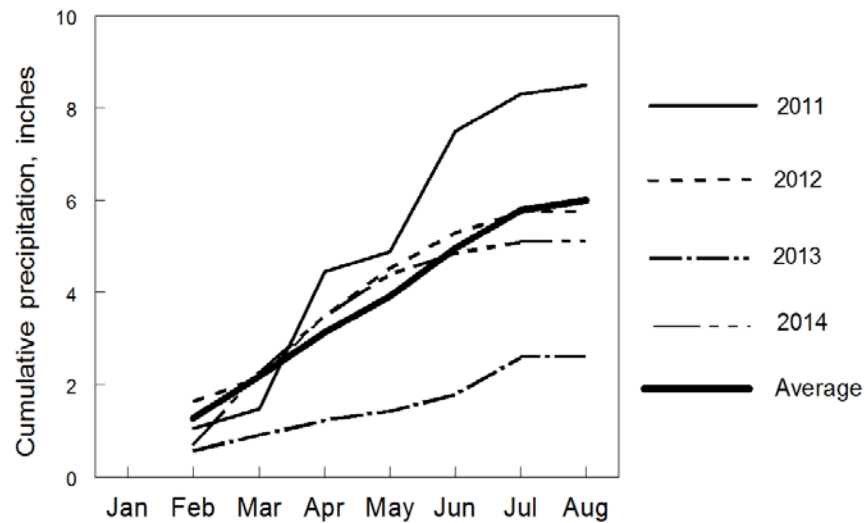


Figure 1. Cumulative annual and 66-year-average precipitation from January through July at the Malheur Experiment Station, Oregon State University, Ontario, OR.

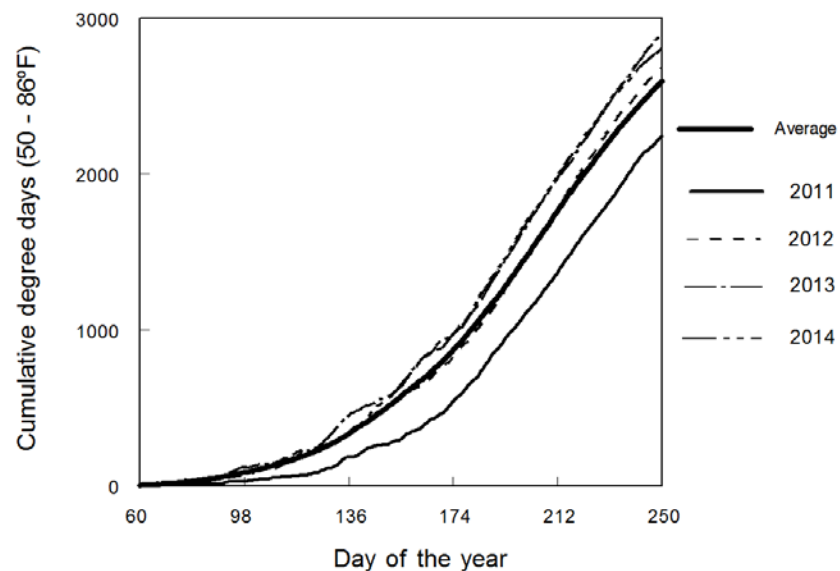


Figure 2. Cumulative growing degree-days (50-86°F) for selected years and 24-year average at the Malheur Experiment Station, Oregon State University, Ontario, OR.

Table 3. Native wildflower seed yield response to irrigation rate (inches/season). Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	2011				2012			
	0 inches	4 inches	8 inches	LSD (0.05)	0 inches	4 inches	8 inches	LSD (0.05)
	----- lb/acre -----				----- lb/acre -----			
<i>Penstemon cyaneus</i>	857.2	821.4	909.4	NS ^a	343.3	474.6	581.2	202.6 ^b
<i>Penstemon pachyphyllus</i>	569.9	337.6	482.2	NS	280.5	215.0	253.7	NS
<i>Penstemon deustus</i>	637.6	477.8	452.6	NS	308.7	291.8	299.7	NS
<i>Eriogonum heracleoides</i>	55.2	71.6	49.0	NS	252.3	316.8	266.4	NS
<i>Dalea searlsiae</i>	262.7	231.2	196.3	50.1	175.5	288.8	303.0	93.6
<i>Dalea ornata</i>	451.9	410.8	351.7	NS	145.1	365.1	431.4	189.3
<i>Astragalus filipes</i>	87.0	98.4	74.0	NS	22.7	12.6	16.1	NS
<i>Lomatium nudicaule</i>					53.8	123.8	61.1	NS
<i>Cymopterus bipinnatus</i>								
<i>Cleome serrulata</i>	446.5	499.3	593.6	100.9 ^b	184.3	162.9	194.7	NS
<i>Cleome lutea</i>					111.7	83.7	111.4	NS

Species	2013				2014			
	0 inches	4 inches	8 inches	LSD (0.05)	0 inches	4 inches	8 inches	LSD (0.05)
	----- lb/acre -----				----- lb/acre -----			
<i>Penstemon cyaneus</i>	221.7	399.4	229.2	74.4	213.9	215.4	215.1	NS
<i>Penstemon pachyphyllus</i>	159.4	196.8	249.7	83.6	291.7	238.6	282.1	NS
<i>Penstemon deustus</i>					356.4	504.8	463.2	NS
<i>Eriogonum heracleoides</i>	287.4	516.9	431.7	103.2	297.6	345.2	270.8	NS
<i>Dalea searlsiae</i>	14.8	31.7	44.4	6.1	60.0	181.4	232.2	72.9
<i>Dalea ornata</i>	28.6	104.6	130.4	38.8	119.4	422.9	476.3	144.1
<i>Astragalus filipes</i>	8.5	9.8	6.1	2.7 ^b	56.6	79.3	71.9	NS
<i>Lomatium nudicaule</i>	357.6	499.1	544.0	NS	701.3	655.6	590.9	NS
<i>Cymopterus bipinnatus</i>	194.2	274.5	350.6	NS	1236	1934	2769	844.7
<i>Cleome serrulata</i>					66.3	80.0	91.3	NS
<i>Cleome lutea</i>					207.1	221.7	181.7	NS

Species	Average			
	0 inches	4 inches	8 inches	LSD (0.05)
	----- lb/acre -----			
<i>Penstemon cyaneus</i>	409.0	477.7	483.7	NS
<i>Penstemon pachyphyllus</i>	325.4	247.0	316.9	NS
<i>Penstemon deustus</i>	433.7	418.3	396.0	NS
<i>Eriogonum heracleoides</i>	223.1	312.6	254.4	NS
<i>Dalea searlsiae</i>	128.3	183.3	194.0	39.9
<i>Dalea ornata</i>	186.3	325.8	347.4	78.3
<i>Astragalus filipes</i>	43.7	41.7	42.0	NS
<i>Lomatium nudicaule</i>	370.9	426.2	398.7	NS
<i>Cymopterus bipinnatus</i>	715.2	1104	1217	NS
<i>Cleome serrulata</i>	211.3	221.4	263.1	NS
<i>Cleome lutea</i>	159.4	152.7	146.6	NS

^a not significant, ^b LSD (0.10)

Table 4, continued on next page. Regression parameters for native wildflower seed yield in response to irrigation rate (inches/season). For the quadratic equations, the amount of irrigation that resulted in maximum yield was calculated using the formula: $-b/2c$, where b is the linear parameter and c is the quadratic parameter. Malheur Experiment Station, Oregon State University, Ontario, OR.

<i>Penstemon cyaneus</i>							
Year	intercept	linear	quadratic	R ²	P	Maximum yield	Water applied for maximum yield
						lb/acre	inches/season
2011	836.6	6.5		0.01	NS ^a		
2012	855.8	29.7		0.84	0.001	1093.6	8.0
2013	221.7	87.9	-10.9	0.63	0.05	399.4	4.0
2014	214.2	0.1		0.01	NS		
Average	419.5	9.3		0.17	NS		
<i>Penstemon deustus</i>							
Year	intercept	linear	quadratic	R ²	P	Maximum yield	Water applied for maximum yield
						lb/acre	inches/season
2011	615.2	-23.1		0.35	0.05	615.2	0
2012	304.6	-1.1		0.01	NS		
2014	356.4	60.8	-5.9	0.26	NS		
Average	452.7	-4.1		0.05	NS		
<i>Penstemon pachyphyllus</i>							
Year	intercept	linear	quadratic	R ²	P	Maximum yield	Water applied for maximum yield
						lb/acre	inches/season
2011	507.1	-11.0		0.04	NS		
2012	263.1	-3.3		0.01	NS		
2013	156.8	11.3		0.33	0.10	247.2	8.0
2014	275.6	-1.2		0.01	NS		
Average	300.7	-1.1		0.01	NS		
<i>Eriogonum heracleoides</i>							
Year	intercept	linear	quadratic	R ²	P	Maximum yield	Water applied for maximum yield
						lb/acre	inches/season
2011	61.7	-0.8		0.01	NS		
2012	271.5	1.8		0.01	NS		
2013	287.4	96.7	-9.8	0.64	0.05	525.1	4.9
2014	297.6	27.2	-3.8	0.08	NS		
Average	223.1	40.8	-4.6	0.56	0.05	313.4	4.4

^anot significant. There was no statistically significant difference in yield between the non-irrigated plots and the plots receiving 4 or 8 inches of water.

Table 4, continued. Regression parameters for native wildflower seed yield in response to irrigation rate (inches/season). Malheur Experiment Station, Oregon State University, Ontario, OR.

Dalea searlsiae

Year	intercept	linear	quadratic	R ²	P	Maximum yield lb/acre	Water applied for maximum yield inches/season
2011	263.3	-8.3		0.49	0.05	263.3	0
2012	175.5	40.7	-3.1	0.62	0.05	309.3	6.6
2013	15.5	3.7		0.54	0.01	45.1	8.0
2014	60.0	39.1	-2.2	0.79	0.001	234.0	8.9
Average	128.3	19.3	-1.4	0.61	0.05	195.5	7.0

Dalea ornata

Year	intercept	linear	quadratic	R ²	P	Maximum yield	Water applied for maximum yield
2011	454.9	-12.5		0.11	NS		
2012	145.1	74.2	-4.8	0.65	0.01	431.8	7.7
2013	28.6	25.3	-1.6	0.88	0.001	130.4	8.1
2014	119.4	107.1	-7.8	0.87	0.001	486.6	6.9
Average	186.3	49.6	-3.7	0.76	0.01	353.4	6.7

Astragalus filipes

Year	intercept	linear	quadratic	R ²	P	Maximum yield lb/acre	Water applied for maximum yield inches/season
2011	90.6	-1.6		0.01	NS		
2012	19.7	-0.8		0.04	NS		
2013	8.5	0.9	-0.2	0.25	NS		
2014	56.6	9.4	-0.9	0.08	NS		
Average	43.3	-0.2		0.01	NS		

Lomatium nudicaule

Year	intercept	linear	quadratic	R ²	P	Maximum yield lb/acre	Water applied for maximum yield inches/season
2012	75.9	0.9		0.01	NS		
2013	373.7	23.3		0.1	NS		
2014	704.5	-13.8		0.08	NS		
Average	384.7	3.5		0.01	NS		

^anot significant. There was no statistically significant difference in yield between the non-irrigated plots and the plots receiving 4 or 8 inches of water.

Table 4, continued. Regression parameters for native wildflower seed yield in response to irrigation rate (inches/season). Malheur Experiment Station, Oregon State University, Ontario, OR.

<i>Cymopterus bipinnatus</i>							Maximum	Water applied for maximum
Year	intercept	linear	quadratic	R ²	P		yield	yield
							lb/acre	inches/season
2013	194.9	19.6		0.07	NS ^a			
2014	1214.6	190.6		0.41	0.05	2739.7		8
Average	761.2	62.8		0.11	NS			
<i>Cleome serrulata</i>							Maximum	Water applied for maximum
Year	intercept	linear	quadratic	R ²	P		yield	yield
							lb/acre	inches/season
2011	439.6	18.4		0.35	0.05	586.7		8
2012	175.4	1.3		0.01	NS			
2014	66.7	3.1		0.16	NS			
Average	206.0	6.5		0.33	NS			
<i>Cleome lutea</i>							Maximum	Water applied for maximum
Year	intercept	linear	quadratic	R ²	P		yield	yield
							lb/acre	inches/season
2012	102.4	-0.031		0.01	NS			
2014	207.1	10.4	-1.7	0.20	NS			
Average	159.3	-1.6		0.04	NS			

^anot significant. There was no statistically significant difference in yield between the non-irrigated plots and the plots receiving 4 or 8 inches of water.

E. Irrigation Requirements of Native Wildflower Species for Seed Production for the Third Set of Species Started in the Fall of 2012

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Experiment Station, Oregon State University, Ontario, OR, 2014

Nancy Shaw and Francis Kilkenny, U.S. Forest Service, Rocky Mountain Research Station, Boise, ID

Introduction

Native wildflower seed is needed to restore rangelands of the Intermountain West. Commercial seed production is necessary to provide the quantity of seed needed for restoration efforts as described above. The trials reported here tested the effects of three low rates of irrigation on the seed yield on a third set seven native wildflower species (Table 1) planted first in the fall of 2012.

Materials and Methods

Plant Establishment

Each wildflower species was planted on 60-inch beds in rows 450 feet long on Nyssa silt loam at the OSU Malheur Experiment Station, Ontario, Oregon. The soil had a pH of 8.3 and 1.1 percent organic matter. In October 2012, drip tapes (T-Tape TSX 515-16-340) were buried at 12-inch depth in the center of each bed to irrigate the rows in the plot. The flow rate for the drip tape was 0.34 gal/min/100 ft. at 8 psi with emitters spaced 16 inches apart, resulting in a water application rate of 0.066 inch/hour.

On October 30, 2012 seed of 11 species (Table 1) was planted in either 15-inch or 30-inch rows using a custom-made plot grain drill with disk openers. All seed was planted on the soil surface at 20-30 seeds/ft. of row. After planting, sawdust was applied in a narrow band over the seed row at 0.26 oz/ft of row (558 lb/acre). Following planting and sawdust application, the beds were covered with row cover. The row cover (N-sulate, DeWitt Co., Inc., Sikeston, MO) covered four rows (two beds) and was applied with a mechanical plastic mulch layer.

Cultural Practices in 2013

Starting on March 29, the row cover was removed. Immediately following the removal of the row cover, bird netting was placed over the seedlings to prevent bird feeding on young seedlings and new shoots. The bird netting was placed over No. 9 galvanized wire hoops. During seedling emergence, wild bird seed was placed several hundred feet from the trial to attract quail away from the trials. Bird netting was removed in early May. On July 26 all plots of *Machaeranthera canescens* were sprayed with Capture at 19 oz/acre (0.3 lb ai/acre) for aphid control. On October 31 seed of *Phacelia linearis* was planted as previously described.

Due to poor stand, seed of *Chaenactis douglasii* was replanted on November 1 as previously described. Stand of *Nicotiana attenuata* was extremely poor and seed was unavailable for replanting.

Cultural Practices in 2014

Starting on March 27, the row cover was removed from *Phacelia linearis* and *Chaenactis douglasii* beds. Immediately following the removal of the row cover, bird netting was placed over the seedlings to prevent bird feeding on young seedlings and new shoots. Bird netting was removed in early May.

Table 1. Wildflower species planted in the fall of 2012 at the Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	Common name	Longevity	Row spacing (inches)
<i>Chaenactis douglasii</i>	Douglas' dustymaiden	perennial	30
<i>Machaeranthera canescens</i>	hoary tansyaster	perennial	30
<i>Phacelia hastata</i>	silverleaf phacelia	perennial	15
<i>Phacelia linearis</i>	threadleaf phacelia	annual	15
<i>Enceliopsis nudicaulis</i>	nakedstem sunray	perennial	30
<i>Heliomeris multiflora</i>	showy goldeneye	perennial	30
<i>Ipomopsis aggregata</i>	scarlet gilia	perennial	15
<i>Nicotiana attenuata</i>	coyote tobacco	perennial	30
<i>Thelypodium milleflorum</i>	manyflower thelypody	biennial	30
<i>Ligusticum porteri</i>	Porter's licorice-root	perennial	30
<i>Ligusticum canbyi</i>	Canby's licorice-root	perennial	30

Irrigation for Seed Production

In March 2013, the strip of each wildflower species was divided into twelve 30-ft long plots. Each plot contained four rows of each species. The experimental design for each species was a randomized complete block with four replicates. The three treatments were a non-irrigated check, 1 inch of water per irrigation, and 2 inches of water per irrigation. Each treatment received four irrigations that were applied approximately every 2 weeks starting with flowering of the wildflowers. The amount of water applied to each treatment was calculated by the length of time necessary to deliver 1 or 2 inches through the drip system. Irrigations were regulated with a controller and solenoid valves.

The drip-irrigation system was designed to allow separate irrigation of each species due to different timings of flowering and seed formation. All species were irrigated separately except the two *Phacelia* spp. and the two *Ligusticum* spp. Flowering, irrigation, and harvest dates were recorded (Table 2) with the exception of *Nicotiana attenuata* which did not germinate and the *Ligusticum* spp. which did not flower.

Results and Discussion

Precipitation from January through July in 2013 (2.6 inches) was below and in 2014 (5.1 inches) was close to the 66-year average of 6.1 inches (Figure 1). The accumulation of growing degree days (50 to 86 °F) was higher than average in 2013 and 2014 (Figure 2).

Stands of *Chaenactis douglasii*, *Ligusticum porteri*, and *Ligusticum canbyi* were poor and uneven, not permitting evaluation of irrigation responses. *Thelypodium milleflorum* is a biennial and set seed in 2014. *Ipomopsis aggregata* had very little flowering in 2013, but flowered and set seed in 2014.

In 2013, seed yields of *Machaeranthera canescens* showed a quadratic response to irrigation with a maximum seed yield at 2.4 inches of water applied (Tables 3 and 4). In 2014, seed yields

of *Machaeranthera canescens* were not responsive to irrigation. Averaged over the 2 years, seed yields of *Machaeranthera canescens* showed a quadratic response to irrigation with a maximum seed yield at 4.1 inches of water applied.

Seed yields of *Phacelia hastata* showed a quadratic response to irrigation with a maximum seed yield at 5.4 and 7.5 inches of water applied in 2013 and 2014, respectively (Tables 3 and 4). Seed yields of *Phacelia linearis* showed a quadratic response to irrigation in 2013 with a maximum seed yield at 6.2 of water applied. In 2014, seed yields of *Phacelia linearis* were not responsive to irrigation.

In 2013, seed yield of *Enceliopsis nudicaulis* was very low and was not responsive to irrigation. In 2014, seed yield of *Enceliopsis nudicaulis* showed a quadratic response to irrigation with a maximum seed yield at 5.4 inches of water applied.

Seed yield of *Heliomeris multiflora* increased with increasing irrigation rate up to the highest tested of 8 inches in 2013 and 2014 (Tables 3 and 4).

In 2014, seed yield of *Thelypodium milleflorum* increased with increasing irrigation rate up to the highest tested of 8 inches. In 2014, seed yields of *Ipomopsis aggregata* were greatest with 4 inches of applied water.

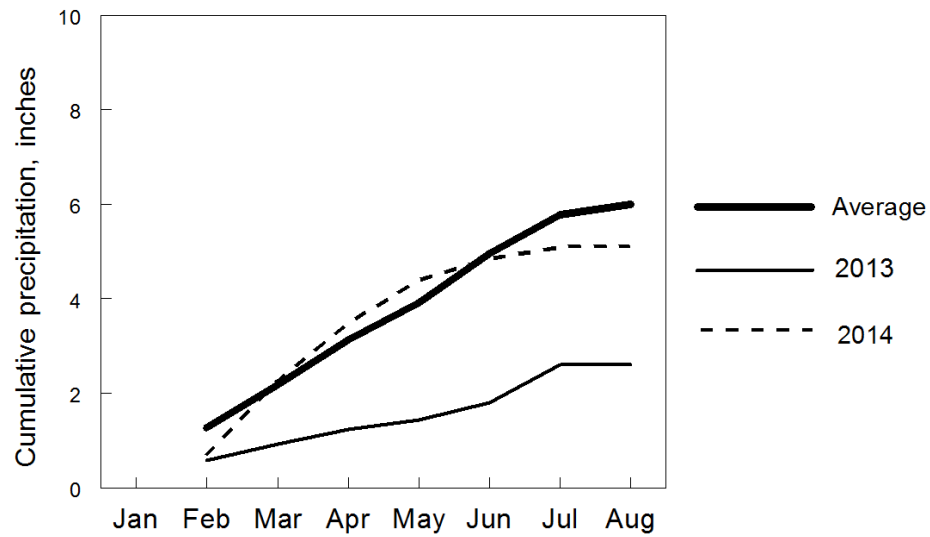


Figure 1. Cumulative annual and 66-year-average precipitation from January through July at the Malheur Experiment Station, Oregon State University, Ontario, OR

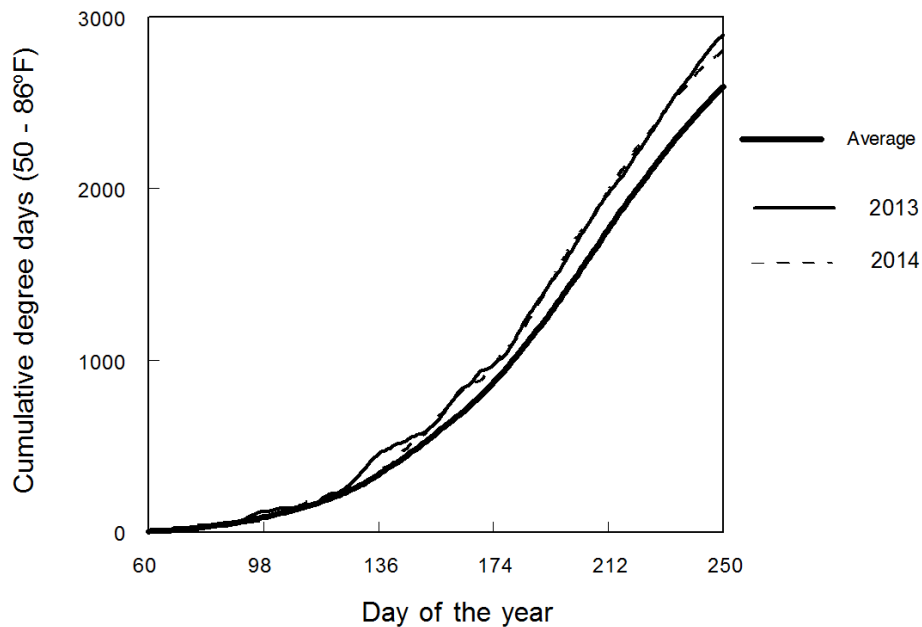


Figure 2. Cumulative growing degree-days (50-86°F) for selected years and 24-year average at the Malheur Experiment Station, Oregon State University, Ontario, OR

Table 2. Native wildflower flowering, irrigation, and seed harvest dates in 2013 and 2014 by species. Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	Flowering			Irrigation		Harvest
	start	peak	end	start	end	
2013						
<i>Chaenactis douglasii</i>	23-May	30-Jun	15-Jul	22-May	3-Jul	2-Jul, 22-Jul
<i>Machaeranthera canescens</i>	13-Aug		1-Oct	17-Jul	28-Aug	2-Oct
<i>Phacelia hastata</i>	17-May		30-Jul	22-May	3-Jul	30-Jul (0 in), 7-Aug, 19-Aug (8 in)
<i>Phacelia linearis</i>	3-May	16-May	15-Jun	2-May	12-Jun	2-Jul
<i>Enceliopsis nudicaulis</i>	30-Jun		15-Sep	3-Jul	14-Aug	8-Aug to 30-Aug
<i>Heliomeris multiflora</i>	15-Jul		30-Aug	5-Jun	17-Jun	8-Aug, 15-Aug, 28-Aug
<i>Ipomopsis aggregata</i>	31-Jul	very little flowering		31-Jul	11-Sep	
<i>Thelypodium milleflorum</i>		No flowering				
2014						
<i>Chaenactis douglasii</i>	20-May		15-Jul	13-May	24-Jun	
<i>Machaeranthera canescens</i>	20-Aug	17-Sep		22-Jul	2-Sep	8-Oct
<i>Phacelia hastata</i>	5-May		10-Jul	29-Apr	10-Jun	14-Jul
<i>Phacelia linearis</i>	5-May	4-Jun	1-Jul	1-May	10-Jun	7-Jul
<i>Enceliopsis nudicaulis</i>	5-May	1-Jul	30-Jul	6-May	17-Jun	14-Jul to 30-Aug
<i>Heliomeris multiflora</i>	20-May	20-Jun	30-Aug	13-May	24-Jun	15-Jul to 15-Aug
<i>Ipomopsis aggregata</i>	22-Apr	13-May	30-Jul	23-Apr	3-Jun	20-Jun
<i>Thelypodium milleflorum</i>	22-Apr	5-May	10-Jun	23-Apr	3-Jun	2-Jul

Table 3. Native wildflower seed yield response to season long irrigation rate (inches). Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	2013				2014			
	0 inches	4 inches	8 inches	LSD (0.05)	0 inches	4 inches	8 inches	LSD (0.05)
	----- lb/acre -----				----- lb/acre -----			
<i>Machaeranthera canescens</i>	206.1	215.0	124.3	73.6	326.9	476.6	420.4	NS
<i>Phacelia hastata</i>	35.3	102.7	91.2	35.7	87.7	305.7	366.4	130.3
<i>Phacelia linearis</i>	121.4	306.2	314.2	96.0	131.9	172.9	127.2	NS
<i>Enceliopsis nudicaulis</i>	2.3	6.8	5.9	NS	1.5	34.6	29.1	20.7
<i>Heliomeris multiflora</i>	28.7	57.6	96.9	NS	154.6	200.9	271.7	107.3 ^a
<i>Thelypodium milleflorum</i>					44.0	65.8	152.8	95.7 ^a
<i>Ipomopsis aggregata</i>					47.1	60.9	63.6	9.0

Species	Average			LSD (0. 05)
	0 inches	4 inches	8 inches	
	----- lb/acre -----			
<i>Machaeranthera canescens</i>	266.5	345.8	272.3	NS
<i>Phacelia hastata</i>	61.5	204.2	228.8	53.0
<i>Phacelia linearis</i>	126.7	239.5	220.7	87.2
<i>Enceliopsis nudicaulis</i>	1.9	26.6	17.5	17.1 ^a
<i>Heliomeris multiflora</i>	91.7	129.2	184.3	60.4

^aLSD (0.10)

Table 4. Regression parameters for native wildflower seed yield response to irrigation rate (inches/season). For the quadratic equations, the amount of irrigation that resulted in maximum yield was calculated using the formula: $-b/2c$, where b is the linear parameter and c is the quadratic parameter. Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	Year	intercept	linear	quadratic	R ²	P	Maximum yield lb/acre	Water applied for maximum yield inches/season
<i>Machaeranthera canescens</i>	2013	206.1	14.7	-3.1	0.54	0.05	223.4	2.4
	2014	326.9	63.2	-6.4	0.34	NS ^a		
	Average	266.5	38.9	-4.8	0.41	0.1	345.8	4.1
<i>Phacelia hastata</i>	2013	35.3	26.7	-2.5	0.66	0.01	107.7	5.4
	2014	87.7	74.2	-4.9	0.76	0.01	367.4	7.5
	Average	61.5	50.5	-3.7	0.88	0.001	233.8	6.8
<i>Phacelia linearis</i>	2013	121.4	68.3	-5.5	0.69	0.01	332.5	6.2
	2014	131.9	21.1	-2.7	0.11	NS		
	Average	126.7	44.7	-4.1	0.48	0.1	247.9	5.4
<i>Enceliopsis nudicaulis</i>	2013	3.1	0.4		0.16	NS		
	2014	1.5	13.1	-1.2	0.6	0.05	37.1	5.4
	Average	1.9	10.4	-1.1	0.46	0.1	27.5	4.9
<i>Helioomeris multiflora</i>	2013	27	8.5		0.38	0.05	95.1	8
	2014	150.5	14.6		0.27	0.1	267.6	8
	Average	88.7	11.6		0.51	0.01	181.4	8
<i>Thelypodium milleflorum</i>	33.1	13.6		0.38	0.05	141.9	8	
<i>Ipomopsis aggregata</i>	48.5	2.1		0.23	NS			

^anot significant. There was no statistically significant difference in yield between the forbs that were not irrigated and those receiving 4 or 8 inches of water.

Publications

Refereed Journal Articles

Shock, C. C.; Feibert, E. B. G.; Shaw, N.; Shock, M.; Saunders, L. D. 2014. Irrigation to enhance native seed production for Great Basin restoration. *Natural Areas Journal* 35(1): 74-82.

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Shock, C. C.; Feibert, E. B. G.; Saunders, L. D.; Shaw, N.; Sampangi, R. S. 2014. Irrigation requirements for native perennial wildflower seed production in a semi-arid environment. P. 166-183. In: Shock, C. C. (ed.). Oregon State University Agricultural Experiment Station, Malheur Experiment Station Annual Report 2013, Department of Crop and Soil Science Ext/CrS 149.

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Presentations

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Shock, C.; Feibert, E. B. G.; Shaw, N. L.; Kilkenny, F. F. 2014 Successful seed production of native Great Basin wildflowers. Society for Ecological Restoration Regional Conference Northwest and Great Basin Chapters; 2014 October 6-10; Redmond, OR.

Shock, C.; Feibert, E.; Saunders, M.; Shaw, N. 2014. Wildflower seed yield in response to irrigation in a dry year. Great Basin Native Plant Project Annual Meeting; 2014 March 17-18; Boise, ID.

Field days

Feibert, E. B. G.; Shock, C. C. 2014. Establishing native wildflower seed production plantings. 2014. Native Wildflower Seed Production Field Day, Oregon State University Malheur Experiment Station; 2014, May 15; Ontario, OR.

Felix, J.; Shock, C. C. 2014. Controlling weeds in native wildflower seed production plantings. Native Wildflower Seed Production Field Day, Oregon State University Malheur Experiment Station; 2014, May 15; Ontario, OR.

Shock, C. C.; Feibert, E. B. G. 2014. Plants that use little water. Native Wildflower Seed Production Field Day, Oregon State University Malheur Experiment Station; 2014, May 15; Ontario, OR.

Shock, C. C.; Feibert, E. B. G. 2014. Irrigation systems for native wildflower seed production. Plants that use little water. Native Wildflower Seed Production Field Day, Oregon State University Malheur Experiment Station; 2014, May 15; Ontario, OR.

Irrigation water requirements for native wildflower seed production

Clint Shock and Erik Feibert, 31 January 2015

Wildflower species irrigated with drip systems at the Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	Common names	Flowering dates*	Irrigation water needs, inches/year	Years to first harvest	Stand life, years	Seed yield, lb/ac per harvest
<i>Eriogonum umbellatum</i>	Sulphur-flower buckwheat	L. May to July	0-8	1	8+	100-350
<i>Eriogonum heracleoides</i>	Parsnip-flowered buckwheat	May to June	0-4	2	4+	50-400
<i>Penstemon acuminatus</i>	Sharpleaf penstemon	L. April to E. June	<4	2	3	100-600
<i>Penstemon deustus</i>	Scabland or hotrock penstemon	May to E. July	0-4	1	5+	200-600
<i>Penstemon speciosus</i>	Royal penstemon	May to June	0-4	2	3	25-350
<i>Penstemon cyaneus</i>	Blue penstemon	May to June	0-8	1	3	200-800
<i>Penstemon pachyphyllus</i>	Thickleaf beardtongue	L. April to E. June	<4	2	3	200-500
<i>Lomatium dissectum</i>	Fernleaf biscuitroot	April to E. May	5-8	4	8+	300-1200
<i>Lomatium triternatum</i>	Nineleaf biscuitroot	April to E. June	4-8	2	8+	700-2000
<i>Lomatium grayi</i>	Gray's biscuitroot	L. March to E. May	0-5	2	8+	300-1200
<i>Lomatium nudicaule</i>	Bare-stem desert parsley	April to May	0-8	3	4+	500-600
<i>Cymopterus bipinnatus</i>	Hayden's cymopterus	April to May	4-8	3	4+	300-2500
<i>Sphaeralcea parvifolia</i>	Smallflower globemallow	May to June	<4	1	4-5	100-500
<i>Sphaeralcea grossulariifolia</i>	Gooseberryleaf globemallow	May to June	<4	1	4-5	150-400
<i>Sphaeralcea coccinea</i>	Scarlet globemallow	May to June	<4	1	4-5	100-300
<i>Dalea searlsiae</i>	Searls' prairie clover	May to June	0-8	2	4+	150-300
<i>Dalea ornata</i>	Western prairie clover	May to June	0-8	2	4+	150-450
<i>Astragalus filipes</i>	Basalt milkvetch	L. April to June	<4	2	4+	10-100
<i>Cleome serrulata</i>	Rocky mountain beeplant	June to August	0-8	1	1	100-500
<i>Cleome lutea</i>	Yellow beeplant	May to July	<4	1	1	100-200
<i>Machaeranthera canescens</i>	hoary tansyaster	Mid-Aug to L. Sept.	4	1	2+	200-400
<i>Phacelia hastata</i>	silverleaf phacelia	May to July	4-8	1	2+	100-300
<i>Phacelia linearis</i>	threadleaf phacelia	E. May to L. June	4	1	1	150-300
<i>Enceliopsis nudicaulis</i>	nakedstem sunray	May to August	4	1	2+	?
<i>Helimeris multiflora</i>	showy goldeneye	L. May to August	8	1	2+	50-250
<i>Ipomopsis aggregata</i>	scarlet gilia	L. April to July	4	2	2+	50-60
<i>Thelypodium milleflorum</i>	manyflower thelypody	L. April-mid June	8	2	2+	?

*Varies with the year and location. E = Early, L = Late

The preceding report describes irrigation and plant establishment practices that can be immediately implemented by seed growers. Multi-year summaries of species seed yield performance in response to irrigation are in the table above.

Additional Products

- Seed produced from these plantings was used to establish commercial seed production fields.
- A field tour for growers and the public was conducted 15 May 2014; a tour of the seed production trials was incorporated into the annual Malheur Experiment Station Field Day activities 9 July 2014.
- Continued improvement of native plant database on the internet (at the moment off line):
- <http://www.malag.aes.oregonstate.edu/wildflowers/>

Acknowledgements

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Project Title Coordination of Great Basin Native Plant Project Plant Materials Development, Seed Increase, and Use

Project Agreement No. 12-JV-11221632-044

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Project Description

Introduction

In 2014, Eastern Oregon Stewardship Services (EOSS) concentrated on assisting with the bluebunch wheatgrass common garden reciprocal transplant study. This study will test the hypotheses that local plant material is best adapted for restoration purposes and whether seed zones perform well in delineating regions of local adaptation.

Reciprocal transplant studies, where plants from multiple populations are planted in a set of sites that represent local and non-local climates, are useful for evaluating the effectiveness of seed transfer guidelines and seed zones. Seed zones and guidelines ensure that adapted plant material is reintroduced after fires, and may be important for long-term resilience of native grass populations.

Objectives

- Prepare and plant bluebunch wheatgrass (*Pseudoroegneria spicata*) common garden study sites in recently burned areas in identified seed zones for reciprocal transplant studies.
- Expand the Great Basin Native Plant Project (GBNPP) Native Seed Growers Information Network.
- Increase native seed collections for GBNPP in Eastern Oregon and Northern Nevada according to research needs and gaps identified by provisional seed zone maps.

Methods

Seed collections were made in 2013, plugs were grown in greenhouses and bluebunch plugs were planted at test sites in fall 2014 (Figure 1). In the Northern Great Basin/Snake River Plain, eight or more source treatments were planted within eight test sites with locations based on developed seed zones. Another eight sites were planted in the Columbia Plateau/Blue Mt. regions.



Figure 1. Quinn #1 site in Santa Rosa Mountains in Northern Nevada seed zone 6a.

Many of the test sites had sagebrush removed and were then tilled as part of seed bed preparation. Bluebunch wheatgrass plugs were planted into numerically identified study blocks consisting of several seed zones in all 16 sites, September through December, 2014 (Figures 2, 3, 4, 5 and 6). Two bluebunch cultivars, Anatone and Goldar, were also planted at select study locations. Two rows of boundary plants were planted as protective borders for the bluebunch plugs at each site. After planting, plugs were watered (Figure 7) and plant identification numbers were recorded for future data collection (Figure 8).



Figure 2. Laying out plots in the Santa Rosa's.



Figure 3. Francis Kilkenny sorting bluebunch plugs for planting.



Figure 4. Chris and Jameson digging holes for planting grass plugs.



Figure 5. Berta planting bluebunch wheatgrass plugs.



Figure 6. Crew planting plugs in the Steens.



Figure 7. Watering plugs after planting.



Figure 8. Brad St. Clair recording plug identification data after planting at Central Ferry, WA.

Results

EOSS assisted with planting six of the study sites (Table 1).

Table 1. EOSS Assistance – Planting Sites

SITES	DATES	ACTIVITIES
Central Ferry WA	September 22-23	Travel and Planting
Stevens Ridge WA	September 24-25	Planting and Travel
Quinn #1 NV	September 29- October 1	Travel and Planting
Quinn #2 NV	October 2-3	Planting and Travel
Steens Mt. OR	October 15-17	Travel and Planting
Crooked River Grasslands, OR	October 18	Delivering Plants

Management Applications and/or Seed Production Guidelines

Previous work on bluebunch (St. Clair et al. 2013) will allow for selecting populations that are more or less adapted to specific climatic variables, as well as allow testing the effectiveness of the prospective seed zones.

References

St. Clair, J. B.; Kilkenny, F. F.; Johnson, R. C.; Shaw, N. L.; Weaver, G. 2013. Genetic variation in adaptive traits and seed transfer zones for *Pseudoroegneria spicata* (bluebunch wheatgrass) in northwestern United States. *Evolutionary Applications* 6(6): 933-948.

Project Title Use of Native Annual Forbs and Early Seral Species in Seeding Mixtures for Improved Success in Great Basin Restoration

Project No. 11-IA-11221632-011

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Project Description

Use of native annual and early seral species in Great Basin rangeland reseeding efforts may increase invasion resistance and facilitate succession to desired vegetation, thus improving restoration/rehabilitation success. Early serals may be similar to exotic annual grasses in growth and resource acquisition strategies. Because they occupy a similar ecological niche, due to functional trait similarities such as growth rates and resource acquisition strategies, theory predicts that early serals would compete more strongly against invasives like cheatgrass (*Bromus tectorum*) and medusahead (*Taeniatherum caput-medusae*). As invasion and success of exotic grasses appears to be associated with soil type, competitive interactions may also depend on soil type.

Objectives

In this study, we used a common garden approach to evaluate the performance of two exotic annual grasses (either cheatgrass or medusahead) and mixtures of native species growing in two soil types of contrasting texture. We assessed seedling emergence and early survival, as well as biomass and reproductive output during the first growing season, because early life stages are critical to restoration success. Our first objective was to assess the relative performance of two native seed mixes (a novel seed mix composed of early seral species versus a representative traditional seed mix composed of late seral species) when seeded in the presence of an exotic annual grass. We hypothesized that the early seral seed mix would be more successful in early life stages in comparison to the late seral seed mix when growing in the presence of an exotic annual grass. Our second objective was to test the potential suppressive effect of the early versus late seral seed mix on the early life stages of exotic annual grasses. Here we hypothesized that the early seral seed mix would have a greater suppressive effect on the exotic annual grasses in comparison to the late seral seed mix, and that this effect would be strongest in the soil type to which the exotic is presumed to be least well adapted. Our third objective was to examine the performance of exotics and natives in two different soil types contrasting in texture (i.e., a clay loam vs. a sandy loam). We hypothesized that the exotics would be more successful when growing in the soil type to which the exotic is presumed to be most well adapted. Specifically, we predicted that medusahead would be most successful on the clay loam, while cheatgrass would be most successful on the sandy loam. For the natives, we hypothesized that performance would differ by soil type when growing with exotics due to soil preference by the exotics.

Methods

We used a common garden approach to assess exotic and native plant performance in two soil types under the same climatic conditions. Three experiments were performed, using completely randomized designs. Two parallel 2x3 factorial experiments, one with each exotic annual grass (either cheatgrass or medusahead), were designed to assess the performance of the early seral native seed mix versus the late seral seed mix when growing in the presence of an exotic annual grass, as well as the relative performance of these two exotic annuals when growing with and without natives. In these experiments, two levels of soil type (clay loam and sandy loam) were crossed with three levels of seed mix (early seral mix, late seral mix, and no mix). A third experiment was designed to evaluate the performance of natives when growing in the absence of exotics. In this 'No Exotic' experiment, levels of soil type (clay loam and sandy loam) were crossed with two levels of seed mix (early seral mix and late seral mix).

Each seed mix consisted of two forbs, two perennial grasses, and one shrub. A novel early seral mix was composed of the following species: bristly fiddleneck (*Amsinckia tessellata*), Veatch's blazingstar (*Mentzelia veatchiana*), squirreltail (*Elymus elymoides*), Sandberg bluegrass (*Poa secunda*) and rubber rabbitbrush (*Ericameria nauseosa*), and these seeds were collected from multiple wild populations. A late seral mix, representative of traditional seeding mixes used in past restoration efforts, was composed of the following species: Palmer's penstemon (*Penstemon palmeri*), goosberryleaf globemallow (*Sphaeralcea grossulariifolia*), Snake River wheatgrass (*Elymus wawawaiensis*), Indian ricegrass (*Achnatherum hymenoides*), and Wyoming big sagebrush (*Artemisia tridentata* spp. *wyomingensis*). These seeds were commercially purchased from Comstock Seeds (Gardnerville, NV). A representative clay loam soil (clayey, smectitic, mesic, Lithic Argixeroll) and a representative sandy loam soil (fine-loamy, mixed, superactive, mesic Durinodic Xeric Haplargid) were collected from multiple field locations, homogenized by soil type, and filled into 41-cm deep treepots.

The pots were then sunk into the ground at the University of Nevada Agricultural Experiment Station in Reno, NV. In each pot, seeds were sown by hand into randomized locations within each pot (15x15 cm² surface area) using a 20-location fixed grid (Oct. 2010). In the 'No Exotic' experiment, we used two species combinations: (1) early seral native species only (10 seeds, consisting of two of each species) and (2) late seral native species only (10 seeds, consisting of two of each species). In the two parallel experiments with exotic grasses, we used three species combinations: (1) exotic species only (10 seeds), (2) exotic and early seral native species together (10+10 seeds), and (3) exotic and late seral native species together (10+10 seeds).



Figure 1. Photo of one of the replicates in the medusahead experiment where several individuals of the exotic and the early seral natives have emerged, taken during emergence monitoring approximately 3 weeks after seeding.

Emergence and seedling survival were monitored biweekly from first emergence (November 2010) through spring of the following year (May 2011) (Figure 1). We also measured aboveground biomass production, seed output, and final establishment through fall 2011. Logistic regression analysis was performed on the emergence and survival of exotics and natives in each experiment. ANOVA was used to analyze establishment, biomass and seed production. Models included seed mix and soil type as factors. For the natives models, functional group (grass, forb, shrub) was also included as a factor. Additionally, ANOVA was used to assess treatment differences in timing of emergence, both for exotics and for natives, using the same model structure described above. Analyses were performed using SAS 9.3 or JMP 9.0 statistical analysis software (SAS Institute, Inc., Cary, NC).

Results

Emergence and Survival

We found that early seral species generally outperformed late seral species when growing with

exotic annual grasses, for emergence probabilities ($P < 0.0001$), survival probabilities ($P < 0.05$, with medusahead), and earlier emergence timing ($P < 0.0001$), though results differed among functional groups and soil types. When growing with cheatgrass, early and late seral native survival differed in sandy loam but not clay loam ($P < 0.01$). Within each seed mix, native grasses exhibited the highest emergence probabilities of the functional groups ($P < 0.0001$). In both the cheatgrass and medusahead experiments, we found that the presence of native species did not have a suppressive effect on the exotics. In contrast, cheatgrass had a higher probability of survival when it was growing with either of the native seed mixes ($P < 0.05$). A suppressive effect of the natives on the exotics is more likely to be expressed in later life stages. In terms of soil preference, we found that cheatgrass performed better in sandy loam, as predicted, both for emergence and survival ($P < 0.0001$).

Contrary to our prediction, medusahead did not have a preference for the clay loam; rather it demonstrated superior performance in both soils. Emergence of all native functional groups was generally higher on sandy loam when growing with exotics ($P < 0.01$). We also found that native grasses had higher survival in sandy loam while forbs and shrubs had higher survival in clay loam when growing with exotics ($P < 0.0001$).

Establishment, Biomass and Reproductive Output in the Medusahead Experiment Establishment of medusahead was not affected by seed mix, but was significantly higher in sandy loam than clay loam ($P = 0.003$). Medusahead establishment was very high in all treatments and ranged from 83% to 93%. When growing with medusahead, establishment of early seral natives was higher than that of late seral natives for grasses and forbs but not for shrubs ($P = 0.02$). Native grasses generally exhibited higher establishment than forbs and shrubs. Establishment of grasses was higher in sandy loam than clay loam, while establishment of forbs and shrubs was not significantly affected by soil type. Both biomass and seed production of medusahead were significantly suppressed by the early seral seed mix relative to when the exotic was growing alone, although this effect was relatively small. Medusahead biomass and seed production were more strongly reduced in the sandy loam (21% and 22%, respectively) than in the clay loam (13% and 14%, respectively). In contrast, biomass and seed production of medusahead were not suppressed by the late seral seed mix. When growing with medusahead, native aboveground biomass production and seed production varied by seed mix, soil type, and functional group (seed mix by soil type by functional group interaction $P = 0.02$).

Both biomass and seed production of early native forbs was higher in clay loam than sandy loam: all other native treatment group means were zero or near zero.

Conclusions

Given their generally higher performance, the early seral natives may have a greater chance of persisting in the presence of cheatgrass or medusahead in comparison to the late seral natives. Success of seeded natives at the seedling stage is likely critical in determining the eventual success of native reseeding efforts. Our findings suggest that use of native annuals and early serals in reseeding efforts may result in greater density of natives in communities where exotics are present, though additional studies will be needed to assess whether these species are able to persist in the long-term. Differences in native emergence and survival on the two different soil types when growing with exotics suggest that use of early serals in restoration seedings may result in greater success in more coarse-textured soils, particularly when native grasses comprise a large proportion of the native seed mix. However, when biomass and reproductive output were

measured, the early seral forb, bristly fiddleneck, had a suppressive effect on medusahead on both soil types. We also found that performance of medusahead is comparable in the two soil types. To date, medusahead invasion has been most closely associated with fine-textured soils, but it has been observed on certain sites with more coarse-textured soils (Dahl and Tisdale 1975). Our results support these observations and suggest that medusahead is capable of expanding its current range in the Intermountain West.

Management Applications and Seed Production Guidelines

This research lends support to the use of early seral natives to improve success rates of rangeland restoration/rehabilitation reseeding in the Great Basin. Given their greater performance when growing with exotics during early life stages, early seral species may have a greater chance of persisting in communities where exotic annual grasses are present. If they persist, and possibly suppress exotics once they mature, their establishment may facilitate succession to a more native dominant community of desired later seral vegetation.

Our research findings on emergence and survival suggest that it would be advisable to rely more on native grasses in Great Basin restoration seedings, based on the relative performance of the different native functional groups. Although the forbs in this study did not establish as well as the native grasses, certain species such as bristly fiddleneck show promise for use in rangeland reseeding. Bristly fiddleneck had lower establishment, but much greater biomass and seed production which produced a suppressive effect on medusahead biomass (reduced by 16%) and reproductive output (17%) across both soil types. Further research to examine whether the use of increased seeding density of bristly fiddleneck, and/or whether greater diversity of species in the seeding mix would enhance exotic suppression, is warranted. Native perennial grasses, especially early seral species, were able to establish in the presence of exotic annual grasses in greater numbers than native forbs or shrubs, demonstrating their importance in restoration, though they did not appear to have a suppressive effect on medusahead during the first growing season.

Additional research is needed to assess the impact of native perennial grasses seeded with exotic annual grasses over a longer time frame to determine whether these species may suppress the exotics during later stages of community development. Our findings suggest that efforts to find additional novel candidate species for seed mixtures may be best focused on early successional species, similar to bristly fiddleneck, to improve restoration/rehabilitation outcomes in disturbed rangeland ecosystems.

The strong performance of medusahead in both soil types indicate that it is able to expand its range beyond fine-textured soils. Therefore, greater efforts to prevent its further spread in the Great Basin should be of high priority.

References

Dahl, B. E.; Tisdale, E. W. 1975. Environmental factors related to medusahead distribution. *Journal of Range Management* 28: 463-468.

Presentations

Uselman, S. M.; Snyder, K. A.; Leger, E. A.; Duke, S. E. Using annual forbs and early seral species in seeding mixtures for improved success in Great Basin restoration. National Native Seed Conference; April 8-10, 2013; Santa Fe, NM. Invited talk).

Publications

Uselman, S. M.; Snyder, K. A.; Leger, E. A.; Duke, S. E. 2014. First-year establishment, biomass and seed production of early vs. late seral natives in two medusahead (*Taeniatherum caput medusae*) invaded soils. *Invasive Plant Science and Management*. 7: 291-302. Selected for an early press release by the journal.

Uselman, S. M.; Snyder, K. A.; Leger, E. A.; Duke, S. E. Emergence and survival of early vs. late seral species in Great Basin restoration during early life stages in two different soil types. *In Revision: Applied Vegetation Science*.

Uselman, S. M.; Snyder, K. A.; Leger, E. A. Comparison of early vs. late seral native biomass and seed production when growing with *Bromus tectorum*. In Preparation.

Products

Outreach: Brochures for the public at the Nevada Agricultural Experiment Station Field Day, College of Agriculture, Biotechnology, and Natural Resources, University of Nevada-Reno; 2013, September 14; Reno, Nevada.

Status of the Current SCA: Completed.

Project Title Restoration of Native Understory Plants in Degraded Sagebrush Steppe Ecosystems

Project Agreement No. L11PG00279 BLM-USGS Interagency Agreement

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Project Description

Objectives

In the Great Basin, efforts to restore native sagebrush steppe plant communities typically begin after sagebrush shrubs have been killed (e.g. after wildfires) or mechanically removed to facilitate traditional revegetation approaches such as drill seeding. However, it may be feasible to begin restoration of native herbaceous plants while the sagebrush canopy is still intact. Our overall goal is to evaluate whether native bunchgrass and forb establishment from seeds and seedlings differs between sagebrush understories and interspaces in degraded sagebrush steppe ecosystems. We are addressing the following questions:

- 1) Does native bunchgrass and forb establishment differ in sagebrush understories vs. interspace gaps?
- 2) Do these patterns differ for seeds vs. seedlings?

Methods

Three native bunchgrasses: bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] A. Love) Thurber's needlegrass (*Achnatherum thurberianum*) and squirreltail (*Elymus elymoides* [Raf.] Swezey), and two native forbs: largeflower hawksbeard (*Crepis occidentalis* Nutt.) and Munro's globemallow (*Sphaeralcea munroana* [Douglas] Spach), are the focal species for this study. At each of the three sites, we established approximately 50 different seeding locations per microhabitat (sagebrush understory, interspace) for bluebunch wheatgrass, squirreltail, globemallow, and largeflower hawksbeard. We repeated this procedure for seedling plantings for bluebunch wheatgrass, squirreltail, globemallow, and a smaller sample of largeflower hawksbeard and Thurber's needlegrass. Seeding occurred in fall 2012, while planting of seedlings occurred in spring 2013. We recorded survival, average height, and number of tillers

for seeds in spring/summer 2013 and 2014. For seedlings we measured survival (live, dead), average height, and basal width in 2014. We also recorded overall site characteristics (e.g. shrub densities, plant cover) in 2012 and 2014.

Results and Discussion

Preliminary results suggest that restoration plantings of bluebunch wheatgrass and squirreltail from seed showed high (61-74%) establishment success across both canopy and interspace microsites after 7 months, but declined markedly after the first year (3-11%). Plantings of seedlings also showed high (81-99%) initial establishment rates (after 7 months); though establishment of squirreltail, appeared to be greater in interspace than canopy microsites at the driest site. Interestingly, this is in contrast to distributions of mature, naturally-established squirreltail plants (assessed over 29 sites, including our three project sites) which occur in higher densities in canopy microsites, particularly at drier sites. Together these results illustrate how plant responses to canopy vs. gap microsites may differ according to species, life stage, and both short- and long-term moisture conditions.

Future Plans

We will continue to analyze data, as well as re-assess seeding and seedling parameters in spring/summer 2015. We also will begin writing up the data for publication

Management Applications

This was a pilot project so lessons learned and application contain cautions associated with studies with few associated with only limited restoration attempts over time and space. However, our study does show that perennial grass associations of mature grasses and seedlings with sagebrush canopies appears to depend on species life stage (seedling or transplant) and moisture conditions. As more information on these relationships are developed, it appears that re-establishing perennial grasses into shrub-dominated communities is possible without waiting for fire to remove shrubs. This should allow these communities to recover resiliency so that when future fires occur, native perennial herbaceous plants will fill the void and resist annual grass invasions.

Presentations

Holthuijzen, M. F.; Veblen, K. E.; Pyke, D. A.; Monaco, T. A. Grass-shrub spatial pattern response to a moisture gradient in Great Basin sagebrush communities. Ecological Society of America meeting; 2014, August 10-15; Sacramento, CA.

Veblen, K. E.; Holthuijzen, M. F.; Wirth, T. A.; DeCrappeo, N.; Pyke, D. A. Plant responses to rainfall and microsite in sagebrush communities: keys to restoration success in the Great Basin? Ecological Society of America meeting; 2013, August 4-9; Minneapolis, MN.

Project Title Science Delivery for the Great Basin Native Plant Project

Project Agreement No. 14-JV-11221632-018

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Project Description

Science integration and science application are integral to the success of the Great Basin Native Plant Project (GBNPP). Completed studies in the areas of plant material development, cultural practices for seed production, and restoration ecology and technology provide a constantly increasing body of knowledge that is published and distributed in many ways: published in journals, theses and dissertations, reports, presented through posters, brochures, flyers, disseminated through e-mail and meeting networking. Sharing and synthesizing this information is essential to rapid and appropriate application in the selection of appropriate plant materials for planting mixes, commercial seed production, and ecological restoration.

Objectives

The objectives of this project are to promote timely, useful, and user-friendly information to GBNPP cooperators and collaborators to advance successful Great Basin restoration efforts.

Results and Discussion

In the second year of this project, procedures and products remain similar to those reported for 2014. Accomplishments related to the identification and sharing of GBNPP scientific developments include:

- Maintaining contact with Great Basin Native Plant Program (GBNPP) cooperators through regular correspondence, event alerts, and communication of project due dates.
- Updating and producing hard copy posters and brochures for Great Basin events and meetings.
- Regularly updating the GBNPP website with meeting announcements, new publications, and updated cooperator information.
- Helping to develop the agenda and secure presenters for the annual GBNPP meeting.
- Tracking and reporting GBNPP accomplishments.

Project Title Evaluating Strategies for Increasing Plant Diversity in Crested Wheatgrass Seedings

Project Agreement No. 10-CR-11221632-117

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Project Description

Introduction

A previous study by Cox and Anderson (2004) suggested that plant diversity in disturbed, formerly sagebrush (*Artemisia tridentata*)-perennial grass communities, could be increased through “assisted succession” by 1) “capturing” the disturbed site from weeds with crested wheatgrass (*Agropyron cristatum* or *A. desertorum*), 2) reducing crested wheatgrass with mechanical or chemical (herbicide) treatments, and 3) seeding the sites with adapted native species. Further, Pellant and Lysne (2005) viewed crested wheatgrass monocultures as “bridge” plant communities that could replace weed-dominated lands for potential future rehabilitation to more diverse plant communities. Recently, research by Hulet et al. (2010) in Utah and Fansler

and Mangold (2011) in Oregon has tested this hypothesis, with mixed results. Our research is an extension of this work in northern Nevada.

Objectives

Specifically, our objectives were to:

- 1) Evaluate various treatments for reducing crested wheatgrass in near-monoculture rangelands.
- 2) Determine the effect of crested wheatgrass control methods on establishment of seeded native species.

Methods

Study Site

The study site was located 24 km southeast of Elko, NV, in the Owyhee High Plateau Major Land Resource Area (MLRA). The area (1615 m elevation, Loamy 8-10 PZ) had a surface soil texture of sandy loam underlain by loam (Orovada Puett association) and was formerly dominated by a Wyoming big sagebrush (*Artemisia tridentata* spp. *wyomingensis*) plant community. The area was seeded to crested wheatgrass during the 1970s. Located within the boundaries of South Fork State Park, the site was fenced to exclude livestock grazing and had the necessary cultural resources clearance from the Nevada State Historic Protection Office (SHPO) to allow the soil disturbance activity associated with this research.

Treatment Implementation

We conducted two study trials, approximately 0.9 km apart (center to center), each 10 ha in size and installed as a randomized block split-plot design with five blocks. For each of the five blocks within a trial location, five 0.4-ha plots were divided in half and randomly selected for either seeding or no seeding. Within each block, the randomly assigned 0.4-ha main plots were either left “undisturbed” (U) or received a treatment as detailed below. Non-seeded split plots were included to simulate the outcome of suppression treatments if the seeding treatment failed.

For Trial 1 (north blocks), “disked only” (D) plots were 3-way disked during November 2007. In May 2008 “spring-applied glyphosate” (G) and “combined disking + glyphosate” (DG) plots were sprayed with glyphosate. In early October 2008, “combined spring + fall-applied herbicide plots” (GG) were sprayed again with glyphosate. For Trial 2 (south blocks), another treatment suite was implemented within the same general study area during 2010 and using the same randomized block, split-plot design. However, because of our poor results with disking and similarly poor results reported in a similar study (Fansler and Mangold 2011), we omitted disking and included additional herbicide treatments. Specifically, crested wheatgrass suppression treatments for Trial 2 consisted of imazapic (I), chlorsulfuron + sulfometuron methyl (CS), glyphosate (G), and half-rate glyphosate (G/2).

For each of the trials, sub-plots selected for seeding were seeded at NRCS-recommended rates by personnel from the NRCS Aberdeen Plant Materials Center with a Truax Rough Rider minimum-till drill during late October 2008 for Trial 1, and late October 2010 for Trial 2. For small-seeded species, seed tubes were pulled so that seed fell on the soil surface; drill disks were raised, no furrows made, and a brillion-type cultipacker was attached to the rear of the drill to press broadcasted seeds into the soil surface. The seed mixture used is identified in Table 1.

Table 1. Seeded species and pure live seed (PLS) seeding rates for South Fork study area treatments, planted in late October 2008 for Trial 1 and late October 2010 for Trial 2.

Species	Cultivar	Seed Size	Seeding Rate (kg PLS /ha)
Indian ricegrass (<i>Achnatherum hymenoides</i>)	‘Nezpar’	Large	2.24
Bottlebrush squirreltail (<i>Elymus elymoides</i>)	‘Toe Jam Creek’	Large	2.24
Needle-and-thread grass (<i>Stipa comata</i>)		Large	2.24
Basin wildrye (<i>Leymus cinereus</i>)	‘Magnar’	Large	2.24
Bluebunch wheatgrass (<i>Pseudoroegneria spicata</i>)	‘Secar’	Large	1.12
Sandberg bluegrass (<i>Poa secunda</i>)		Small	0.84
Munro globemallow (<i>Sphaeralcea munroana</i>)		Large	0.56
Lewis flax (<i>Linum lewisii</i>)	‘Appar’	Large	0.84
Western yarrow (<i>Achillea millefolium</i>)		Small	0.22
Wyoming big sagebrush (<i>Artemisia tridentata wyomingensis</i>)		Small	0.22
Spiny hopsage (<i>Grayia spinosa</i>)		Small	0.56

Weather Data and Vegetation Sampling

We compiled precipitation data for South Fork State Park from the National Weather Service. During the summers of 2009, 2010, 2011, and 2013 for Trial 1 and 2012 and 2013 for Trial 2, we used a stratified random sampling design to measure vegetation parameters: cover and density of crested wheatgrass, cover of annual weeds, and density of seeded species. We established five 18 m transects in each subplot, 10 m apart. Along each transect, we measured density and canopy cover on ten 0.25-m² frames placed at 2 m intervals along each transect. Density of crested wheatgrass and seeded species was determined by counting each individual plant within the sampling frame; cover was estimated based on modified Daubenmire cover classes (Daubenmire 1959) as follows: 1) 0-5%, 2) 6-25%, 3) 26-50%, 4) 51-75%, and 5) 76-100%. To determine percent cover, we calculated the midpoint of the cover classes and averaged across subplots.

For Trial 1, because of difficulty distinguishing species among seeded perennial grass seedlings during the first growing season, we grouped all into seeded perennial grasses, but the seeded forb and shrub species were readily identified and were recorded by species. Because of the high mortality of seeded species that we observed between the first and second growing season for Trial

1, we delayed initial data collection for Trial 2 until the second growing season after seeding.

Statistical Methods

We assessed the effect of treatment, seeding, and year on the density and cover of crested wheatgrass using linear mixed models (*Mixed* procedure, SAS v. 9.4). Trials 1 and 2 were analyzed separately because they involved different treatments and sampling years. The fixed effects were treatment, seeding, and year and all two-way interactions. The three-way interaction term (treatment*seeding*year) was dropped due to lack of significance and poorer model fit when it was included (higher AIC_C). Because of the split-plot design (i.e., seeding was applied to half of each treated block), block and treatment-by-block were treated as random effects. Year was a repeated effect implemented with unstructured covariance (SAS “type = un”), which produced models with better fit (lower AIC_C) than did compound-symmetric or first-order autoregressive covariance models (types “cs” and “ar (1)”). For each crested wheatgrass response, we compared treatment means pairwise for both the Trial 1 and Trial 2 blocks, using the Dunn-Sidak method to control for multiple comparisons (i.e., maintain test-wide Type 1 error at $\alpha = 0.05$). Cover percentage was arcsine-squareroot transformed and density was log- transformed

We used the same method as for crested wheatgrass to assess weed cover by species and total weed cover. As for crested wheatgrass, weed cover percentages were arcsine-squareroot transformed prior to analysis.

For seeded species, we assessed the effect of treatment, year, and treatment-by-year on log-transformed density using repeated-measures analysis of variance. Each species was analyzed separately, and we ran analyses for total seeded species, perennials, and forbs. For each response, we compared treatment means pairwise for both Trial 1 and Trial 2 blocks, again using the Dunn-Sidak method to control for multiple comparisons. In the species-specific analyses, a large number of zeroes in the Trial 1 blocks for seven species and for all seeded species in the Trial 2 blocks, led to non-normal residuals, and therefore suspect statistical conclusions.

Results

Precipitation

Precipitation by water year and crop year is summarized in Table 2. Crop year precipitation (October through June) varied from a low of 55% of normal (2012) to a high of 124% of normal (2011).

Effect of Treatment, Seeding, and Year on Crested Wheatgrass

We found that mechanical treatment (disking) was less successful at reducing crested wheatgrass than was herbicide. Among herbicides, G treatment best reduced crested wheatgrass cover compared to U. In Trial 1, DG, G, and GG reduced crested wheatgrass cover significantly lower than D and U (Figure 1, left). In Trial 2, G and G/2 treatments had lower mean crested wheatgrass cover values than the other herbicides (CS and I) and then U (Figure 1, right). However, crested wheatgrass density responded differently to G application in the two trials. In Trial 1, G treatment reduced crested wheatgrass density compared to U (Figure 2, left), but in Trial 2, the two G treatments approximately tripled crested wheatgrass density compared to controls (Figure 2, right). The other tested herbicides, CS and I, produced crested wheatgrass cover and density means similar to U (Figure 1-2, right).

Crested wheatgrass cover increased significantly by year across treatments in Trial 1 (2009 – 2013), while decreasing in Trial 2, but only in the non-G treatments (Figure 1). The consistent effect of year on crested wheatgrass across treatments in Trial 1 meant no interaction with treatment, while there was a marginal treatment-by-year interaction in Trial 2 ($P = 0.102$). Crested wheatgrass density also changed significantly by year, experiencing a spike in 2011 in Trial 1, and in 2012 in Trial 2 (Figure 2). The proportional changes in density by year differed by treatment in both trials, producing year-by-treatment interactions.

Table 2. Precipitation (mm) by quarter for water year and crop year, 2008-2013, South Fork State Park.

Water Yr	Oct-Dec	Jan-Mar	Apr-Jun	Jun-Sep	Water Yr Total	Crop Yr (Oct-Jun)	
						Total	% of Normal
2008-2009	73	67	133	29	302	274	119
2009-2010	55	57	69	31	212	182	79
2010-2011	140	46	101	15	302	287	124
2011-2012	25	71	31	16	143	127	55
2012-2013	48	51	35	11	145	135	58

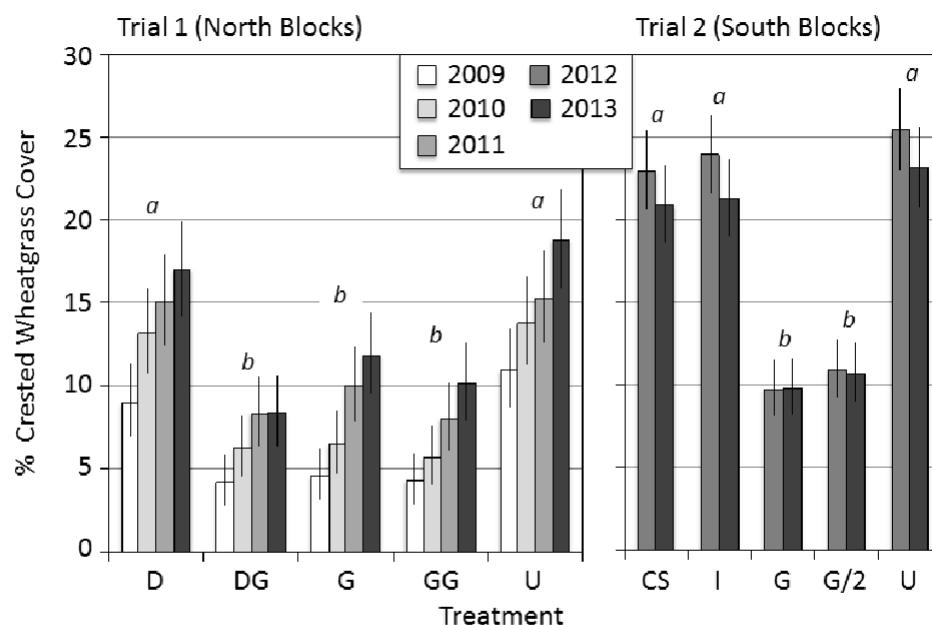


Figure 1. Crested wheatgrass cover by treatment and year in 2 northern Nevada trials. Treatments are disking (D); disking + glyphosate (DG); spring-applied glyphosate (G); spring & fall-applied glyphosate (GG); untreated (U); chlorsulfuron + sulfometuron methyl (CS); imazapic (I); and half-rate glyphosate (G/2). Bars represent mean values with associated 95% confidence intervals. By treatment (across years), a group of treatment bars without a common letter are different at $p < 0.05$.

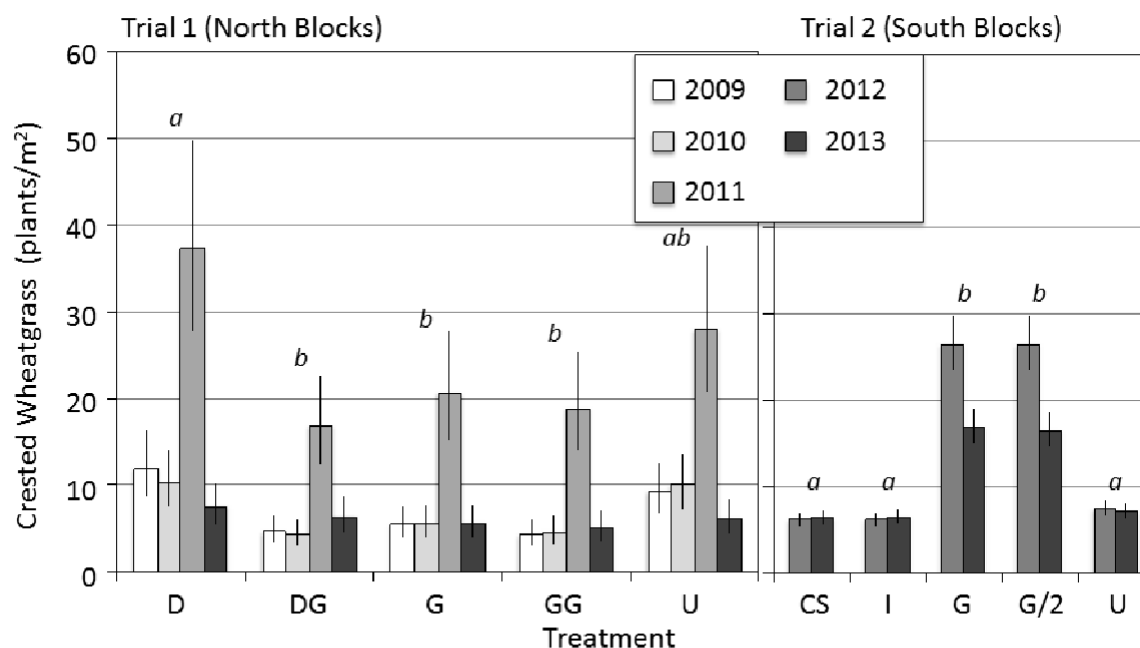


Figure 2. Crested wheatgrass density by treatment and year in 2 northern Nevada trials. Treatments are disking (D); disking + glyphosate (DG); spring-applied glyphosate (G); spring & fall-applied glyphosate (GG); untreated (U); chlorsulfuron + sulfometuron methyl (CS); imazapic (I); and half-rate glyphosate (G/2). Bars represent mean values with associated 95% confidence intervals. By treatment (across years), a group of treatment bars without a common letter are different at $p < 0.05$.

Effect of Treatment, Seeding, and Year on Weedy Species

By effectively reducing the competition from crested wheatgrass cover, G treatment stimulated the growth of weedy species. We detected at least five species of weeds in the Trial 1 blocks and four in the Trial 2 blocks. Mean weed cover values ranged from 0 – 7% in Trial 1 and 0 – 0.8% in Trial 2, with halogeton (*Halogeton glomeratus*) and exotic mustards (*Sisymbrium altissimum* and *Descurainia pinnata*) typically the most abundant species. Cheatgrass (*Bromus tectorum*) occurred at extremely low densities in both trial areas (mean cover < 0.1% across treatments).

In the Trial 1 blocks, we found significantly higher total weed cover across years in the DG and GG treatments than in the D and U treatments (Figure 3, left). Mean weed cover in the G treatment fell between these two groups. In the Trial 2 blocks, weed cover was again higher in the G treatment than in U, as well as the CS and I herbicide treatments (Figure 3, right). Mean weed cover resulting from the G/2 treatment fell between these two groups. In Trial 1, weed cover peaked in 2011 (a relatively wet year), and dropped off thereafter, resulting in an effect of year ($p < 0.0001$). Moreover, the peak in 2011 was only pronounced in the glyphosate treatments (DG, G, GG), resulting in a year-by-treatment interaction ($p < 0.0001$). In Trial 2, an effect of year and year-by-treatment (i.e., year in G) was also detected, but of much smaller magnitude (Figure 3, right).

Effects of Treatment and Year on Seeded Native Species

Herbicide, but not mechanical treatment, increased the density of seeded native species in both trials. We detected 10 of the seeded species in the Trial 1 blocks: Wyoming big sagebrush, all 6 perennial grass species, and all 3 forb species. Seven species were detected in the Trial 2 blocks, including Wyoming big sagebrush, four perennial grass species, and two forb species. We found no evidence of the seeded spiny hopsage in either of the trials.

Across years and treatments, total densities of seeded species ranged from 0-15.7 plants/m² in the Trial 1 blocks (grasses: 0-15.4, forbs: 0-1.5) and from 0-1.1 plant/m² in the Trial 2 blocks (grasses: 0-0.8, forbs: 0-0.2). In Trial 1, the most abundant grasses across years were Indian ricegrass and bottlebrush squirreltail, and the most abundant forb was Munro globemallow. However, by 2013, Indian ricegrass was undetected in the Trial 1 blocks, leaving basin wildrye, bottlebrush squirreltail, and Munro globemallow as the most abundant seeded species. Average densities of seeded species in the Trial 2 blocks were much lower than in the Trial 1 blocks (Figure 4), yet by 2013 the same three species were the most abundant, but only consistently present in the G treatment.

Glyphosate treatments, but not disking or other herbicides, increased the density of seeded species in both Trial 1 and Trial 2 by effectively reducing the competitive cover of crested wheatgrass. In Trial 1, across years, the mean density of seeded species was significantly higher in the glyphosate treatments (DG, G, and GG) than in U (Figure 4, left). In the D treatment, the mean total seeded species density, across years, was higher than in the U treatment and lower than in the glyphosate treatments (DG, G, and GG), but not significantly when accounting for multiple comparisons. In Trial 2, again the G treatment produced higher mean densities of seeded species than the other herbicides (CS and I) and U, but the lower dose glyphosate (G/2) did not result in significantly higher densities when accounting for multiple comparisons (Figure 4, right). There were much larger transient effects of sampling year in Trial 1 (note extreme decreases in seeded species density by year in Figure 4, left), and the year effect was more

pronounced in the D and U treatments, leading to a year-by-treatment interaction.

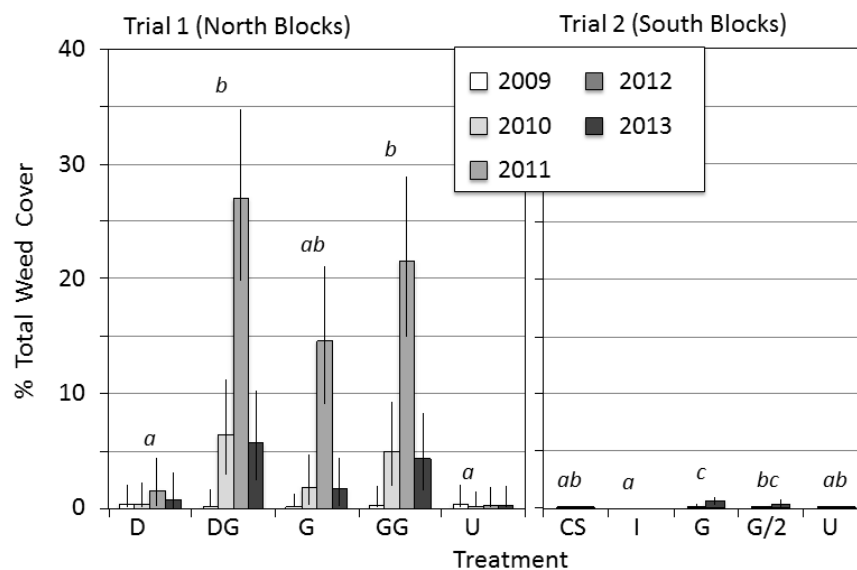


Figure 3. Percent total weed cover by treatment and year in 2 northern Nevada trials. Treatments are disking (D); disking + glyphosate (DG); spring-applied glyphosate (G); spring & fall-applied glyphosate (GG); untreated (U); chloresulfuron + sulfometuron methyl (CS); imazapic (I); and half-rate glyphosate (G/2). Bars represent mean values with associated 95% confidence intervals. By treatment (across years), a group of treatment bars without a common letter are different at $p < 0.05$.

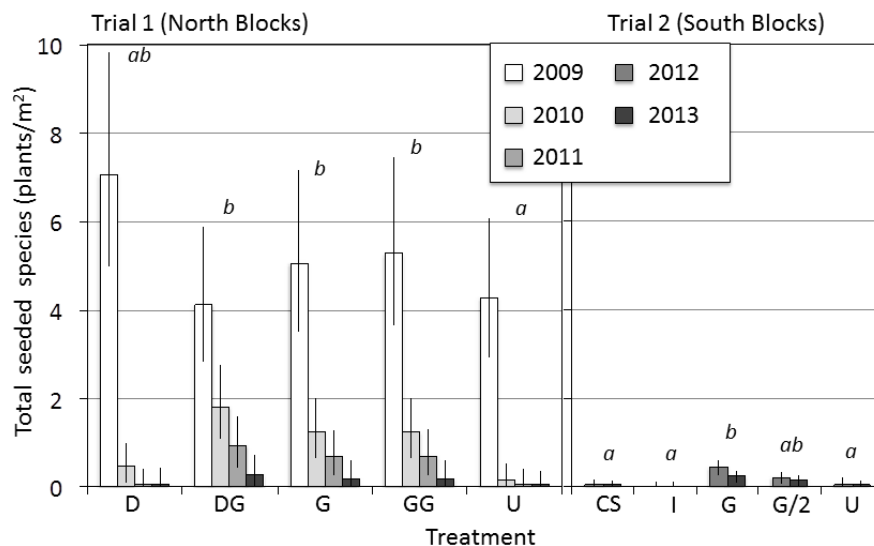


Figure 4. Total seeded species density by treatment and year in 2 northern Nevada trials. Treatments are disking (D); disking + glyphosate (DG); spring-applied glyphosate (G); spring & fall-applied glyphosate (GG); untreated (U); chloresulfuron + sulfometuron methyl (CS); imazapic (I); and half-rate glyphosate (G/2). Bars represent mean values with associated 95% confidence intervals. By treatment (across years), a group of treatment bars without a common letter are different at $p < 0.05$.

Management Applications

The following management applications were derived from this study:

- Disking treatments are ineffective in reducing crested wheatgrass cover and actually increase crested wheatgrass density in some cases.
- Imazapic and chlorsulfuron + sulfometuron methyl are ineffective at suppressing crested wheatgrass.
- Glyphosate treatments can be effective in reducing crested wheatgrass cover, but effectiveness diminishes within a few years as crested wheatgrass rebounds in treated areas. Re-treatment may be necessary to reduce competition.
- Reducing crested wheatgrass opens a window for weed invasion.
- After initial establishment of seeded native species, survival may decline steadily in successive years as crested wheatgrass rebounds.

Presentations

McAdoo, J. K.; Boyd, C.; Sheley, R. 2014. Transplanting Wyoming big sagebrush in grass-dominated sites. Collaborative Restoration Conference, Sponsored by the Great Basin and Northwest Chapters, Society for Ecological Restoration Regional Conference; 2014 October 6-10; Redmond, OR. Abstract published.

McAdoo, K.; Swanson, J.; Shaw, N. 2014. Reestablishing native plant diversity in crested wheatgrass seedings in northern Nevada. Great Basin Native Plant Annual Meeting; 2014 March 17-18; Boise, ID.

Publications

A journal manuscript summarizing this research is in preparation and targeted for submission to the journal, Ecological Restoration.

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Project Title The Ecology of Great Basin Native Forb Establishment

Project Agreement No. 13-JV-11221632-102

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Project Description

Objectives

Forbs are a key functional group in sage steppe systems yet forb seed is expensive and many forb seedlings fail, greatly limiting the ability of practitioners to increase native forb density in degraded systems (Eiswerth et al. 2009; Fansler and Mangold 2011; Hardegree et al. 2011). Forb recruitment is likely limited by a complex set of interacting biotic and abiotic factors including competition, drought, and soil physical properties (Humphrey and Schupp 1999; Seabloom et al. 2003). The broad objective of this research is to examine the degree to which crested wheatgrass competition and seedbed environmental conditions (soil texture as well as moisture and temperature dynamics) influence recruitment of key native forb species. Restoration research has traditionally examined the intensity of ecological processes such as competition (Funk et al. 2008). However, there is little effort placed on understanding the relative importance of these processes for determining plant community structure, which is ultimately the information practitioners want to know. Understanding the relative importance of various ecological processes in influencing forb establishment will provide the foundation for improving the ability of land managers to capitalize on the array of forb plant material available through the Great Basin Native Plant Project (GBNPP) and improve restoration outcomes. This line of work also will help us understand how to integrate available plant material with other potential restoration practices such as invasive plant control, seedbed preparation, and selection of appropriate spatial and temporal windows to conduct management activities to improve restoration outcomes (Boyd and Davies 2012).

Methods

This project consisted of two phases. The first phase assessed general patterns of survival of native grass and forb seed following post fire restoration practices on BLM rangeland. The final results of this phase have been published (James et al. 2011) and this final report focuses on the methods and results of the second phase, quantifying ecological processes and conditions limiting native forb establishment.

In the second study phase we seeded two key native forb species across nine sites (Figure 1) in the Great Basin that differ in soil texture, annual precipitation and a number of other factors that influence seed bed abiotic conditions. Sites were seeded in fall 2012 and fall 2013 in 1m x 1m plots. Germinated seed and emerged seedlings were tracked through fall, winter, spring and summer.

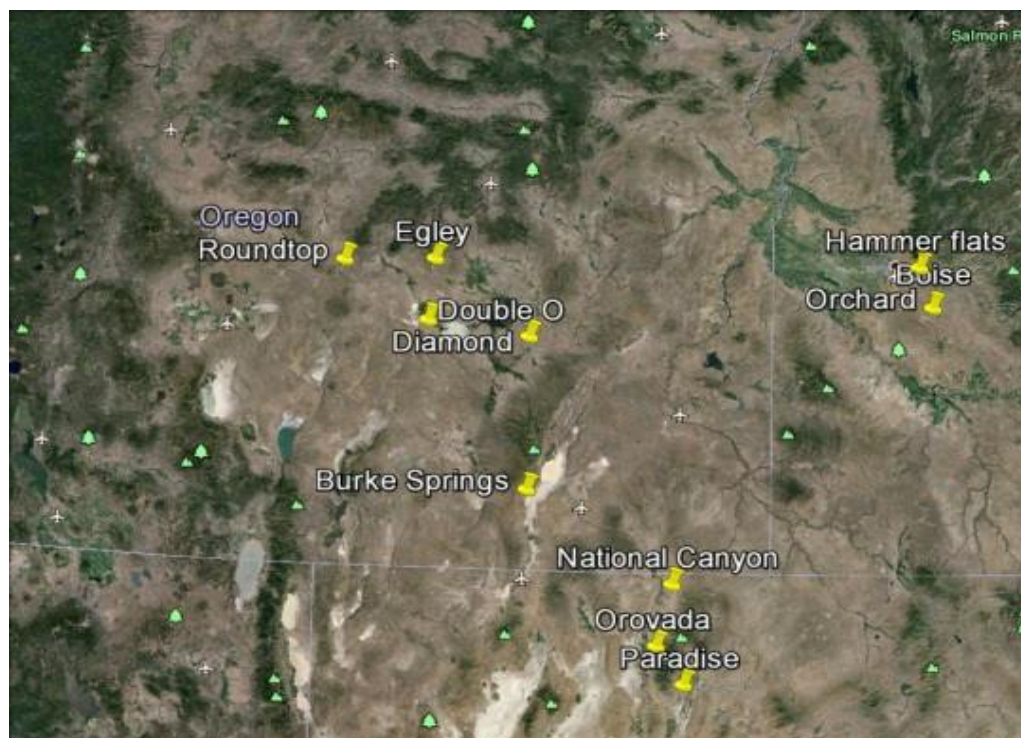


Figure 1. Location of the nine study sites for phase 2.

The forbs used for this study include western yarrow (*Achillea millefolium* var. *occidentales*) and biscuitroot (*Lomatium dissectum*). Forbs were seeded at the recommended seeding depth and a rate of 600 PLS m⁻² in each plot. Ten plots were seeded for each species at each site and half of these plots also were seeded with crested wheatgrass (*Agropyron desertorum*) at 600 PLS m⁻².

Crested wheatgrass often is included in restoration species as a bet hedging strategy for managers. Depending on drill and seed mixtures these seeds may or may not be planted in the same rows as forbs. This crested wheatgrass seeding treatment allows us to quantify the degree to which these seeding practices may influence native forb establishment. Forb and crested wheatgrass seeds (50 seeds bag⁻¹) were also sown in germination bags (James et al. 2011) in the fall of the planting year to quantify germination rates and express seedling emergence rates as a function of seeds that germinated in the field (James et al. 2011). Plots were monitored monthly in spring for demographic transitions key in seedling recruitment including emergence and survival during the first spring and then monthly through the growing season.

We quantified seedbed microenvironmental conditions using the Simultaneous Heat and Water model (SHAW model) (Flerchinger and Hardegree 2004; Hardegree et al. 2013). We installed soil water and temperature sensors at three depths at each site as well as a micrometeorological

station to collect the necessary input parameters for the model. Output of the model is a favorability index (Hardegree et al. 2013) that indicates the relative favorability of the seedbed to support the temperature and moisture conditions favorable for germination and seedling growth. Higher numbers indicate more favorable seedbed conditions. Soil texture samples were collected at multiple depths to develop soil water content/ soil water potential relationships for each site.

Results and Discussion

Germination for the native forb species differed by site ($p < 0.01$) and broadly corresponded to mean annual precipitation with wet sites showing higher germination (Figure 2). Crested wheatgrass showed higher and less variable germination than the native forbs and high germination ($> 85\%$) across all sites. Seeding crested wheatgrass with forbs, however, had no effect on native forb germination rates (Figure 3). Emergence was categorically low for both forbs regardless of seedbed favorability across the nine sites and, in addition to germination, represented a major barrier in the recruitment process. Even in the best case scenario with high germination (LODI, wet silt loam site with 80% germination) less than 2% of the germinated seeds emerged and survived through the first growing season. This bottleneck also was key limitation to crested wheatgrass recruitment where across sites less than 2% of crested wheatgrass emerged and survived. Even with relatively high crested wheatgrass densities (Figure 3, lower panel), seeding crested wheatgrass with forbs had little effect on forb recruitment ($p > 0.5$). The 2012-2013 and 2013-2014 water years (Oct. 1 to Sept. 30) were about 30% to 50% below normal across sites with exceptionally dry winter.

Collectively, these results suggest both germination and emergence are major recruitment barriers for these two key forb species and that biotic interactions with crested wheatgrass, at least at the recruitment stage, are not a major factor limiting forb recruitment. Biscuitroot appears to have slower seedling growth rates than yarrow, as well as longer cold stratification rates that may ultimately drive large differences in recruitment between these two species (Sheley and Bates 2008; Scholten et al. 2009). High recruitment rates by yarrow have been observed in a number of studies (Sheley and Half 2006; Juran et al. 2008). In the current study, even in sites with favorable germination, recruitment never exceeded four plants per square meter, and in most cases was less than one plant per square meter. Because seeded yarrow tended to initiate germination during late winter, it is likely that the severe winter droughts observed across both study years were a major factor contributing to these low recruitment rates. Much less is known about how biscuitroot performs in large scale restoration efforts but the long cold stratification requirements may have precluded some of the planted seed from germinating and emerging.

These plots will be followed over the next winter and early spring to determine if more favorable subsequent winter time conditions increase recruitment.

The germination and emergence patterns observed in the forb species greatly contrast with what is commonly observed among seeded grasses (James et al. 2011). Namely, forbs germination and emergence during the first growing season following seeding appear to be significant barriers to recruitment. With many grasses, in contrast, as observed here with crested wheatgrass, germination is often very high and most grass mortality is associated with death of germinated seed prior to emerging above the soil surface. With the forbs examined here, low germination, in addition to death of germinated seed, contributed to low recruitment.

If managers are trying to target specific time periods for native forb recruitment, it would be helpful to examine how large-scale deployment of treatments to break dormancy or accelerated rates of seedling development influence restoration outcomes (Menz et al. 2013). An additional line of work that could be useful would be to evaluate how seed treatments that alleviate some of the winter or spring time environmental stresses could be used to increase germination rates and/or speed rates of seedling development (Madsen et al. 2012a, b).

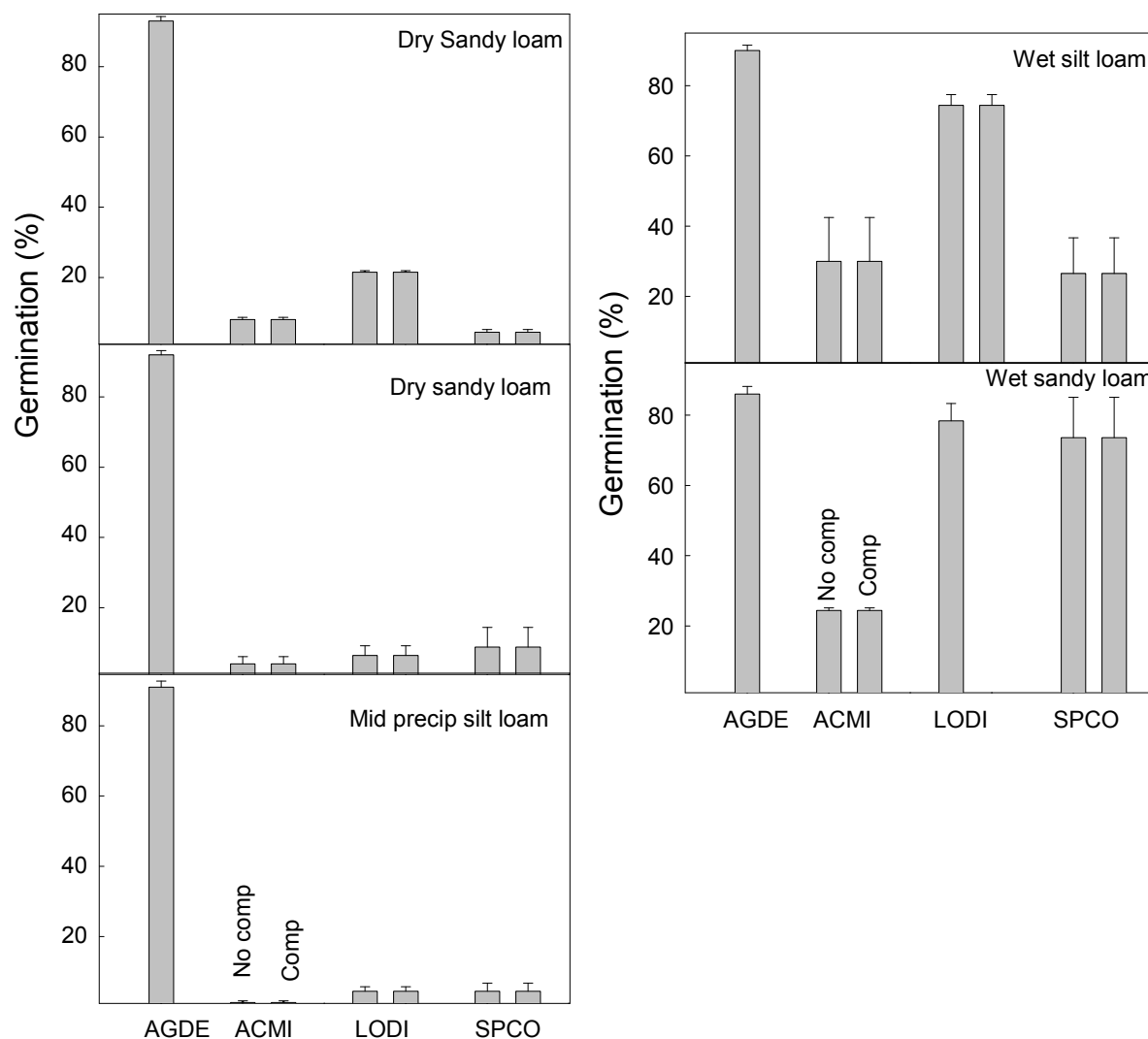


Figure 2. Field germination of the four study species across the study sites and competition treatments (No crested wheatgrass planted = No comp, crested wheatgrass planted = Comp). Sites were sown fall 2012 and characterized by mean annual precipitation and soil texture from published ecological site descriptions. Species codes AGDE, ACMI, LODI, and SPCO indicate *Agropyron desertorum*, *Achillea millefolium* var. *occidentales*, *Lomatium dissectum*, and *Sphaeralcea coccinea*, respectively. Germination was quantified using germination bags planted with 50 PLS bag⁻¹. *Sphaeralcea coccinea* seeds were scarified with sulfuric acid prior to planting.

Management Applications and/or Seed Production Guidelines

Under the conditions of this study, seeding crested wheatgrass with forbs had no short term negative effects on forb recruitment. As a result, managers may be able to simultaneously seed forbs and grasses without these two contrasting functional groups negatively affecting forb recruitment. At sufficient densities there may be negative effects of grasses on forbs later as plants increase in size but during the initial phases of restoration this does not seem to be a main barrier. For forbs, abiotic limitations that either constrain germination or kill germinated seed appear to contribute up to 98% of forb mortality. Decreasing the time between sowing and when seedlings emerge in spring may mitigate this mortality to some degree. For plant material selection and development, these results indicate that it is extremely important to understand and quantify traits related to germination and emergence and that selection on these traits may be one way to accelerate our ability to increase native forb establishment in restoration efforts. Over the long run, seed coating technologies that buffer seeds from environmental stress or accelerate development may also be helpful in overcoming these barriers.

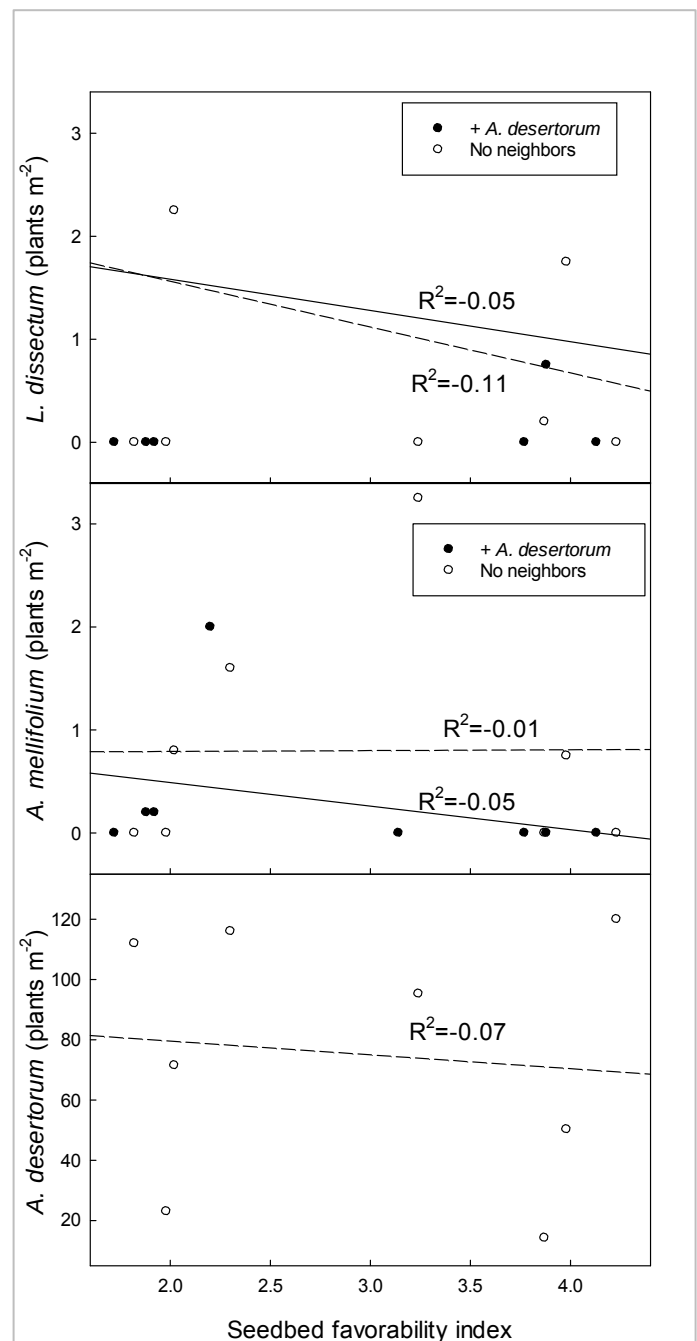


Figure 3. Seedling establishment of *Lomatium dissectum* (top panel), *Achillea millefolium* var. *occidentales* (middle panel), and *Agropyron desertorum* (lower panel) at the end of the first growing season in relation to site favorability quantified using the SHAW model. Open circles and dashed lines are for forbs planted with no crested wheatgrass, closed circles and solid lines are for forbs planted with crested wheatgrass.

Presentations

James, J. 2012. Increasing native plant recruitment in dryland systems. University of California; 2012 October; Berkeley, CA.

James, J. 2012. Restoring native plant diversity in the Great Basin. Sage grouse working group; 2012 April; Susanville, CA.

Gornish, E. S.; James, J. J. 2014. Demographic assessment of a native bunchgrass species for rangeland restoration in the Great Basin. Ecological Society of America Annual Meeting; 2014 August; Sacramento, CA. <http://esa.org/am/>

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James, J. J.; Boyd, C. S.; Svejcar, T. 2013. Seed and seedling ecology research to enhance restoration outcomes. *Rangeland Ecology & Management* 66: 115-116.

Svejcar, T.; James, J.; Hardegree, S.; Sheley, R. 2014. Incorporating plant mortality and recruitment into rangeland management and assessment. *Rangeland Ecology & Management* 67: 603-613.

Additional Products

- My 2013 Journal of Applied Ecology paper was selected as Editor's choice (1 of 6 for 2013) which included a podcast release
- Selected to serve on international dryland restoration advisory committee through Kings Park and Botanic Garden, University of Western Australia providing advice on research project development and implementation as well as lead and contribute to peer-reviewed manuscripts
- Enhancing native plant establishment on Great Basin Rangeland (BLM Agreement # L14AC00014) 2013-2018

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Project Title Presence of Native Vegetation in Crested Wheatgrass Seedlings and the Influence of Crested Wheatgrass on Native Vegetation

Project Agreement No. 11-IA-11221632-003

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Project Description

Objectives

The objectives of our study were to:

1. Determine vegetation successional trajectories of native perennial bunchgrasses that were co-planted with crested wheatgrass and whether they persist in the community.
2. Determine the variability in native vegetation presence in stands of crested wheatgrass and determine what factors (management, site/environmental characteristic, etc.) are associated with native plant recruitment in crested wheatgrass (*Agropyron cristatum*) plant communities.

Methods

We sampled 120 crested wheatgrass plant communities in southeastern Oregon to try to determine which factors promote native plant recruitment in crested wheatgrass plant communities between May through August 2012, and June through September 2013. Sites were selected with input from BLM Rangeland Management Specialists to represent a wide range of management practices such as timing (spring or fall) and intensity (distance to water/fence lines) of grazing, a range of time since seeding, and a variety of environmental factors (elevation, aspect and slope; proximity to untreated areas).

Slope, aspect, elevation and UTM location were recorded at each plot.

To sample vegetation, 60x50m plots were used to sample each site. In each plot, four 50m transects were deployed at 20m intervals along the 60m transect. Along each transect, herbaceous vegetation basal cover and density were visually estimated by species inside 40x50cm frames located at 3m intervals on each transect line (starting at 3m and ending at 45m), resulting in 15 frames per transect and 75 frames per plot. Percentage ground cover (bare ground, rock, litter and crypto-biotic crust) were measured in the 40x50cm frames. Shrub canopy cover by species was measured by line intercept. Canopy gaps less than 15cm were included in the canopy cover measurements. Shrub density was determined by counting all rooted individuals in five, 2x50m belt transects at each plot.

Soil samples were collected at three locations in each plot with a 24 inch hole located at the center of the plot and at 15m NW and SE of the center of the plot. From each of these holes soil samples were taken from 0-15cm, 0-8 inches, and 8-24 inches. Depth to hardpan was recorded if it fell within the 24 inches. The values for each of the samples per plot were averaged into a single plot value. Soil texture for the 0-8 inch and 8-24 inch samples was measured using the hydrometer method. The 0-15cm samples were used to obtain soil pH, nitrogen, carbon and total organic matter for each site.

Actual use data for sites was collected whenever available and for the maximum time period available. Disturbance and seeding history are collected for each site whenever possible.

Results and Discussion

Annual forbs occurred in 93%, annual grasses in 89%, Sandberg bluegrass in 85%, shrubs in 81%, large native perennial forbs in 75%, and large native perennial bunchgrasses (LNBP) in 59%, of the 121 sites sampled. All sites contained at least one native species. Average herbaceous perennial species diversity was 0.6 ± 0.05 . Total species richness, including shrub and herbaceous species, was between 2 and 37 species with an average of 13.2 ± 0.8 . Squirreltail (*Elymus elymoides* [Raf.] Swezey) was the most common LNBP, occurring on 35% of the sites. Wyoming big sagebrush was the most common shrub and occurred on 63% of the sites. LNBP and Wyoming big sagebrush occurred together on 49% of the sites while LNBP, sagebrush and perennial forbs occurred together on 39% of the sites.

Basal cover and density varied widely among and within herbaceous functional groups (Table 1 and 2, respectively).

Plant community composition of crested wheatgrass stands was quite variable. Though near-monoculture areas of crested wheatgrass existed, some stands had large quantities of native vegetation, especially shrubs. Correlations between environmental variables and vegetation characteristics suggest that some of the variability in the abundance of native vegetation in crested wheatgrass stands is likely caused by environmental differences. Big sagebrush was the most common native species in stands of crested wheatgrass.

Table 1. Mean, median and standard error of basal cover of Sandberg bluegrass (*Poa secunda*), crested wheatgrass (*Agropyron cristatum*), large native perennial bunchgrass (LNPB), annual grass, perennial forbs, and annual forbs; foliar cover of shrubs and ground cover of moss and biological soil crusts across 121 crested wheatgrass stands sampled in southeastern Oregon.

	Sandberg bluegrass	Crested wheatgrass	LNPB	Annual grass	Perennial forbs	Annual forbs	Shrubs	Moss	Crypto-biotic crust
Mean	3.3	5.9	0.4	0.3	0.2	0.1	6.0	3.7	1.1
Median	2.4	5.2	0.0	0.1	0.0	0.1	3.4	3.3	0.5
Std err	0.3	0.4	0.1	0.1	0.0	0.0	0.6	0.3	0.2

Table 2. Mean, median and standard error of density (plants m⁻²) of functional groups across 121 crested wheatgrass stands sampled in southeastern Oregon.

	Sandberg bluegrass	Crested wheatgrass	LNPB	Annual grass	Perennial forbs	Annual forbs	Shrubs
Mean	25.9	7.6	1.0	72.2	4.4	77.8	0.5
Median	19.8	7.7	0.1	13.3	0.7	29.3	0.4
Std err	2.4	0.4	0.2	12.9	0.6	11.5	< 0.1

Environmental factors explained as little as 24% of the variability in annual forb density and as much as 51% of the variability of annual grass density. Perennial forb basal cover, annual grass and Sandberg bluegrass basal cover and density variability were also well explained (43-46%) by environmental factors.

Though a variety of environmental factors were included in regression models, soil texture appeared to be quite important. Soil texture was included in the best regression models for cover and density of all plant functional groups (Tables 3 and 4).

Large native perennial bunchgrasses (LNPB) was the least likely functional group to occur in crested wheatgrass communities we sampled across southeastern Oregon. Although 10% of our sampled sites had a higher density of native perennial bunchgrasses than crested wheatgrass, we found, overall, few LNPB in most stands of crested wheatgrass. This likely confounded our ability to find meaningful associations between LNPB and environmental factors. LNPG basal cover and density were negatively correlated with sandy soil (Tables 3 and 4).

Perennial forb density and basal cover were, similarly to large native perennial bunchgrasses, lower on sandy soil.

Annual forbs, annual grasses, and Sandberg bluegrass were the three most prevalent herbaceous functional groups in stands of crested wheatgrass, and all tend to avoid resource limitations by growing early in the season when resources are more plentiful (Volire et al. 2009; Ludlow et al. 1989).

Wyoming big sagebrush (*Artemisia tridentata* Nutt. Ssp. *wyomingensis*) constituted the majority of the shrub cover and density measurements. Similarly to Davies et al. (2007), we did not find a strong correlation between Wyoming big sagebrush density, cover, or any of the other measured environmental variables. Our data does suggest that, in agreement with Davies et al. (2006, 2007) and in contrast to Williams (2009), Wyoming big sagebrush was negatively correlated with more sandy soils. Plant communities with higher numbers of shrubs, most of which were Wyoming big sagebrush, tended to be associated with soils higher in silt and lower in precipitation. However, associations were relatively weak as only 25% of the variation in Wyoming big sagebrush density was explained by environmental variables. Therefore, soil texture may not have much effect on the likelihood of sagebrush reestablishment into crested wheatgrass seedings. Although the relationship was not strong, there was a negative correlation between crested wheatgrass basal cover and Wyoming big sagebrush foliar cover (adj. $R^2 = 0.26$, $p < 0.001$). However, there did not appear to be a relationship between Wyoming big sagebrush and crested wheatgrass density ($R^2 < 0.10$, $p > 0.05$).

Though we could only explain a small portion of the variability in Wyoming big sagebrush density and cover, it occurred on 63% of the seedings. Wyoming big sagebrush recovery after disturbance can be slow, often taking several decades to a century (Watts and Wambolt 1996; Baker 2006; Boyd and Svejcar 2011). Thus, having 15% of the seedings with 10% or higher sagebrush cover suggests that sagebrush recovery can occur and provide habitat for sagebrush associated wildlife species. At 10% sagebrush cover these seedings meet the minimal sagebrush cover requirements suggested by Connelly et al. (2000) for Greater sage-grouse (*Centrocercus urophasianus*) winter habitat. Similarly, McAdoo et al. (1989) reported that sagebrush associated species reoccupied crested wheatgrass seedings after sagebrush reestablished.

Most communities seeded to crested wheatgrass were degraded, burned in a wildfire and/or treated to remove shrub species prior to seeding (Heady 1988), thus the limited native vegetation at some sites may have been an artifact of plant community composition at the time it was seeded. The type and severity of disturbance as well as plant composition prior to seeding is likely to have affected current plant composition on the site (Burke and Grime 1996).

Future Plans

We are currently analyzing data to determine the relationship between management (i.e. time since seeding/fire and grazing history) and the abundance of native vegetation in crested wheatgrass stands and whether environmental characteristics of a site interact with management history.

Management Applications and/or Seed Production Guidelines

Our data suggests that there are some environmental factors, especially related to soil texture, that influence plant community composition of crested wheatgrass seedings regardless of management and initial floristics. Our results also suggest that the effects of seeding crested wheatgrass likely vary considerably by site characteristics and that native vegetation can co-occupy some rangelands seeded with crested wheatgrass. This information may be useful for prioritizing where restoration of sagebrush communities seeded with crested wheatgrass should be applied and assessing the potential effects of seeding crested wheatgrass.

Table 3. Multiple linear regression models for functional group cover in crested wheatgrass stands for directional chart shown in Table 4. All models shown have adjusted $R^2 > 0.20$.

Functional Group	Adj. R^2	Best fit regression equation	S. E.
Sandberg bluegrass	0.46	$219.13 + 0.10 \cdot \text{Silt} - 1.89 \cdot \text{Longitude}$	
Crested wheatgrass	0.29	$-11.89 + 32.84 \cdot \text{Nitrogen} + 0.77 \cdot \text{C:N ratio} - 0.096 \cdot \text{Silt} + 1.76 \cdot \text{pH} - 0.14 \cdot \text{Gravel}$	
Sqrt(LNPB)	0.24	$2.51 - 0.0066 \cdot \text{Sand} - 0.23 \cdot \text{pH} + 0.019 \cdot \text{Gravel}$	
Sqrt(Annual grass)	0.46	$1.08 - 0.0071 \cdot \text{Sand} - 0.013 \cdot \text{Silt} - 0.00056 \cdot \text{Elevation} + 0.025 \cdot \text{Litter}$	
Sqrt(Perennial forb)	0.43	$2.95 + 2.16 \cdot \text{Nitrogen} - 0.0050 \cdot \text{Sand} - 0.36 \cdot \text{pH} - 0.0052 \cdot \text{Litter}$	
Sqrt(Shrubs)	0.26	$11.59 - 0.021 \cdot \text{Sand} + 0.0022 \cdot \text{Elevation} - 1.01 \cdot \text{pH} - 0.022 \cdot \text{Litter} - 0.015 \cdot \text{Precipitation}$	
Sqrt(Wyoming big sagebrush)	0.25	$15.18 + 0.79 \cdot \text{Carbon} - 1.46 \cdot \text{pH} - 0.036 \cdot \text{Litter} - 0.013 \cdot \text{Precipitation}$	

Table 4. Multiple linear regression models for functional group density in crested wheatgrass stands for directional chart shown in table 3. All models shown have adjusted $R^2 > 0.20$.

Functional Group	Adj. R^2	Best fit regression equation	S. E.
Sandberg bluegrass	0.49	$1291.38 + 0.19 \cdot \text{Silt} + 11.81 \cdot \text{Longitude}$	
Sqrt(LNPB)	0.31	$3.50 - 0.0085 \cdot \text{Sand} - 0.41 \cdot \text{pH} + 0.046 \cdot \text{Gravel cover}$	
Sqrt(Annual grass)	0.51	$8.08 - 0.074 \cdot \text{Silt} - 0.010 \cdot \text{Elevation} + 0.40 \cdot \text{Litter cover} - 0.13 \cdot \text{Gravel cover}$	
SqrtPerennial forbs)	0.43	$12.02 - 0.040 \cdot \text{Sand} - 1.31 \cdot \text{pH}$	
Sqrt(Annual forbs)	0.24	$299.81 + 0.15 \cdot \text{Clay} + 2.56 \cdot \text{Longitude} + 0.16 \cdot \text{Bare ground} + 0.29 \cdot \text{Rock cover}$	
Sqrt(Shrubs)	0.24	$3.19 - 0.0044 \cdot \text{Sand} - 0.00055 \cdot \text{Elevation} - 0.30 \cdot \text{pH} - 0.0084 \cdot \text{Litter} - 0.0032 \cdot \text{Precipitation}$	
Sqrt(Wyoming big sagebrush)	0.25	$2.79 - 0.0034 \cdot \text{Sand} - 0.28 \cdot \text{pH} - 0.012 \cdot \text{Litter}$	

Publications

Nafus, A. M.; Svejcar, T. J.; Ganskopp, D. C.; Davies, K. W. [In press]. Abundances of co-planted native bunchgrasses and crested wheatgrass after 13 years. *Rangeland Ecology and Management*.

Project Title Seeding Native Species Following Wildfire in Wyoming
Big Sagebrush (*Artemisia tridentata* ssp. *wyomingensis*):
Effects of a New Fire Incident

Project Agreement No. 11-IA-11221632-077

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Project Description

Objectives

A post-fire seeding experiment was implemented across four sites in the northern Great Basin beginning in 2007. The experiment was designed to compare the effectiveness of different seeding techniques for establishing native plants and suppressing exotic annual weeds in burned Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) communities. Previous reports have presented results based on the first 2 years of vegetation monitoring following treatment. Additional data have been collected from some sites during the third or fifth year. In this report, we highlight third-year monitoring results for a site that partially re-burned between the second and third year.

Methods

Study Site and Experimental Treatments

The Saylor Creek study site is located at 42°39'43" N, 115°28'18" W, ca. 1200 m elevation in Elmore County, Idaho. Mean annual precipitation is 223 mm/year (Centre for Forest Conservation Genetics 2014) and surface soil texture ranges from loam to silt loam to very fine sandy loam (Soil Survey Staff 2015). The Black Butte wildfire burned through mature Wyoming big sagebrush at this site on 29 June 2010. Experimental treatments were applied the following fall (27-28 Oct. 2010) or winter (15 Feb. 2011) in five blocks that were fenced to exclude livestock. Within blocks, each treatment was randomly assigned to a 30 m × 70 m rectangular plot.

Treatments differed by seeding method (rangeland drill vs. aerial broadcast), drill type (conventional vs. minimum-till), aerial broadcast timing (fall vs. winter) and sagebrush seeding rate (50 vs. 250 vs. 500 pure live seed/m²). Rangeland drills were configured to place large seeds (drill mix) and small seeds (broadcast mix) in alternate rows (Table 1). The drill mix passed through the drill assembly and was placed in furrows, while the broadcast mix was allowed to fall to the soil surface of the intervening rows. Aluminum pipes 7.6 cm in diameter were added to the conventional drill to direct the broadcast mix to the soil surface where seeds were covered by drag chains. The minimum-till drill was equipped with imprinter units to press the broadcast mix into the soil. Aerial seeding was simulated by hand-seeding the broadcast mix on plots that had been drill-seeded in alternate rows with the broadcast seed boxes empty. Drill treatments applied with empty seed boxes for both mixes served as non-seeded controls in addition to a fully untreated (non-drilled/non-seeded) control.

Detailed comparisons of treatment effects on plant establishment and survival were presented in previous years' reports. In the current report we simplify our analysis by merging treatments into two categories, seeded and non-seeded. Previous reports focused on data from the first two years following treatment, but here we add data from a third year so that the effects of a second wildfire can be evaluated. The Kinyon Road fire burned through the Saylor Creek site in early July 2012, shortly after second-year data collection. It burned irregularly leaving a mosaic of burned and unburned sections.

Table 1. Seed mixes for post-fire seeding at Saylor Creek site.

Common Name	Scientific Name	Source/Cultivar/Germplasm	PLS*(%)	PLS*/m ²
<u>Drill Mix</u>				
Bluebunch wheatgrass	<i>Pseudoroegneria spicata</i>	Anatone Germplasm	80.0	60
Bottlebrush squirreltail	<i>Elymus elymoides</i>	Emigrant Germplasm	97.0	35
Indian ricegrass	<i>Achnatherum hymenoides</i>	'Rimrock'	96.6	50
Thurber needlegrass	<i>Achnatherum thuberianum</i>	Snake River Plain - pooled	55.4	30
Needle-and-thread	<i>Hesperostipa comata</i>	Millard Co., UT	77.6	20
Munro's globemallow	<i>Sphaeralcea munroana</i>	Uintah Co., UT (1550 m)	61.0	40
Basalt milkvetch	<i>Astragalus filipes</i>	Deschutes Co., OR (1330 m)	90.0	14
<u>Broadcast Mix</u>				
Sandberg bluegrass	<i>Poa secunda</i>	Mountain Home Germplasm	82.0	100
Wyoming big sagebrush	<i>A. tridentata</i> spp. <i>wyomingensis</i>	Power Co., ID (1390 m)	28.4	50-500**
Rubber rabbitbrush	<i>Ericameria nauseosa</i>	Utah Co., UT (1650 m)	40.5	85
Western yarrow	<i>Achillea millefolium</i>	Eagle Germplasm	94.3	100
Royal penstemon	<i>Penstemon speciosus</i>	Northern Great Basin - pooled	57.8	15

*Pure live seed

**Big sagebrush seeding rate varied by treatment (50, 250, or 500 PLS/m²)

Data Collection and Analysis

Vegetation data were collected using protocols modified from Herrick et al. (2005) and Wirth and Pyke (2007). Five 20m transects were established 10m apart, perpendicular to the long axis of each plot. Canopy cover by species was recorded by line point intercept at 20 points along each transect in late spring of the first three years following treatment (2011-2013). Density of seeded forbs and shrubs was recorded in belts 2m wide centered on transects during the first and third year. To the extent that newly-burned patches could be discerned in the third year, each cover point and density count was categorized as burned or non-burned (or borderline/uncertain). The percentage of belt areas within these categories was estimated so that densities by burn category could be calculated.

Differences between treatments (simplified to seeded and non-seeded) and years were analyzed using general linear mixed effects models in SAS 9.3 (SAS Institute Inc. 2011) with treatment and year as fixed effects and block as a random effect. Mean comparisons were applied using Tukey's HSD at $\alpha = 0.05$.

Using third-year data from the seeded treatment, deviations from expected cover or density in newly-burned vs. non-burned categories were analyzed using statistical tests in R (R Core Team 2012). We used binomial proportion tests to compare observed versus expected cover proportions (canopy hits: total points) and chi-square contingency table tests to analyze density (density count and belt area on one table axis; burned and non-burned categories on the other).

Results and Discussion

Treatment Comparisons (Seeded vs. Non-seeded) Across Three Years

Seeded species generally had low cover in 2011, the first year following fire and seeding treatment, then increased dramatically in cover by 2012 (Figure 1A-B). By 2013, following the second (partial) burn, cover of most seeded species decreased to levels intermediate between

2011 and 2012 (Figure 1B). Each year, cover of seeded species was higher in seeded than non-seeded treatments, with the exception of Sandberg bluegrass (*Poa secunda*), which was abundant in non-seeded treatments as fire-surviving residual plants (Fig 1B). Seeding clearly had a significant effect on plant establishment which persisted even in the aftermath of the second fire.

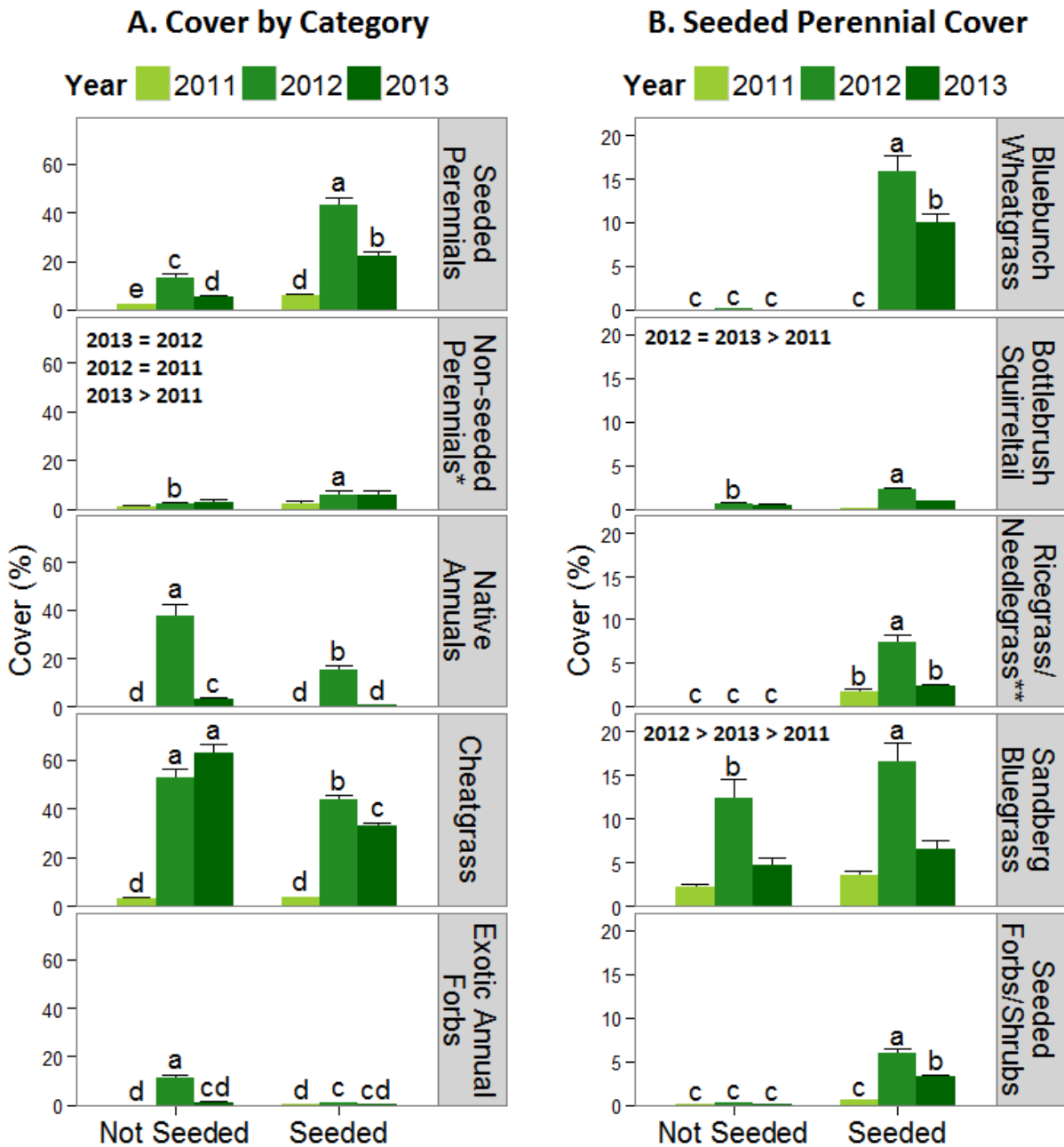
Like seeded species, cover of non-seeded species categories (native perennials, native annuals, cheatgrass and exotic annual forbs) generally increased between 2011 and 2012 then decreased in 2013 (Figure 1A). However, cheatgrass cover decreased between 2012 and 2013 only in the seeded treatments, and was significantly higher in non-seeded than seeded treatments in both 2012 and 2013 (Figure 1A). Exotic annual forbs (primarily tumblemustard, *Sisymbrium altissimum*) had minimal cover except in the non-seeded treatment in 2012. These results provide evidence that seeded plants competitively suppressed cheatgrass and exotic annual forbs in the seeded treatments.

Of the seeded forbs and shrubs counted in belt transects, the species with the highest first-year (2011) establishment in seeded treatments (Table 2) were western yarrow (*Achillea millefolium*; 3940 plants/acre), royal penstemon (*Penstemon speciosus*; 2,860 plants/acre) and Wyoming big sagebrush (2,333 plants/acre). By the third year (2013), density had dropped by 38% for western yarrow, 51% for royal penstemon and 82% for Wyoming big sagebrush. Munro's globemallow (*Sphaeralcea munroana*) and rubber rabbitbrush (*Ericameria nauseosa*) had comparatively lower first-year densities of 140-282 plants/acre, but their densities had increased to 219-624 plants/acre by the third year (Table 2). Basalt milkvetch (*Astragalus filipes*) began at 225 plants/acre then declined to 143 plants/acre during this period (Table 2).

Effects of 2012 Fire on 2013 Seeded Treatments

Declines in density and cover from 2011-2012 to 2013 (Figure 1, Table 2) might have been caused by the intervening fire, but other factors such as precipitation patterns could have also have played a role. Statistical tests comparing newly-burned versus non-burned sections of the 2013 seeded treatments allowed us to assess the influence of the fire relative to other factors. Species with higher than expected density/cover in non-burned sections can be inferred to have been negatively impacted by the fire, while those that were higher than expected in burned sections can be inferred to have been positively impacted by the fire even if they had decreased relative to previous years.

Wyoming big sagebrush, rubber rabbitbrush, western yarrow and Sandberg bluegrass were higher than expected in non-burned sections, suggesting that the fire had a net negative impact on these species (Tables 3, 4). The contrast between observed and expected was most pronounced for Wyoming big sagebrush (Table 3), which is known for its limited post-fire resprouting capacity. Royal penstemon and Indian ricegrass (*Achnatherum hymenoides*) showed the opposite pattern of higher than expected density or cover in burned sections (Tables 3, 4), suggesting a stimulatory effect of the fire on regrowth and/or seed germination. Bluebunch wheatgrass (*Pseudoroegneria spicata*), bottlebrush squirreltail (*Elymus elymoides*), Munro's globemallow and basalt milkvetch occurred in both burned and non-burned sections without higher than expected abundance in one or the other (Tables 3, 4). Thurber's needlegrass (*Achnatherum thurberianum*) and needle-and-thread (*Hesperostipa comata*) were recorded only in burned sections, but were too uncommon for reliable statistical inference.



*Native species only; does not include traces of non-native perennials

**Includes Indian ricegrass, Thurber needlegrass and needle-and-thread

Figure 1. Canopy cover by treatment (seeded vs. not), year (2011-2013) and species/category at the Saylor Creek site. The entire site burned in 2010 and partially reburned in 2012; reburned sections are not differentiated here. Within cells, means with the same letter were not significantly different ($p < 0.05$). Year differences are shown separate from treatment differences in cases where the interaction was non-significant.

Table 2. Densities of seeded forbs and shrubs in seeded treatments at the Saylor Creek site in 2011 (first year following seeding) and 2013 (following new fire; reburned and non-burned sections not differentiated).

	2011	2013	Higher Year**
Basalt milkvetch	225 ± 40*	143 ± 26	2011
Munro's globemallow	282 ± 46	624 ± 100	2013
Wyoming big sagebrush	2333 ± 741	404 ± 129	2011
Rubber rabbitbrush	140 ± 16	219 ± 25	2013
Western yarrow	3940 ± 683	2433 ± 422	2011
Royal penstemon	2860 ± 497	1378 ± 240	2011

*values shown are plants/acre ± standard error

**year with significantly higher density ($p < 0.05$)

Table 3. Results of chi-square tests comparing densities of seeded forbs and shrubs in burned and non-burned sections of seeded treatments at the Saylor Creek site. Observed values are counts within a total area of 10,000 m².

	<u>Burned</u>	<u>Non-burned</u>	<u>p value</u>	<u>Higher than</u>
	<u>Observed(Expected)</u>	<u>Observed(Expected)</u>		<u>Expected:</u>
Basalt milkvetch	341(330)	64(75)	0.1626	
Munro's globemallow	1305(1290)	279(294)	0.3255	
Wyoming big sagebrush	141(770)	885(256)	<0.0001	Non-burned
Rubber rabbitbrush	424(476)	165(113)	<0.0001	Non-burned
Western yarrow	4273(4752)	1937(1458)	<0.0001	Non-burned
Royal penstemon	3195(2963)	348(580)	<0.0001	Burned

Among non-seeded species, perennial western wheatgrass (*Pascopyrum smithii*) had higher than expected cover in burned sections, while the annuals western tansymustard (*Descurania pinnata*) and clasping pepperweed (*Lepidium perfoliatum*) had higher than expected cover in non-burned sections (Table 4). Although live cheatgrass cover did not differ from expected between burned and non-burned sections, litter cover (dominated by dead cheatgrass from previous years) was proportionally lower in the burned sections (Table 4).

Future Plans

Data will be re-collected from the Saylor Creek site in 2015, adding to fifth-year data that has already been collected from other sites of the broader study. These data will be used to evaluate post-fire seeding effectiveness beyond the typical 1-3 year monitoring time frame.

Management Applications

This study demonstrates that post-fire seeding with native species can be successful on Wyoming big sagebrush sites with characteristics similar to the Saylor Creek site. Seeded native perennials can compete with exotic annuals leading to lower abundance of exotics than in the absence of

seeding. Once established, native seedlings have the capacity to rebound following fire even though they may not immediately return to pre-burn levels of cover and density. Species demonstrating high resilience to fire should be sought for seeding in fire-prone areas. Species that are more sensitive to fire, such as Wyoming big sagebrush, may need to be reseeded following each fire episode.

Table 4. Results of binomial proportion tests comparing cover of prominent species and cover categories in burned and non-burned sections of seeded treatments at the Saylor Creek site. Proportions shown are hits/total points within burned and non-burned.

	Burned	Non-burned	p value	Higher than Expected:
Native seeded perennials	0.221	0.229	0.6536	
Bluebunch wheatgrass	0.101	0.099	0.8640	
Bottlebrush squirreltail	0.011	0.003	0.0666	
Indian ricegrass	0.027	0.002	<0.0001	Burned
Sandberg bluegrass	0.061	0.095	0.0003	Non-burned
Western yarrow	0.014	0.040	<0.0001	Non-burned
Native non-seeded perennials	0.089	0.055	0.0012	Burned
Western wheatgrass	0.082	0.047	0.0006	Burned
Native annuals	0.005	0.014	0.0110	Non-burned
Western tansymustard	0.005	0.014	0.0110	Non-burned
Exotic annual grass (cheatgrass)	0.330	0.336	0.7714	
Exotic annual forbs	0.002	0.023	<0.0001	Non-burned
Clasping pepperweed	<0.001	0.018	<0.0001	Non-burned
Tumblemustard	<0.001	0.001	0.7944	
Litter	0.267	0.563	<0.0001	Non-burned

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Additional Products

Steering Committee Member, National Seed Strategy (N. Shaw).

Conference Co-chair, Society for Ecological Restoration Northwest and Great Basin Chapters Joint Annual Conference (N. Shaw).

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Project Title A New Biological Control Strategy for Cheatgrass and *Ventenata dubia* Based on Fungal Endophytes

Project Agreement No. 10-CR-11221632-182

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Project Description

Fusarium Greenhouse Bioassays

Endophytic fungi identified were isolated from surface sterilized *ventenata* and cheatgrass plants collected from Latah County, ID. Twenty *Fusarium* spp. isolates (10 isolated from *ventenata* and 10 from cheatgrass) were chosen for a series of greenhouse experiments. *Fusarium* spp. were of particular interest because members of this genus are often pathogenic on local grasses and cereal grain crops. Blocked, randomized seed trays were planted with three grasses: bluebunch wheatgrass, cheatgrass and *ventenata*. Each seed was inoculated with spores and mycelia from

the cheatgrass- or *ventenata*-derived isolates. The ten *Fusarium* spp. inoculum derived from *ventenata* and the ten *Fusarium* spp. inoculum derived from cheatgrass were first bulked together as treatments on the three grass species seeds. A second set of experiments inoculated the three grass species with spores/mycelium from the individual *Fusarium* isolates. All 20 *Fusarium* isolates were sequenced in the ITS region and identified through comparison in the GenBank database.

Results from the bulked inoculum treatments showed that both *ventenata*-derived and cheatgrass-derived *Fusaria* treatments significantly decreased germination and aboveground biomass of bluebunch wheatgrass compared to the control. Both *ventenata*-derived and cheatgrass-derived *Fusaria* treatments had no impact on cheatgrass germination, but did significantly decrease its aboveground biomass. The *ventenata*-derived *Fusaria* had a significantly negative effect on *ventenata* germination (unlike the cheatgrass-derived *Fusaria* which was not significantly different), while both *ventenata*-derived and cheatgrass-derived *Fusaria* had positive effects on aboveground biomass. Results from the single-isolate inoculations varied somewhat, though generally followed the same patterns. These experiments additionally showed a significant decrease in cheatgrass germination caused by several *ventenata*- and cheatgrass- derived *Fusaria* treatments, as well as a significant increase in *ventenata* germination by a few of the *ventenata*-derived *Fusaria* treatments and decrease in germination by a few cheatgrass-derived *Fusaria* treatments.

Lab experiments using assays to determine whether various *ventenata* and cheatgrass derived *Fusaria* would infest and kill seedlings was conducted. A highly pathogenic strain of *Fusarium culmorum* was obtained from WSU Plant Pathology to further test *ventenata*'s susceptibility to these relatively common pathogens. This is partly inspired by the ability of some non-pathogenic, endophytic *Fusarium* spp. to protect against disease caused by *Fusarium* pathogens in other systems. Although *F. culmorum* did not infest *ventenata* seeds or seedlings on water agar plates in the laboratory, it did cause disease (and death) of nearly all *ventenata* plants in a greenhouse experiment where *ventenata* and winter wheat were planted in the same pots and both inoculated with *F. culmorum* spore suspension. Data indicating whether the *ventenata*-derived *Fusarium* species protect *ventenata* from infection or disease onset by *F. culmorum* is still being analyzed.

This work is currently being prepared as part of a Ph.D. dissertation and for submission to peer-reviewed journals by David Griffith.

Ventenata Fungal Communities via Metagenomics

While limited isolations of fungi as described in the experiments above have been done, virtually nothing is known about the fungal symbionts and pathogens of *ventenata*. In the Palouse region of north-central Idaho and east-central Washington, *ventenata* appears to be a state of enemy release from pathogens according to field surveys done in the spring and summer of 2014, even when adjacent to other grasses showing active signs and symptoms of disease. Preliminary work has shown that *ventenata* germination is negatively affected in laboratory conditions by wheat pathogen *Fusarium culmorum*, as well as other *Fusaria* (see above). It is not known whether these pathogens are commonly present and affect *ventenata* in the field. Nor is there any other known information on other fungal symbionts and how they may be driving (or limiting) the invasion of *ventenata*.

Samples of *ventenata* plants were collected from 22 sites across Latah, Nez Perce, Lewis and Clearwater counties in Idaho, Gallatin County in Montana, and Grant County in Oregon in the spring and summer of 2014. Surrounding ecotypes and crops were noted along with latitude and longitude. Elevation ranged approximately 1,000 to 4,900 feet. The samples were surface sterilized and freeze-dried for storage. DNA extracted from plants, and associated endophytic fungal material, will be sequenced using a MiSeq Illumina processor. This method will allow broad scale environmental sampling of the fungal and potentially bacterial metagenomics using millions of short reads that can be compared to known species in the GenBank database. It will offer a snapshot of *ventenata* fungal communities across a geographic and elevational range. DNA are currently be extracted and PCR conditions optimized. Analysis of sequence data is projected for spring 2015. This work is supporting an M.S. project by Sara Ashiglar.

Management Applications

The work on fungal endophytes will provide baseline knowledge on how cheatgrass and *ventenata* are successfully invading native perennial grasslands and out-competing native species. The metagenomics work describing fungal communities of *ventenata* will be compared with future work looking for potential biocontrol agents on *ventenata* fungal communities from its native range.

Three scientists (Newcombe, Ashiglar, and Griffith) attended the MtnSEON *ventenata*-focused working group (“The Processes, Patterns and Mechanisms of *Ventenata* dubia Invasion in Complex Western Landscapes”) meeting in Moscow, ID. At this meeting, attention was brought to key researchers of the potential problems of *ventenata* infestations in areas where it is not yet well established. Collaborations between scientists across the West ensued to help understand the gaps in knowledge and inconsistencies in monitoring protocols about this species. The social and economic implications of the spread of *ventenata* across the west is more clearly understood and will be brought up in future meetings with relevant stakeholders. Known management protocols for control, and areas where such protocols need to be developed, were discussed and disseminated.

One scientist (Griffith) attended the MtnSEON Blue Mountain Working Group meeting held in LaGrande, OR on January 27, 2015. This meeting focused on stakeholder and management input into ongoing and future research goals for the Starkey Experimental Forest and Range. Detection and control of *ventenata*, and the impact of cheatgrass, medusahead, and other annual grass invaders in our region was discussed. Griffith will be attending another meeting in Portland, OR, at the invitation of USFS, of the Blue Mountain Working Group focused on designing research goals, where he will present knowledge about cheatgrass and *ventenata* microbial ecology derived from the funded project.

Presentations

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Griffith, David L.; Newcombe, George; Ashiglar, Sara. 2015. The Mountain Social Ecological Observatory Network (MtnSEON), Blue Mountain Working Group meeting; 2015 January 30-31; Moscow, ID. Workshop participation and research discussion.

Ashiglar, Sara. 2015. *Ventenata* and *Fusarium*. 2015. The Mountain Social Ecological Observatory Network (MtnSEON), Blue Mountain Working Group meeting; 2015 January 30-31; Moscow, ID. Presentation.

Publications and Additional Products

A manuscript, titled “Revisiting the life cycle of *Sordaria fimicola*” was submitted to PLOS ONE and has currently been resubmitted after first reviews were received and revisions made.

A manuscript is being prepared for submission to The Journal of Ecology on field experiments demonstrating the effects on biomass and fecundity of inoculating cheatgrass with *Sordaria fimicola*.

A manuscript is being prepared for submission on laboratory and greenhouse experiments with *ventenata* and cheatgrass-derived *Fusaria*, and their effects on the growth and competitive abilities of cheatgrass, *ventenata*, and bluebunch wheatgrass.

Research conducted under this agreement will inform a third chapter of Griffith’s dissertation, on Social Ecological Systems frameworks for research and management focused on plant invasion in the American West. This chapter will be revised for submission in summer of 2015.