

Great Basin Native Plant Project

2016 Progress Report



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

GREAT BASIN NATIVE PLANT PROJECT

2016 PROGRESS REPORT

USDA FOREST SERVICE, ROCKY MOUNTAIN RESEARCH STATION AND
USDI BUREAU OF LAND MANAGEMENT, BOISE, ID
November 2018



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GREAT BASIN NATIVE PLANT PROJECT 2016 PROGRESS REPORT

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. Special thanks also to our resident technicians and volunteers: Kimberly Stocks and Chirs Link for help in compiling this report and for managing our field and laboratory research.

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FISCAL YEAR SUMMARY

GBNPP PROJECTS	
Closing Projects	0
Continuing Projects	18
New Projects	5

PROJECT ACTIVITY	
Presentations	29
Publications	18

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2016 HIGHLIGHTS

NEW PROJECTS

GENETICS AND CLIMATE CHANGE

Genetic and Environmental Regulation of Functional Traits: New Approaches for Restoration in a Changing Climate

Brad Butterfield.....19

- Using seed of plants that are adapted to the local conditions of a restoration site is critical for successful restoration outcomes
- We propose that functional trait variation within and among populations and species can help to identify locally appropriate seed resources
- We conducted a meta-analysis and greenhouse experiment with multiple accessions from across the climatic/geographic distributions of nine perennial bunchgrass species that are commonly used in restoration across the Great Basin and Colorado Plateau
- We successfully propagated, grew and harvested over 800 plants, each of which were sampled for several leaf, root, and whole plant functional traits. Sample processing is ongoing, with final results expected by fall of 2017.

PLANT MATERIALS AND CULTURAL PRACTICES

Great Basin Research Center Seed Increase

Kevin Gunnell.....87

- Continued growout for increase of native plant materials. Expanded existing increase plots of thistleleaf beardtongue (*Penstemon pachyphyllus*), Nevada goldeneye (*Heliomeris multiflora nevadensis*), and Lewis flax (*Linum lewisii*) in spring 2016. Implemented new increase plots of scarlet gilia (*Ipomopsis aggregata*) and increase fields of basalt milkvetch (*Astragalus fillips*) and Searls' prairie clover (*Dalea searlsiae*) in spring 2016. Implemented new increase plots of firecracker penstemon (*P. eatonii*), Palmer's penstemon (*P. palmeri*), Rocky Mountain beeplant (*Cleome serrulata*), and barestem biscuitroot (*Lomatium nudicaule*) in fall 2016.
- Harvest of seed for distribution for further research and commercial increase. Successfully harvested seed from thistleleaf beardtongue, Nevada goldeneye, Lewis flax, needle and thread (*Heterostipa comata*), nakedstem sunray (*Enceliopsis nudicaulis*) and Searls' prairie clover.
- Distribution of thistleleaf beardtongue seed to grower for commercial scale increase. Distribution of thistleleaf beardtongue seed for further research.
- Installed infrastructure for a further 80 increase plots.

RESTORATION STRATEGIES

Placing Fall-harvested Wyoming Big Sagebrush Plants to Catch Snow and Provide Seed for Creating Sagebrush Islands

Kent McAdoo and Kirk Davies.....174

- We plan to evaluate the fall placement of Wyoming big sagebrush (*Artemisia tridentata* spp. *wyomingensis*) plants, harvested at near seed-ripe, in recently burned areas. The harvested sagebrush plants will serve both as snow catchments and seed source as the seeds dehisce.
- We anticipate that sagebrush seed that drops from the fall-harvested plants will have higher survival and establishment rates than broadcast-seeded sagebrush. If indeed this is the case, land managers will have another tool for establishing islands of sagebrush that could become seed sources for gradual colonization of sagebrush into larger areas for postfire rehabilitation.

Long-term Effects of Post-fire Seeding Treatments

Jeff Ott and Francis Kilkenny 177

- We followed up on an operational-scale seeding experiment that was initiated in 1999 to test different seed mixes used for post-fire rehabilitation in the Great Basin. Early stages of post-fire vegetation recovery had been reported by Thompson et al. (2006), but longer-term effects of the seeding treatments had not been evaluated. We revisited the experimental study sites in 2015 and 2016 to collect new vegetation data and evaluate vegetation recovery.
- Post-fire seeding treatments had effects on vegetation composition that lasted more than a decade, as we illustrate using data collected in 2015 from one of the study sites where drill-seeding treatments had been applied in 1999. We found that perennial grasses dominated the seeded treatments while invasive annuals dominated the non-seeded treatments. Areas that had been treated with seed mixes containing predominately non-native species had slightly higher perennial grass cover and lower invasive annual cover than seed mixes containing only native species. However, shrub cover was higher in the native seedings and the unseeded control treatment compared to the non-native seedings where shrubs largely failed to establish.
- Our results indicate that long-term rehabilitation objectives of perennial establishment and invasive annual suppression can be achieved using native seed mixes as an alternative to conventional mixes containing non-native species. Non-native seed mixes can be more effective at suppressing invasive annuals, but native seed mixes are preferable for restoring vegetation composition and structure including shrubs that are important to wildlife..

SCIENCE DELIVERY

Climate Smart Restoration Tool

*Brad St. Clair, Nikolas Stevenson-Molnar, Brenden Ward, Francis Kilkenny, and Bryce Richardson.....*188

- Work has begun on a web-based application with interactive maps that matches seed sources with future climate conditions.



2016 HIGHLIGHTS CONTINUING PROJECTS

GENETICS AND CLIMATE CHANGE

Bluebunch Wheatgrass: Seedling Traits, Seed Production, Phenology, and Soil Phenotype Relationships

Kathryn Alexander, Matt Orr, Ron Reuter, Francis Kilkenny, Brad St. Clair, and

Holly Prendeville.....14

- Quantify early development and above ground traits (leaf shape, biomass and root to shoot ratio) across seed zones 1, 3a, 4, & 7b for bluebunch wheatgrass (*Pseudoroegneria spicata*). Variation has been documented for mature plants, but information is limited on seed-to-seedling development. Since initial establishment often constitutes an obstacle to restoration success, it is important to analyze this stage of development. We expect to find significant differences in some or all of the traits listed above, and that these differences will be roughly grouped according to the seed zones from which each population was collected from.
- Quantify phenological variation within each of the eight seed zones. We expect to find variation in the timing of seed maturation sufficient enough to justify multiple harvest dates by commercial growers.
- Perform an exploratory analysis of existing soil, and bluebunch wheatgrass phenotypic trait data, to identify potentially important soil-phenotype relationships. The results of this study will be used to generate one or more hypotheses with respect to natural selection in terms of soil characteristics.

Evaluation of Local Adaptation in *Achnatherum hymenoides* and *Artemisia* spp.: Implications for Restoration in a Changing Regional Climate

Lesley DeFalco, Daniel Shryock, and Todd Esque 24

- Global climate change is predicted to increase aridity across the southwestern United States, potentially shifting the distributions of plant taxa. Our project aims to evaluate the vulnerability of southern Great Basin restoration species to climate change by placing populations in common gardens located within the arid Mojave Desert. Transplanting southern Great Basin populations to warmer conditions will mimic future climate changes.
- Using our novel sampling design for Indian ricegrass (*Achnatherum hymenoides*) – which incorporates empirically-derived climate zones, climate change velocity predictions, and ecological distances – we will evaluate the degree to which Great Basin populations exhibit intraspecific variability in response to climate change and in restoration of arid sites.

- Based on our classification of the southern Great Basin into six climate zones using precipitation and temperature variables, we sampled two zones showing high climate change velocities and either low or high ecological similarity to the Mojave Desert.
- Individuals from seven Indian ricegrass populations were sampled and tillers were propagated in the greenhouse in preparation for outplanting to the common gardens. The collections took place in the fall and winter of 2016 and will be planted in up to five Mojave Desert common gardens in early 2017. These experiments will facilitate development of management guidelines to select germplasm suitable for the restoration of arid sites in transition to warmer, drier conditions.

Analyses of Common-Gardens to Inform Seed-Transfer Guidelines in the Great Basin

Matthew Germino.....34

- Variation in traits affecting drought resistance were measured among the 16 GBNPP common gardens of bluebunch wheatgrass (*Pseudoroegneria spicata*) across the Northern Great Basin
- A network of sagebrush common gardens was established along an elevation transect on the 2015 Soda Wildfire site, starting from seeds and seedlings, and using nearly all of the many seed lots aurally distributed by BLM over the burn area plus local seed sources.
- In a collaboration with land managers, metrics for post-fire seeding success were discussed, defined, and evaluated, as a first step towards developing tools needed for monitoring seeding and related post-fire treatments.

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

R.C. Johnson, Vicki Bradley, Mike Cashman, and Steve Love 41

- Extensive genetic variation for key plant traits was identified among 73 diverse populations of sulfur-flowered buckwheat (*Eriogonum umbatellum*) from the Great Basin, suggesting potential climate driven adaptations.
- Taxonomic varieties of sulfur-flowered buckwheat were determined among common garden populations for assessing the role of variety in climatic adaptation.
- Seed zones for Basin wildrye (*Leymus cinereus*) were published and the role of ploidy in adaptation assessed.
- To enhance utilization, shape files of seed zone maps from project species are available on-line at <https://www.fs.fed.us/wwetac/threat-map/TRMSeedZoneData.php>

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

Elizabeth A. Leger and Sarah Barga.....47

- Native forbs are important components of sagebrush ecosystems, and understanding their habitat preferences can lead to more efficient restoration practices
- Our goal was to use herbarium collections to identify the climate niche that describes the potential habitat of ten Great Basin annual and perennial herbaceous species
- The habitat of each species was associated with a unique assemblage of climate characteristics

- Species grew in areas that differed in mean climate conditions, and tolerated different levels of inter-annual climate conditions
- Some species had large ranges that encompassed wide variation in climatic conditions; while others were restricted to more narrow conditions
- Herbarium records can be a way to describe preferences of species for which common garden studies have not been conducted

Climate Change Effects on Native Plant Establishment and Annual Grass Invasion: Implications for Restoration

Beth Newingham and Keirith Snyder 58

- This project investigates the effects of climate change (warming and/or drought) on invasive and native plant emergence, growth, and reproduction. In addition, we will investigate what native species mixtures may compete with invasive annual grasses in future climate.
- In field experiments, we will plant cheatgrass (*Bromus tectorum*) or red brome (*B. rubens*) with and without various native grass and forb mixtures.
- To date, we have tested new designs for warming chambers, collected cheatgrass and red brome seed, and are still investigating appropriate field sites.
- Our results will provide information on 1) the basic biology and competitiveness of native and invasive plant species under future climate scenarios, 2) the ability of red brome to expand its range in the Great Basin.
- Results will provide managers information on appropriate native species selection under future climate and their ability to compete with invasive annual grasses.

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

Holly Prendeville, Francis Kilkenny, and Brad St. Clair 64

- In the Intermountain West a reciprocal transplant experiment is underway with 15 common garden sites located in two transects at sites representing different environmental conditions. Each site was planted with 20 replicates from 39 populations plus two propagated lines of bluebunch wheatgrass (*Pseudoroegneria spicata*).
- Over the three years of the study, plant survival declined from 90% survival in spring 2015 to 52% survival in spring 2017. Only one site failed shortly after planting due to extreme weather and after a replanting was subsequently lost due to vandalism.

Morphological and Genetic Characterization of Blue Penstemon (*Penstemon cyaneus*)

Mikel Stevens and Robert Johnson.....71

- Across 2015/16 a total of 125 populations of blue penstemon (*Penstemon cyaneus*) have been identified, voucher specimens collected, and eight tissue samples secured for molecular evaluations. Furthermore, 68 total seed collections were made across the two years.
- DNA extractions have been completed for eight individuals from 125 populations for a total of 1,000 plant samples.
- DNA sequencing initiated for a genome reference.

- Seedlings of 42 populations initiated in the greenhouse for potential use in our common garden study.
- Taxonomic verification of species from field voucher specimens from 2015 and 2016 was completed using current taxonomic treatments. Many specimens that were field identified as blue penstemon) were later verified to be Minidoka penstemon (*P. perpulcher*).

PLANT MATERIALS AND CULTURAL PRACTICES

Developing Protocols to Maximize Seedling Establishment and Seed Production for Utah Trefoil (*Lotus utahensis* Ottley)

B. Shaun Bushman and Douglas Johnson.....82

- Putative collections of Utah lotus (*Lotus utahensis* Ottley) were made in the southern Great Basin in Utah and Nevada and Kaibab Plateau and central mountains in Arizona. The five collections from Arizona were later found to be scrub lotus (*Lotus wrightii* [A. Gray] Greene)
- Within the 14 Utah lotus collections, there was tentative evidence for population structures, suggesting a relatively narrow distribution and substantial gene flow among populations.
- There was significant variation for all traits. Regarding traits that affect plant fitness, collections near the southern boundary of collection sites showed the highest seed production, highest biomass, and intermediate flowering times.
- Transplants from promising collections were planted for seed increase necessary to begin seeding experiments.

Plant Material Work at the Shrub Science Lab

Scott Jensen 91

- Distributed 53 seed sources to accommodate a variety of cooperative projects.
- Study installation: Forb Islands: Possible Techniques to Improve Forb Seedling Establishment for Diversifying Sagebrush-Steppe Communities
- Produced native grasses and forbs under aquaponics
- In excess of 2948.4 kg of seed have been produced by the commercial sector from stock seed sources distributed from our office.

Seed Production of Great Basin Native Forbs (7 Part Report)

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

1. Irrigation Requirements for Native Buckwheat Seed Production in a Semi-Arid Environment 97

- The seed yield of sulphur-flower buckwheat (*Eriogonum umbellatum*) and parsnipflower buckwheat (*E. heracleoides*) were evaluated over multiple years in response to four biweekly irrigations applying either 0, 1 or 2 inches of water (0, 4, or 8 inches/season).
- Seed yield of sulphur-flower buckwheat responded to irrigation plus spring precipitation in 10 of the 11 years, with 5 to 11 inches of water applied plus spring precipitation maximizing yields, depending on year.
- Averaged over 11 years, seed yield of sulphur-flower buckwheat showed a quadratic response to irrigation rate plus spring precipitation and was estimated to be maximized at

232 lbs/acre/year by applying 5.4 inches of water with average spring precipitation of 2.8 inches.

- Over six seasons, seed yield of parsnipflower buckwheat was responsive to irrigation only in 2013, a dry year when seed yield was maximized by 4.9 inches of applied water.
 - Averaged over 6 years, seed yield of parsnipflower buckwheat showed a quadratic response to irrigation rate with the highest yield achieved with 5 inches of water applied.
2. Irrigation Requirements for Seed Production of Five *Lomatium* species in a Semi-arid Environment 106
- The seed yield response to four biweekly irrigations applying either 0, 1, or 2 inches of water (total of 0, 4, or 8 inches/season) was evaluated for four *Lomatium* species over multiple years starting in 2007.
 - On average, over eight seed production seasons, fernleaf biscuitroot (*L. dissectum*) seed yield was maximized by 9.8 inches of water, including applied water and natural spring precipitation (7 inches of water applied plus 2.8 inches of spring precipitation).
 - On average, over ten seed production seasons, Gray’s biscuitroot (*L. grayi*) seed yield was maximized by 14 inches of water, including applied water plus spring, winter, and fall precipitation (5.1 inches of water applied plus 8.9 inches of spring, winter, and fall precipitation).
 - On average, over ten seed production seasons, nineleaf biscuitroot (*L. triternatum*) seed yield was maximized by 10.6 inches of water, including applied water plus spring precipitation (7.8 inches of water applied plus 2.8 inches of spring precipitation).
 - Over five seed production seasons, barestem biscuitroot (*L. nudicaule*) seed yield did not respond to irrigation.
 - In three seed production seasons, seed yield of Suksdorf’s deserparsley (*L. suksdorfii*) responded to irrigation in one year.
3. Irrigation Requirements for Seed Production of Five Native *Penstemon* Species in a Semi-Arid Environment.....119
- The seed yield response of five *Penstemon* species to four biweekly irrigations applying either 0, 1, or 2 inches of water (a total of 0, 4, or 8 inches of water/season) was evaluated over multiple years.
 - Sharpleaf penstemon (*P. acuminatus*), seed yields were maximized by 4 – 8 inches of water applied per season in warmer, drier years and did not respond to irrigation in cooler, wetter years.
 - In 6 years of testing, thistleleaf beardtongue (*P. pachyphyllus*) seed yields only responded to irrigation in 2013 with 8 inches of applied water maximizing yields.
 - In 6 years of testing, seed yields of scabland penstemon (*P. deustus*) only responded to irrigation in 2015, with highest yields resulting from 5.4 inches of water applied.
 - In 6 years of testing, blue penstemon (*P. cyaneus*) only responded to irrigation in 2013, a dry year and in 2012, a year with average spring precipitation.
 - Royal penstemon (*P. speciosus*) seed yields were maximized by 4 – 9 inches of water applied plus spring precipitation.
4. Prairie Clover and Basalt Milkvetch Seed Production in Response to Irrigation 132

- Four biweekly irrigations applying either 0, 1, or 2 inches of water (a total of 0, 4, or 8 inches/season) were tested.
 - Over the 6-year period of study, Searls' prairie clover (*Dalea searlsiae*) seed yield was maximized by 13-17 inches of water applied plus spring, winter, and fall precipitation per season.
 - Blue Mountain or western prairie clover (*D. ornata*) seed yield was maximized by 13-16 inches of water applied plus spring, winter, and fall precipitation per season.
 - Seed yield of basalt milkvetch (*Astragalus filipes*) did not respond to irrigation.
5. Native Beeplant (*Cleome* spp.) Seed Production in Response to Irrigation in a Semi-Arid Environment 139
- The seed yield response of Rocky Mountain beeplant (*C. serrulata*) and yellow spiderflower (also known as yellow beeplant; *C. lutea*) to four biweekly irrigations applying either 0, 1, or 2 inches of water (total of 0, 4 cm, or 8 inches/season) was evaluated over multiple years.
 - Rocky Mountain beeplant seed yield was maximized by 8 inches of water applied per season in 2011, but did not respond to irrigation in 2012, 2014, or 2015.
 - *Cleome lutea* seed yield did not respond to irrigation in 2012, 2014, or 2015.
 - Beeplant stands were lost to flea beetles in 2013.
6. Irrigation Requirements for Seed Production of Various Native Wildflower Species Started in the Fall of 2012 144
- By burying drip tapes at 12-inch depth and avoiding wetting the soil surface, experiments were designed 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.
7. Direct Surface Seeding Systems for the Establishment of Native Plants in 2016 152
- In 2016, 14 species for which stand establishment has been problematic were included and an additional species (royal penstemon; *Penstemon speciosus*) was chosen as a check, because it has reliably produced good stands at Ontario.
 - Planting systems including row cover have been the most consistent factor for improving stand establishment over the years of trials at the Malheur Experiment Station.
 - Seed treatment, sawdust, and sand are factors that, for some species, in some years, have shown value in improving stand but their performance has not been consistent.

RESTORATION STRATEGIES

Restoring Sagebrush After Large Wildfires: An Evaluation of Different Restoration Methods Across a Large Elevation Gradient

- Kirk Davies*.....164
- Evaluated five different methods to restore sagebrush after wildfires across a 914.4 m (3000 ft.) elevation gradient.

- Determined the effects of site characteristics on restoration treatment success and natural recovery.

Forb Islands: Possible Techniques to Improve Forb Seedling Establishment for Diversifying Sagebrush-Steppe Communities

Douglas Johnson, Thomas Monaco, and Kristin Hulvey 167

- Seeded plots were established at two field study sites in Utah (Spanish Fork, Clarkston) and one in Idaho (Virginia). Each study site had three main site treatments (snow fence, N-sulate, control) laid out in a randomized complete block design with four replications.
- The snow fence used was the unique patented Hollow Frame Fence System (HFFS) that allowed for the capture of snow in a uniform, densely packed drift between HFFS panels oriented perpendicular to the prevailing winds at each site. The N-sulate fabric treatment was a white fabric covering typically used to enhance seedling growth in small-seeded horticultural species. The third site treatment was a Control treatment.
- Plots at each study site were seeded on a PLS basis during November 2015. Thirty-three rows were seeded in each site treatment/replication combination with rows being 3 m (10 ft.) long with 61 cm (2 ft.) spacing between rows. Half of the row was a study that involved 16 various seed treatments for each of two Great Basin legume species (basalt milkvetch (*Astragalus filipes*); western prairie clover (*Dalea ornata*)). The other half of the row involved an evaluation of 10 diverse Great Basin forb species with three seed treatments compared to two check species.
- Soils were sampled in Fall 2015, Spring 2016, and Fall 2016 at each study site by taking 2.5 cm cores to a depth of 10 cm in six plots of each study block. Soils will be sampled again in Spring 2017, and data will be analyzed to compare how the three main site treatments influence mineral-N content of soils.
- Nylon-mesh seed germination bags were buried at each site in each treatment/replication combination during the seeding of each site. Each bag contained 60 mL of sieved field soil and 25 seeds of each combination of seed species and seed coating treatment used in the two legume study and diverse native forb study.
- The effects of HFFS and N-sulate treatments on seed germination varied by site, with Spanish Fork having the highest germination rates in both HFFS and N-sulate treatments, followed by Clarkston and Virginia.
- Seed coatings generally increased germination at all sites, suggesting that scarification, fungicide, and hydrophobic coatings provided an advantage that is sustained across latitudinal gradients.
- Within HFFS and N-sulate treatments, the effects on seedling emergence varied by site. HFFS increased seedling emergence at Spanish Fork and Clarkston, while N-sulate increased seedling emergence at Virginia. However, densities of established native forbs remained low across all treatments at all sites.

SCIENCE DELIVERY

SeedZone Mapper Mobile App Development

Andrew Bower and Charlie Schrader-Patton 184

- Development of several mobile applications that function on both Android, iOS (Apple), and PC devices for both online and offline data collection and location information.
- Documentation including download and installation instructions, and tutorial posted to the WWETAC TRM Mobile Seed Zone Mapping website page (<https://www.fs.fed.us/wwetac/threat-map/TRMSeedZoneMobile.php>).

Science Delivery for the Great Basin Native Plant Project

Corey Gucker 187

- 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).

SPECIES INTERACTIONS

Impacts of Climate Change and Exotic Species on Native Plant-Microbial Interactions

Kevin C. Grady.....192

- Our research is focused on eco-evolutionary approaches to increase the effectiveness of sagebrush restoration confronted with the multiple challenges of exotic species invasion and climate change. Using a series of common garden provenance-based tests, we are examining local adaptation to both biotic and abiotic selection, intraspecific facilitation among sagebrush plants to increase competitiveness with weeds, and soil microbial inoculation.
- In order to design seed zone transfer guidelines, delineate eco-regions by genetic similarity, and test the usefulness of assisted migration for coping with climate change, we collected seeds from eight sagebrush individuals from each of 25 sites from a wide geographic area (throughout the Great Basin and Colorado Plateau) and transferred them to two common garden sites at both the warm and cold edge of the thermal distribution of sagebrush. These gardens that included approximately 2,000 individuals each were planted in 2016. Initial survival measurements conducted in spring 2017 indicated high survivorship of 97 percent at the warm site and 91 percent at the cold site. Provenance variation has not yet been analyzed.
- Intraspecific facilitation is being examined by planting each provenance in four different treatments: with weed competition at high sagebrush density; with weed competition at low sagebrush density, and; no weed competition with both high and low density. First year survivorship data has been collected but not analyzed/interpreted. We expect that high density sagebrush plantings will increase sagebrush growth in competition with weeds.

- To test the usefulness of microbial inoculation during restoration, we teamed up with an already existing project that included plantings of a total of 9,000 sagebrush and squirreltail (*Elymus elymoides*) with and without inoculation and weeds at three sites (Utah, Idaho, Arizona). Performance data after 1.5 years indicates that sagebrush does not benefit from soil microbial inoculation in extremely dry sites but potentially benefitting in wetter sites.

Isolation and Identification of Root Fungal Endophytes Associated with Wyoming Big Sagebrush Seedlings

Marcelo Serpe and Craig Carpenter.....197

- Roots from field-grown Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) seedlings were surface-sterilized and used as a source to obtain endophytic fungi.
- From hyphae growing from surface-sterilized root fragments, a dark septate fungus was isolated. DNA sequences from the ITS and 28S regions of rRNA genes revealed that the isolate was within the genus *Darksidea* in the Pleosporales.
- Inoculation of Wyoming big sagebrush seedlings under *in vitro* conditions showed that the fungus formed extensive associations with the roots without negative symptoms to the seedlings. These results in combination with observations of microsclerotia in the roots indicate that the isolate is a dark septate endophyte.

Comprehensive Assessment of Restoration Seedings to Improve Restoration Success

Kari Veblen and Thomas Monaco.....203

- This project will assess the short-term establishment and long-term persistence of seeded shrub, grass, and forb species in the Great Basin, Colorado Plateau, and Rocky Mountain physiographic provinces
- We will use > 150 restoration sites that are monitored as part of the Utah Watershed Restoration Initiative (WRI) to 1) investigate the roles of different pre-seeding restoration treatments, seeding approaches, environmental factors, and plant species traits on success of seeded species and 2) quantify the cost effectiveness and efficiency of these seeding efforts.
- This effort will provide critical information to compare the biological- and cost-effectiveness of different restoration treatments and seeding approaches. Our effort will also quantitatively assess the performance of species based on biological traits, which can be used to enhance plant material development and influence seeding success over both short and long-term periods.



GENETICS AND CLIMATE CHANGE



Project Title Bluebunch Wheatgrass: Seedling Traits, Seed
Production, Phenology, and Soil Phenotype Relationships

Project Agreement No. 15-JV-11221632-174

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Project Description

Introduction

The early developmental stages (germination - seedling growth) associated with bluebunch wheatgrass are poorly understood within the context of restoration and local adaptation. While many functional trait studies focus on linking adult plant traits with resource use and acquisition, the progression through early development stages may have a large impact on overall restoration outcomes (Larson et al. 2015). In addition, the impact of soils on early development and local adaptation is poorly understood. For this project, we will examine this species' early development traits, phenological variation in seed production timing, and explore phenotypic variation along soil gradients. Our project is part of a larger effort designed to test the efficacy of seed zones in bluebunch wheatgrass (Kilkenny & St. Clair 2014). By examining the early development traits of bluebunch wheatgrass in more detail, it may be possible to uncover additional mechanisms of local adaptation, and maximize the effectiveness of seed zones in the restoration setting. Additionally, this study will help land managers to better understand the life history and morphological traits underpinning population differences and plant fitness.

The overriding goal for these three complementary studies (i.e. early development, phenology, and soils) is to support or refine the seed zones developed for bluebunch wheatgrass, and to gain a more nuanced understanding of the species' adaptation to local conditions. This enhanced understanding will add to the knowledge base for this species in particular, and the study of local adaptation in general. By adding to this body of knowledge, land managers will have more tools with which to carry out effective restoration. In particular, the early development study will help land managers better understand the link between local adaptation and early development of these plants in the field, the phenology study will help to improve the cultivation protocols for bluebunch wheatgrass, and the soils study has the potential to refine the existing seed zones which will then be more effective.

Objectives

Our research asks: 1) Do seedling-stage phenotypic traits of bluebunch wheatgrass differ among seed source populations? 2) Do these early traits result in different groupings of seed source populations (seed zones)? 3) Does seed production phenology of bluebunch wheatgrass vary with seed source population? 4) Do relationships exist between bluebunch wheatgrass phenotypic traits and soil characteristics at the seed zone and seed source population level? These research questions have prompted the following:

1. We hypothesize that natural selection has affected seedling traits in bluebunch wheatgrass, and thus seedling root-to-shoot ratio and leaf length have evolved in response to local climate. We predict that these adaptations occur in a localized manner, matching empirically delineated seed zones for this species. If these hypotheses are supported, then it will suggest that seed zones delineated based on adult traits will also help seedlings survive a selectively rigorous environment shortly after germination. If there is no evidence of genetic differentiation in bluebunch wheatgrass seedlings, then using seedling traits in seed zone delineation for this species will not enhance restoration success. If observed genetic differentiation in seedling traits is not accounted for by seed zones, then it will suggest that early developmental traits need more consideration during seed zone delineation.

2. We hypothesize that the date-range of seed maturation of bluebunch wheatgrass is an expression of climate-driven natural selection, and is thereby genetically controlled. We predict that bluebunch wheatgrass sourced from more arid environments will produce seed earlier, and for a shorter duration than those sourced from less arid environments when grown in a common garden. If this hypothesis is supported, then it will suggest that seed source population climate conditions are a selective factor in seed production phenology. If we are unable to support my hypothesis, then it will suggest that day-length, water-stress inducing precipitation patterns, or other factors may instead control seed production phenology in bluebunch wheatgrass.

3. Our objective is to identify important soils characteristics at seed source locations that influence phenotypic traits in bluebunch wheatgrass. If we find correlations between bluebunch wheatgrass phenotypes and local soils, then soils and not just climate, may require more serious consideration during seed zone delineation. If we are unable to correlate bluebunch wheatgrass phenotypes with soils characteristics, then we will conclude that soils are (most likely) not a dominant factor in the genetic differentiation of this species.

This research will accomplish the following; 1) A detailed understanding of the early development traits of bluebunch wheatgrass (both above and below ground), and how these traits vary within and among the bluebunch wheatgrass seed zones; 2) Seed harvest protocol recommendations for seed producers that selects for the most genetically diverse seeds; 3) An overview of soil variability among bluebunch wheatgrass seed zones and an understanding of how soil gradients may contribute to phenotypic variation within this species.

Methods

For the early development study, we will propagate 810 plants in a greenhouse setting that, as a whole, represent four seed zones comprising the greatest land area within the range of the species. The seeds from each zone will include collections from 3 different populations within each zone and will be representative of the northern and southern portions of the seed zones. Seeds will be placed in sand-filled propagation tubes and grown for 10 days after germination. The seedlings will then be removed from growth tubes and roots cleaned. Each plant will be imaged with a high definition scanner and analyzed using image analysis software to measure root and leaf morphology. Lastly, the plant will be divided into leaves and roots using a razor blade and dried. Once dry, each portion of the plant will be weighed separately to determine the leaf and root biomass. We will perform an analysis of variance to determine if there are significant trait differences between seedlings that were grown within one seed zone and/or different zones.

To determine the range of flowering and seed maturity dates for bluebunch wheatgrass we will monitor each individual in an on-going common garden experiment. The common garden was planted with 39 populations from eight seed zones and two propagated lines (Anatone and Goldar) for a total of 820 plants surrounded by two rows of buffer plants. We will record when each plant develops flowers, when seeds are produced and become mature, and when these seeds are dispersed. These data will be analyzed to determine the range of dates when mature seeds are present for propagules within each seed zone. Using this information, we will make seed zone specific recommendations for growers that maximize seed collection volume and genetic diversity.

To better understand bluebunch wheatgrass phenotype-soil relationships, soil maps containing all available soil traits will be compiled for the study area. Soil series descriptions along with a survey of the current literature will be used to assemble a set of soil traits that are relevant to plant growth and that exist in the study area. Phenotypic trait data (such as leaf length, basal width, leaf curl, and seed production) will be gathered from a common garden study (Prendeville et al. unpublished work). This study occurred over two growing seasons, and encompassed 15 planting sites across the study area. The dataset includes mean values (at the population level $n = 39$) for various phenotypic traits and survival at each common garden.

To uncover soil phenotype relationships, we will use the geographically weighted regression analysis tool in ArcMap, to test for correlations in continuously varying soils traits (such as depth to bedrock, percent clay, and pH) and bluebunch wheatgrass phenotypic traits at the population level. A principle component analysis (PCA) will visualize differences among bluebunch wheatgrass populations in phenotypic trait space. Pearson's correlation coefficient r will report correlations between soils characteristics and ordination axes. The results from this analysis will identify the soil characteristics that are the most highly correlated with differences in phenotypic traits of bluebunch wheatgrass plants growing in each of sixteen common gardens in the study area. Multiple response permutation procedure will test the significance of the similarity in phenotypic traits between soil classifications. The results from this exploratory analysis will generate one or many hypotheses relating bluebunch wheatgrass phenotypes to soils traits.

Expected Results and Discussion

We expect to find that the variability in certain early developmental traits such as root to shoot ratio, leaf length, and early survival, can be partially predicted by seed zone membership. By measuring these traits in detail, we will be able determine how large an impact natural selection has on the early development and survival of this species. This information will serve to strengthen the justification for, and the applicability of, these seed zones in the restoration setting. Additionally, by exploring the variability in seed production timing, and making meaningful suggestions to seed growers about how to capture the greatest possible genetic diversity, we expect that the resulting restored populations will have enhanced fitness and long-term survival in the field. We expect to find statistically significant relationships between bluebunch wheatgrass phenotypes and one or several, soil traits. We also expect that the geographic distribution of these soil traits is not always consistent with the seed zones for bluebunch wheatgrass. Information obtained about genetic differentiation due to soils, seedling traits, and seed production phenology in bluebunch wheatgrass has the potential to create better seed zones, and thus help land managers to achieve higher success rates in restoration. This study will also fill three common and possibly important information gaps in the process of seed zone delineation and verification, not only for bluebunch wheatgrass, but for the process in general, and as applied to other grassland species.

Presentations

Alexander, Kathryn A.; Orr, Matt; Reuter, Ron; St. Clair, Brad; Kilkenny, Francis; Prendeville, Holly. 2016. Restoration with Bluebunch Wheatgrass: Soils, Seeds & Seedlings. Poster presented at the Society for Ecological Restoration Great Basin Chapter / Great Basin Native Plant Project annual meeting; 2016 April 11-12; Boise ID. Third place student poster awardee.

Alexander, Kathryn A.; Orr, Matt; Reuter, Ron; St. Clair, Brad; Kilkenny, Francis; Prendeville, Holly. 2016. Bluebunch Wheatgrass: Soils, Seeds & Seedlings. New project oral presentation at the Society for Ecological Restoration Great Basin Chapter / Great Basin Native Plant Project annual meeting; 2016 April 11-12; Boise ID.

Alexander, Kathryn A.; Orr, Matt; Reuter, Ron; St. Clair, Brad; Kilkenny, Francis; Prendeville, Holly. 2016. Restoration with Bluebunch Wheatgrass: Soils, Seeds & Seedlings. Poster presented at the Western Forestry Graduate Research Symposium; 2016 April 22; Corvallis OR.

References

Kilkenny, F.; St. Clair, Brad. 2014. Testing the efficacy of seed zones for re-establishment and adaptation of bluebunch wheatgrass (*Pseudoroegneria spicata*). Great Basin Native Plant Project: 2013 Progress Report. Boise, ID: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. 222 p.

Larson, Julie E.; Sheley, Roger L.; Hardegree, Stuart P.; Doescher, Paul S.; James, Jeremy J. 2015. Seed and Seedling Traits Affecting Critical Life Stage Transitions and Recruitment Outcomes in Dryland Grasses. *Journal of Applied Ecology*. 52(1): 199-209

Prendeville, Holly; St. Clair, Brad; Kilkenny, Francis. Title TBD Reciprocal transplanting study at 16 bluebunch wheatgrass common gardens. Unpublished draft.

Project Title Genetic and Environmental Regulation of Functional Traits: New Approaches for Restoration in a Changing Climate

Project Agreement No. 15-JV-11221632-203

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Project Description

Introduction

Identifying genetically suitable native plant materials for specific restoration sites and establishing populations that can persist under climate change are two critical challenges facing ecological restoration efforts. Climate change in particular means that “local is best” may not be true for long. Effective solutions to these problems have included common garden and genecology studies used to develop seed transfer zones or transfer functions for individual species (Kilkenny 2015). However, extending such species-specific analyses, which have been conducted for relatively few focal groups, to the hundreds to thousands of other important restoration species is difficult. Because of funding constraints, and because climate impacts on plant populations have already begun, it is critical to develop methods that rely on detailed analyses of workhorse species but that can be extended to other important restoration taxa.

One way to extend common garden research is through identification of the functional traits associated with local adaptive divergence among populations in existing common gardens. Plant performance is mediated by functional traits – organismal characteristics that determine responses to the local environment (Lavorel and Garnier 2002), and we know that there are strong relationships between functional traits and the environment (Wright et al. 2004; Swenson et al. 2011). However, we know little about which functional traits are relatively genetically constrained, and which are more plastic, a distinction that is critical for development of seed transfer guidelines. For example, we have shown that specific leaf area (SLA), a critical integrator of the “leaf economics spectrum” (Wright et al. 2004), exhibits significant broad-sense heritability among populations of blue grama grass (*Bouteloua gracilis*) grown in a common garden, and is strongly correlated with source location temperature (Figure 1; Butterfield and Wood, *In review*). While population-specific SLA may serve as a good indicator of suitable climate niche in this species, more data are needed from a reasonable sample of model restoration species. Whether such easy to measure functional traits can be used to predict habitat suitability of different seed sources for many species, both under current and future climates, remains an open question.

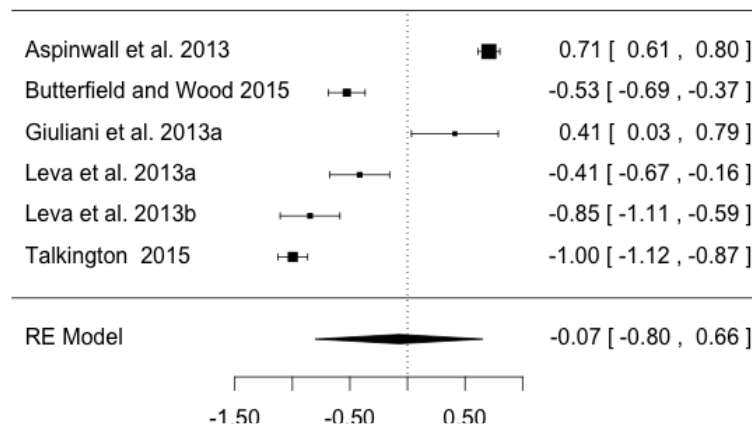


Figure 1. Correlations between specific leaf area and source population annual mean temperature. Box size is proportional to number of species in the study. SLA-temperature relationships appear to be context-dependent globally, necessitating a regional focus such as the empirical work that we have proposed for Great Basin and Colorado Plateau species.

Objectives

Our specific objectives are to:

- Conduct a meta-analysis of functional trait heritability and its climatic-dependence from published studies of grass common gardens in order to identify knowledge gaps
- Measure a suite of standard functional traits on plants already established in a greenhouse container common environment
- Assess genetic variation in these functional traits
- Determine the environmental correlates of functional trait variation

These objectives represent an important first step toward extending the utility of common garden research on a limited set of species in informing generalized transfer guidelines.

Methods

All data collection and analyses have been completed for the meta-analysis. A number of interesting trends have been identified (e.g. Figure 1), and we are in the process of writing the publication. The target journal is *Plant Ecology*.

To achieve the remaining objectives of our proposed research, we will quantify broad-sense heritability of functional traits and their climatic-dependence on 10 species of native grasses that have been identified as being of interest to restoration on the Great Basin and Colorado Plateau: purple threeawn (*Aristida purpurea*), blue gramma grass, squirreltail (*Elymus elymoides*), prairie Junegrass (*Koeleria macrantha*), basin wildrye (*Leymus cinereus*), James' galleta (*Pleuraphis jamesii*), muttongrass (*Poa fendleriana*), Sandberg bluegrass (*Poa secunda*), bluebunch wheatgrass (*Pseudoroegneria spicata*), sand dropseed (*Sporobolus cryptandrus*). We have seeded 10 containers x 10 populations of each of these species (1000 plants total) in a research greenhouse at Northern Arizona University in Flagstaff. Seeds were acquired from Germplasm Resources Information Network (GRIN) and Seeds of Success (SOS). When more than 10

accessions from natural populations were available, we stratified our selection to uniformly cover the climate space occupied by that species. Establishment success has been quite high (>90%).

Table 1. We will measure a suite of ecologically relevant functional traits on each plant:

Organ	Functional trait	Relevance	References
Whole plant	Seed mass	Shade tolerance, seed bank	Westoby <i>et al.</i> 2002
	Height	Light competition	Westoby 1998
	Lateral spread	Space competition, clonality	Navas & Moreau-Richard 2005
Leaf	Specific leaf area	Photosynthetic capacity, heat tolerance	Wright <i>et al.</i> 2004
	Leaf dry matter	Water use efficiency	Butterfield & Briggs 2011
	Leaf size	Aridity tolerance	Niklas 1994
Stem	Stem density	Frost tolerance	Zanne <i>et al.</i> 2013
Root	Specific root length	Belowground competition	Cornelissen <i>et al.</i> 2003
	Root density	Drought tolerance	Butterfield & Suding 2013

Leaf and stem traits will be measured on several stems of each plant sampled, and root traits, if not detrimental to primary study goals, will be measured on tissues sampled with small diameter soil cores. Methods will follow Perez-Harguindeguy *et al.* (2013). Forage quality analysis, which includes protein, non-structural carbohydrate, and lipid content, among other variables, will be conducted on a subset of samples by Chandler Analytical Laboratories. Relationships between functional traits and these other variables will allow us to link environmental responses via functional traits to restoration objectives related to forage production and quality.

Two analyses will be conducted on each trait for each species. First, analysis of variance will be used to assess significant genetic differentiation in functional trait values among populations and/or population groups. Second, all subsets multiple regression and Bayesian information criteria will be used to determine the most parsimonious set of climate variables for explaining trait variation across individuals, populations, and species. Climate variables will include the standard 19 bioclimatic variables used in macroecology research (Hijmans *et al.* 2005), and, when sufficient extent is available, complementary variables from PRISM or Climate WNA will be analyzed.

The above results will be placed in a meta-analytic framework in order to look for general patterns in environmental control of functional trait variation. Effect sizes will be calculated for both genetic variation (scaled to the ratio of within to among population variance) of functional traits and its environmental predictors. Consistent effect sizes across species will be used to identify traits and associated environmental variables to target for measurements on additional species in the field, to guide seed selection for restoration, and to design explicit experimental (targeted out-planting) tests of key study conclusions.

Expected Results and Discussion

We anticipate consistent patterns of heritable trait variation within populations of most species, and consistent trait-environment relationships within most species.

Management Applications and/or Seed Production Guidelines

If our expectations are borne out, seed sources could be selected based on their trait values and applied in locations with suitable environmental conditions for those given trait values. At a higher level, we anticipate that this trait-based approach to seed selection and application could help to provide a reasonable compromise between the “local is best” approach, which could theoretically necessitate dozens of accessions and increases for each species, and the typical one or two cultivars per species that are currently available at a commercial level. By selecting several accessions that maximize the functional diversity represented for each species, matching trait to environment could greatly improve restoration outcomes across diverse environments using a manageable number of seed sources for each species.

References

- Butterfield, B.J.; Briggs, J.M. 2011. Regeneration niche differentiates functional strategies of desert woody plant species. *Oecologia*, 165:477-487.
- Butterfield, B.J.; Suding, K.N. 2013. Single-trait functional indices outperform multi-trait indices in linking environmental gradients and ecosystem services in a complex landscape. *Journal of Ecology*, 101:9-17.
- Butterfield, B.J.; Wood, T. 2015. Local climate and cultivation, but not ploidy, predict functional trait variation in *Bouteloua gracilis* (Poaceae). *Plant Ecology*, 216:1-9.
- Cornelissen, J.H.C.; Lavorel, S.; Garnier, E.; Diaz, S.; Buchamann, N.; Gurvich, D.E.; Reich, P.B.; Ter Steege, H.; Morgan, H.D.; Van Der Heijden, M.G.A.; Pausas, J.G. 2003. A handbook of protocols for standardized and easy measurement of plant functional traits worldwide. *Australian Journal of Botany*, 51:335-380.
- Hijmans, R.J.; Cameron, S.E.; Parra, J.L.; Jones, P.G.; Jarvis, A. 2005. Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology*, 25:1965-1978.
- Kilkenny, F. 2015. Genecological approaches to predicting the effects of climate change on plant populations. *Natural Areas Journal*, 35:152-164.
- Lavorel, S.; Garnier, E. 2002. Predicting changes in community composition and ecosystem functioning from plant traits: revisiting the Holy Grail. *Functional Ecology*, 16:545-556.
- Navas, M.L.; Moreau-Richard, J. 2005. Can traits predict the competitive response of herbaceous Mediterranean species? *Acta Oecologica*, 27:107-114.
- Niklas, K.J. 1994. Plant allometry: the scaling of form and process. The University of Chicago Press, Chicago, IL.
- Pérez-Harguindeguy, N.; Diaz, S.; Garnier, E.; Lavorel, S.; Poorter, H.; Jaureguiberry, P. 2013. New handbook for standardized measurement of plant functional traits worldwide. *Australian Journal of Botany*, 61:167-234.

Swenson, N.G.; Enquist, B.J.; Pither, J.; Kerkhoff, A.J.; Boyle, B.; Weiser, M.D.; Elser, J.J.; Fagan, W.F.; Forero-Montana, J.; Fyllaas, N.; Kraft, N.Jl. 2011. The biogeography and filtering of woody plant functional diversity in North and South America. *Global Ecology and Biogeography*, 21:798-808.

Westoby, M. 1998. A leaf-height-seed (LHS) plant ecology strategy scheme. *Plant and Soil*, 199:213-227.

Wright, I.J.; Reich, P.B.; Westoby, M.; Ackerly, D.D.; Baruch, Z.; Bongers, F.; Cavender-Bares, J.; Chapin, T.; Cornelissen, J.H.; Diemer, M.; Flexas, J. 2004. The worldwide leaf economics spectrum. *Nature*, 428:821-827.

Zanne, A.E.; Tank, D.C.; Cornwell, W.K.; Eastman, J.M.; Smith, S.A.; FitzJohn, R.G.; McGlinn, D.J.; O'Meara, B.C.; Moles, A.T.; Reich, P.B.; Royer, D.L. 2013. Three keys to the radiation of angiosperms into freezing environments. *Nature*, 506:89-92.

Project title Evaluation of Local Adaptation in *Achnatherum hymenoides* and *Artemisia* spp.: Implications for Restoration in a Changing Regional Climate

Project Agreement No. 15.IA.11221632.178

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Project Description

Introduction

Climate change and novel disturbances have the potential to alter distributions and population trajectories of plant species worldwide (Walther 2002; Parmesan 2006). Impacts may be especially pronounced in arid regions where high rates of climate change are expected (Brown et al. 1997; Weiss and Overpeck 2005; Loarie et al. 2009). The Great Basin is predicted to experience increased temperatures and aridity (IPCC 2015), and recent vegetation die-offs suggest that plant populations may be vulnerable to such changes (Breshears et al. 2005; Miriti et al. 2007). Climate change effects will likely be expressed at the subspecies rather than the species level (Reusch and Wood 2007; Valladares et al. 2014), reflecting the accumulated responses of local populations to altered conditions. Local adaptation is widespread across plant taxa and expected to drive variability in population-level responses to climate change, particularly where complex topography creates gradients in exposure intensity (Loarie et al. 2009).

Characterizing local adaptation in plants of the Great Basin is an important step towards increasing restoration effectiveness in a changing climate. Habitat for the greater sage-grouse (*Centrocercus urophasianus*) in the southern Great Basin ecosystem is imperiled by multiple-use

activities – such as Solar Energy Zones, off-highway vehicle use, and mining – as well as wildfires fueled by invasive annual grasses. Revegetation of disturbed habitat has proven challenging for low elevation, arid sites in the Great Basin, particularly burned areas (Knutson et al. 2014). Understanding whether ecotypes exist that may both enhance re-vegetation efforts and exhibit resilience in the face of climate change is important but infrequently addressed.

Common garden experiments characterize genetic differences in fitness traits arising from local adaptation in plant populations. However, these experiments also serve as natural laboratories for climate change research if populations are located in common garden environments that mimic predicted future conditions. This approach may identify resilient ecotypes and those with desirable traits, such as drought tolerance (e.g., Bansal et al. 2014), particularly when paired with genetic testing across environmental gradients. We adopt this approach by evaluating the performance of Great Basin populations of important restoration species in multiple Mojave Desert common gardens of increasing aridity. These experiments will develop management guidelines for selecting Great Basin ecotypes suitable for restoration of arid sites in transition to warmer, drier conditions.

Objectives

Southern Great Basin populations of Indian ricegrass have been sampled and will be placed in common gardens located in the arid Mojave Desert, mimicking potential future climates. Pending additional funding, this project will support tissue and seed collections for Indian ricegrass and sagebrush (*Artemisia nova* and/or *A. tridentata*), two taxa that are used in restoration and are important for wildlife habitat in the southern Great Basin (Connelly et al. 2000, 2011).

The sample design included Great Basin populations of contrasting aridity and predicted levels of exposure to climate change. Our experimental design addresses three key questions:

- (1) Do populations exhibit genetic differentiation leading to differential resilience when transplanted to the arid Mojave Desert;
- (2) Do climatic conditions of source populations consistently predict performance across common gardens of increasing aridity, such that management guidelines can be developed; and
- (3) Which source populations are most and least resilient to increased aridity, and which possess desirable traits for restoration?

Methods

Sample Design

Potential locations supporting Indian ricegrass populations within the southern Great Basin were derived from the SEInet and Calflora herbaria networks (<http://swbiodiversity.org>, <http://ucjeps.berkeley.edu/consortium/>; Figure 1). The southern Great Basin ecoregion (defined as the Environmental Protection Agency's (EPA) "Central Basin and Range" ecoregion) was delineated into six climate zones based on 11 precipitation and temperature variables. Climate layers were derived at a 2 km² scale using the program ClimateWNA (Wang et al. 2012). Six climate zones were then identified using partitioning-around-medoids (r package "cluster"), a robust form of k-means clustering (Figure 2). Each of the zones were ranked according to two

criteria: (1) average ecological distance to Mojave Desert common garden sites, with larger distances indicating less similar climate conditions (Figure 3); and (2) average predicted climate change velocity (Hamann et al. 2015), with higher velocities indicating more severe exposure to climate change (heightened temperatures and aridity; Figure 4). Climate change predictions were based on a near-term (2040-2070), high-emission scenario (RCP8.5) for three CMIP5 models (CCSM4, GFDL-CM3, HadGEM2-ES; IPCC 2015). We selected two climate zones, one and five (Figure 2), with low and high ecological distances to the Mojave Desert common gardens, respectively, and with high predicted climate change velocities as suitable for sampling.

Collection

Potential collection sites were selected for each zone/velocity combination from herbaria records. We collected from sites that had a population of 20 or more healthy individuals spaced at least 20 meters apart. In total, we collected from eight locations (Fig. 5-13). Two sites that we visited had too few plants and another had completely frozen ground). We returned to one site, Ainslee, to re-collect individuals because many from the initial sampling did not survive.

Greenhouse and Common Gardens

We selected zones one and five as priorities for sampling, representing contrasting climatic conditions of arid and mesic sites. Within each zone, we identified both leading-edge (high climate change velocity) and trailing-edge (lower velocity) areas (Figure 14). Sampling within each climate zone included two leading edge populations and two trailing edge populations. We collected tillers from eight Great Basin populations of ricegrass and planted them into 7.62cm x 7.62cm x 30.48cm (3in x 3in x 12in) plant bands at the U.S. Geological Survey (USGS) greenhouse (Boulder City, Nevada). These tillers, in combination with those from collections made within the Mojave Desert ecoregion (N=21 populations), will be transplanted into multiple Mojave Desert common gardens in early 2017 (original fall 2016 planting date delayed as approvals are being finalized for construction of the gardens on Bureau of Land Management (BLM) lands).

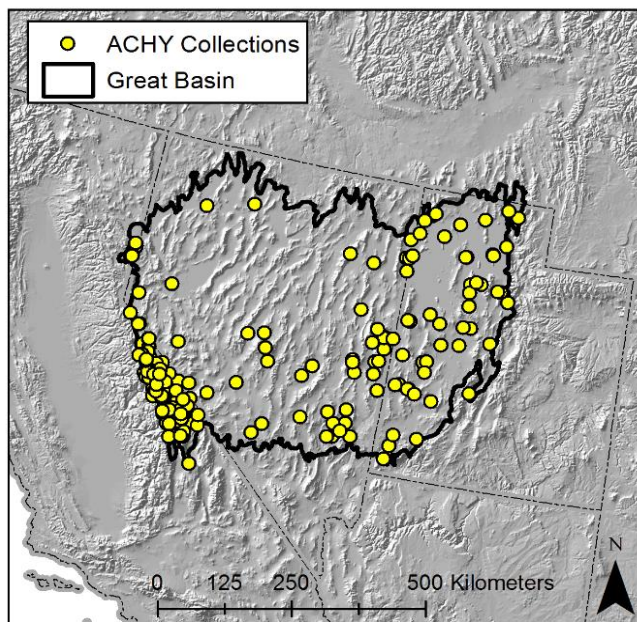


Figure 1. Potential Indian ricegrass (ACHY) populations drawn from herbaria records.

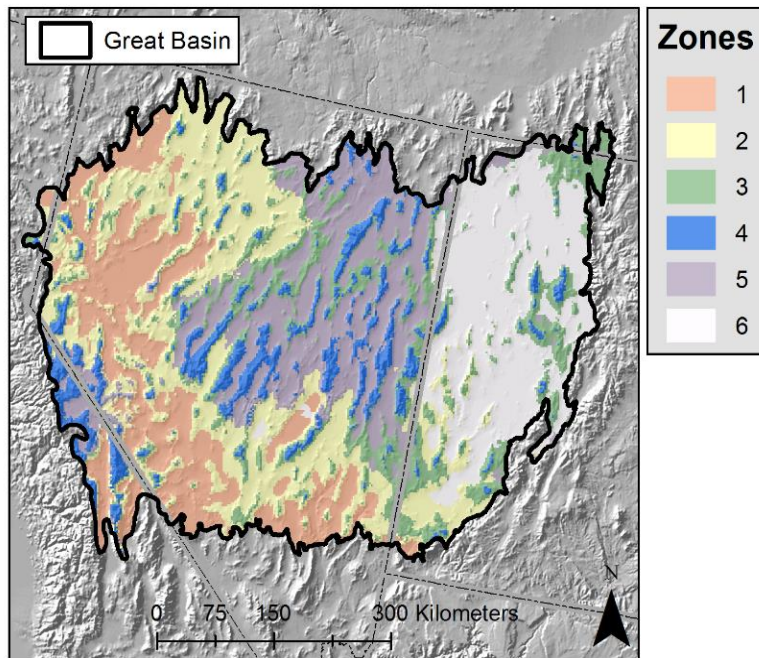


Figure 2. Six climate zones in the southern Great Basin derived through cluster analysis of temperature and precipitation characteristics.

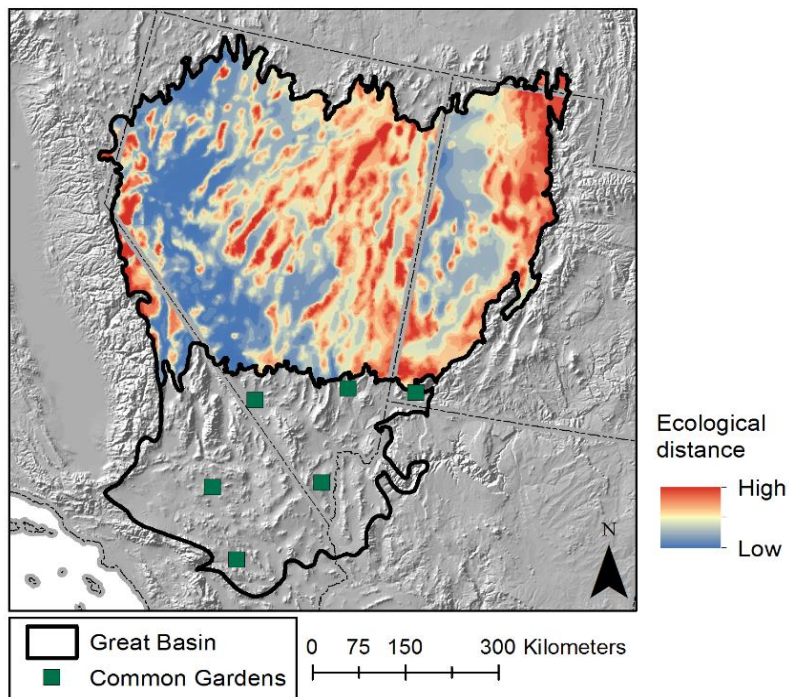


Figure 3. Ecological distances between the southern Great Basin (northern polygon) and Mojave (southern polygon) common gardens.

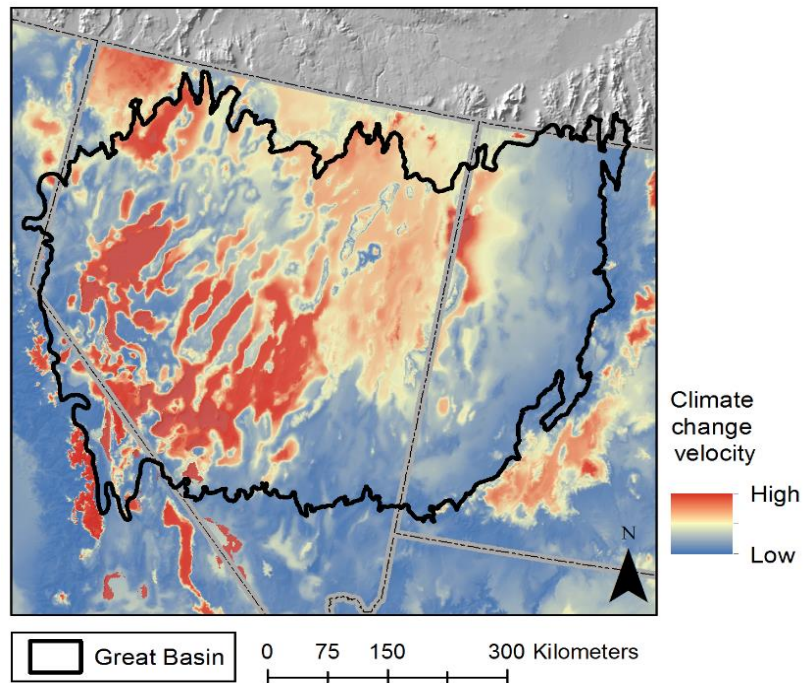


Figure 4. Velocity of climate change predicted for the southern Great Basin (Hamann et al. 2015).

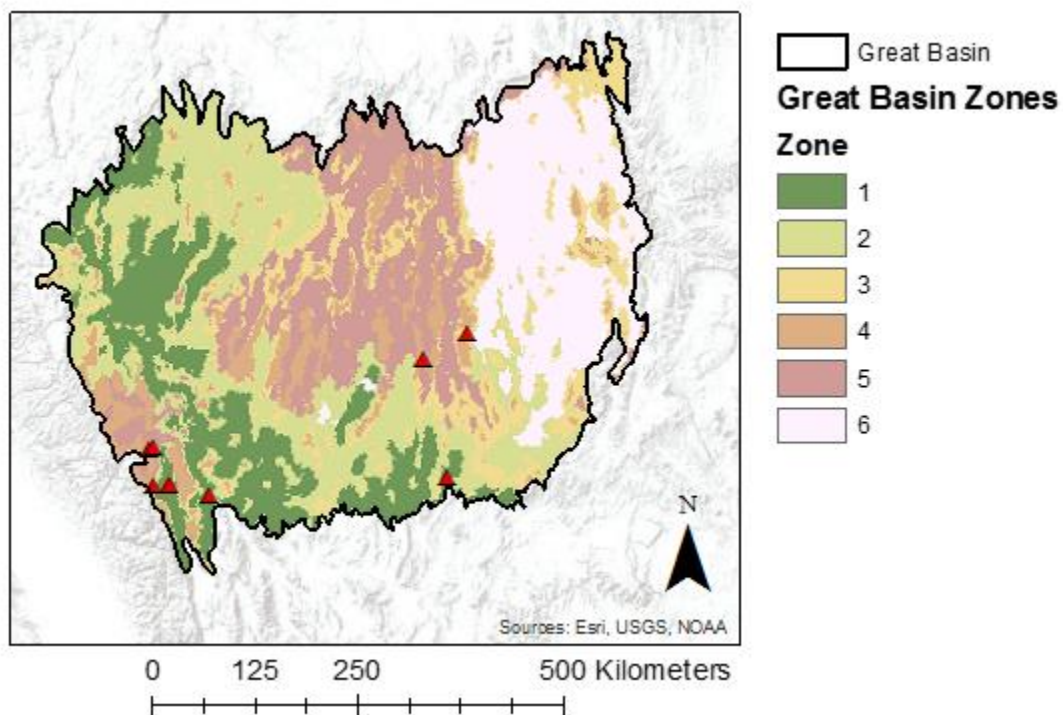


Figure 5. Great Basin ACHY collection locations



Figure 6. Buck site (Zone 1, Low velocity)



Figure 7. Ainslee site (Zone 1, Low velocity)



Figure 8. Molly site (Zone 1, High velocity)



Figure 9. Piper site (Zone 1, High velocity).



Figure 10. Adobe site (Zone 5, Low velocity)



Figure 11. White Pine site (Zone 5, Low velocity)



Figure 12. Fish Slough site (Zone 5, High velocity)



Figure 13. Granite site (Zone 5, High velocity)

Expected Results and Discussion

In each common garden, we will measure performance traits, including growth, survival, and reproductive characteristics. These performance traits will enable us to develop response functions linking source population climate with predicted performance at proposed restoration sites. Expected products from this research include: (1) identification of resilient ecotypes for restoring arid, low-elevation sites; (2) increased understanding for how Great Basin species will respond to climate change at an intraspecific level; and (3) interactive, spatial planning tools for resource managers that display suitable seed source areas for particular restoration sites. These products aim to increase restoration effectiveness for arid sites in a changing climate.

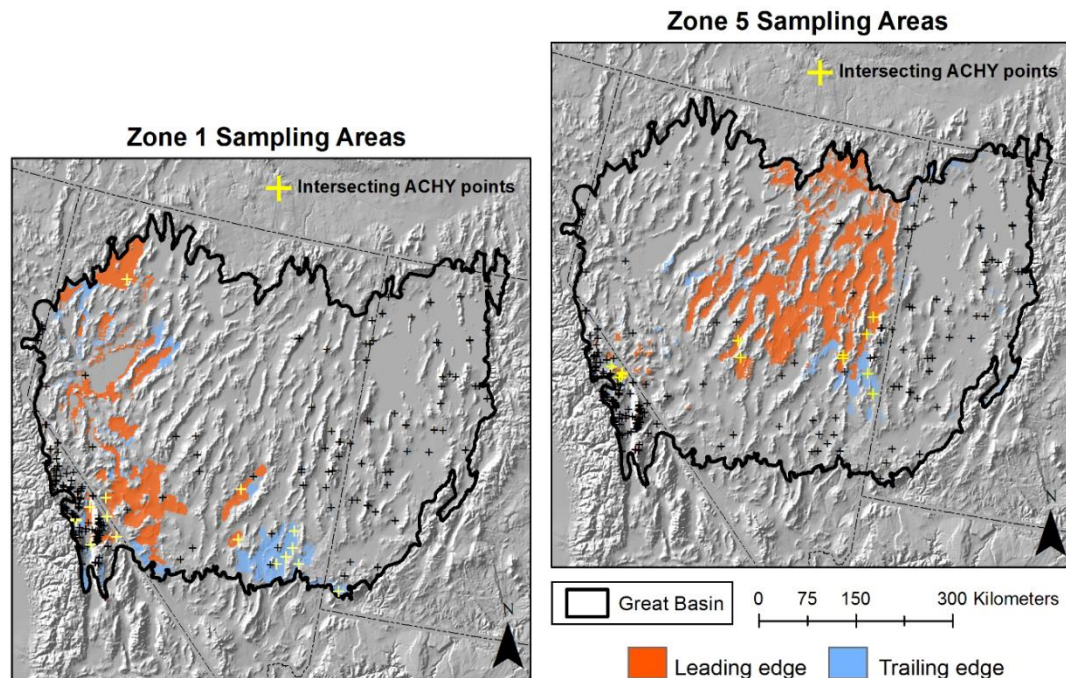


Figure 14. Leading- and trailing-edge areas within the two climate zones from which Indian ricegrass was sampled.

References

- Bansal, S.; Harrington, C. A.; Gould, P. J.; St. Clair, J. B. 2015. Climate-related genetic variation in drought-resistance of Douglas-fir (*Pseudotsuga menziesii*). *Global Change Biology* 21: 947-958.
- Breshears, D. D.; Cobb, N. S.; Rich, P. M.; Price, K. P.; Allen, C. D.; Balice, R. G.; et al. 2005. Regional vegetation die-off in response to global-change type drought. *Proceedings of the National Academy of Sciences of the USA* 102: 15144-15148.
- Brown, J. H.; Valone, T. J.; Curtin, C. G. 1997. Reorganization of an arid ecosystem in response to recent climate change. *Proceedings of the National Academy of Sciences of the USA* 94: 9729-9733.
- Connelly, J. W.; Schroeder, M.; Sands, A. M.; Braun, C. E. 2000. Guidelines to manage sage grouse populations and their habitats. *Wildlife Society Bulletin* 28: 967-985.
- Connelly, J. W.; Rinkes, E. T.; Braun, C. E. 2011. Characteristics of greater sage-grouse habitats: a landscape species at micro- and macroscales. In: Knick, S. T.; Connelly, J. W., eds. *Greater sage-grouse: Ecology and Conservation of a landscape species and its habitats. Studies in Avian Biology*, 38. University of California Press, Berkeley, CA: Cooper Ornithological Society: chapter 4.
- Hamann, A.; Roberts, D. R.; Barber, Q. E.; Carroll, C.; Nielsen, S. E. 2014. Velocity of climate change algorithms for guiding conservation and management. *Global Change Biology* 21: 997-1004.
- IPCC [Intergovernmental Panel on Climate Change]. 2013. *Climate change 2013: the physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge.
- Knutson, K. C.; Pyke, D. A.; Wirth, T. A.; Arkle, R. S.; Pilliod, D. S.; Brooks, M. L.; Chambers, J. C.; Grace, J. B. 2014. Long-term effects of seeding after wildfire on vegetation in Great Basin shrubland ecosystems. *Journal of Applied Ecology* 51: 1414-1424.
- Loarie, S. R.; Duffy, P. B.; Hamilton, H.; Asner, G. P.; Field, C. B.; Ackerly, D. D. 2009. The velocity of climate change. *Nature* 462: 1052-1055.
- Miriti, M. N.; Rodríguez-Buritica, S.; Wright, S. J.; Howe, H. F. 2007. Episodic death across species of desert shrubs. *Ecology* 88: 32-36.
- Parmesan, C. 2006. Ecological and evolutionary responses to recent climate change. *Annual Review of Ecology, Evolution, and Systematics* 37: 637-669.
- Reusch, T. B. H.; Wood, T. E. 2007. Molecular ecology of global change. *Molecular Ecology* 16: 3973-3992.

Valladares, F.; Matesanz, S.; Guilhaumon, F.; Araujo, M. B.; Balaguer, L.; Benito-Garzon, M.; Cornwell, W.; et al. 2014. The effects of phenotypic plasticity and local adaptation on forecasts of species range shifts under climate change. *Ecology Letters* 17: 1351-1364.

Wang, T.; Hamann, A.; Spittlehouse, D. L.; Murdock, T. 2012. ClimateWNA – high-resolution spatial climate data for Western North America. *Journal of Applied Meteorology and Climatology* 51: 16-29.

Walther, G. R.; Post, E.; Convey, P.; Menzel, A.; Parmesan, C.; Beebee, T. J. C.; et al. 2002. Ecological responses to recent climate change. *Nature* 416: 389-395.

Weiss, J. L.; Overpeck, J. T. 2005. Is the Sonoran Desert losing its cool? *Global Change Biology* 11: 2065-2077.

Project Title Analyses of Common-Gardens to Inform Seed-Transfer Guidelines in the Great Basin

Project Agreement No. 14-IA-11221632-012

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Project Description

Knowing how different seed sources or plant provenances vary in their physiological response to climate contributes substantially to the basis for seed-transfer guidelines for restoration. We are measuring a comprehensive set of variables in common gardens that provide important insight on how seed provenances of foundational restoration species, specifically sagebrushes and bluebunch wheatgrass, differ in their climate responses. Measurements focus on how different populations from around the Great Basin vary in traits that relate to drought and temperature stress. Publications from 2016 demonstrate the importance of seed sources for initial establishment of sagebrush, along with the importance of associated management treatments such as herbicides, mowing, and seeding herbs. A large dataset of physiological, morphological, and anatomical traits of seedlings or adult plants at Great Basin Native Plant Project (GBNPP) common gardens around the Great Basin continues to be developed.

Introduction

Increased wildfire activity poses a major challenge for big (*Artemisia* sp.) and low sagebrush (*A. arbuscula*) communities. Seeding and plantings of sagebrush and desirable bunchgrasses such as bluebunch wheatgrass have been extensive and will continue as a central part of the Department of Interior (DOI) Secretarial Order #3335. However, restoration 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. Additionally, new efforts to do seeding in the context of adaptive management have highlighted the need to better consider metrics for seeding success. Defining these metrics are essential because they affect how monitoring occurs and also the management of seeding areas, e.g. grazing. These topics are thus part of our GBNPP research and extension/outreach.

We are continuing to develop or adapt techniques and applications of a laboratory capable of high-throughput “phenotyping” of the many plants in many Native Plant Project (NPP) gardens in the Great Basin. Measurement of a greater variety of functional traits in individual plants or populations increases the objectivity of assessments of climate adaptation, increasing the reliability of conclusions about which processes and climate parameters most limit plant

establishment and distinguish different seed sources. Our measurements focus on traits that relate to temperature and water stress, which are the dominant factors affecting plant establishment in the cold deserts of the Great Basin. Several of our measurements quantify threshold temperatures or water levels for plant survival.

Objectives

- 1) provide quantitative and standardized analyses of climate adaptation for plants in common gardens in the Great Basin, and
- 2) determine how the climate adaptation varies among populations, subspecies or cultivars, seed zones, and species.
- 3) provide guidance on metrics for seeding success, including setting objectives, monitoring plans, and interpreting monitoring results.

Methods

Our efforts are in close collaboration with Bryce Richardson, who performs lab tests for sagebrush identification and established some of the big sagebrush gardens we work on, and with Francis Kilkenny, Holly Prendeville, Brad St. Clair, Matt Fisk, and others who facilitate our measurements on their bluebunch wheatgrass common gardens.

For our overall GBNPP efforts, we have devised a “sequential filtering” approach to isolating factors affecting survival and establishment. We quantify variation in ecophysiological traits of the following aspects of populations in common gardens:

- At the native site (i.e., measured upon seed collection)
- In common nursery settings (i.e., in container stock without strong environmental selection)
- After acclimation to garden sites has occurred, but before post-planting mortality has occurred (while maladapted plants are culled, allow us to identify which plant climate/weather parameters are most important)
- After appreciable culling and selection have occurred (identifies the ecophysiological trait values that confer survival or mortality, and their specific climate drivers)

Assessing trait variation before and after environmental stress and mortality greatly increases what can be learned about climate adaptation beyond measurements of growth and survival, and notably can provide key insight within a few years of garden planting (contrasting the many years typically required to learn from survival of garden outplants). The resulting ecophysiology information will corroborate or refine the specific climate parameters most appropriate for seed zones, and furthermore will provide information that can help refine the selection of temperature or precipitation increments with which to separate seed zones.

Our screening protocol across populations and gardens of each species includes:

- carbon isotopes as an indicator of differences in water use efficiency and stress
- pressure-volume relationships to identify minimum water status thresholds
- freezing point and photosynthetic resistance to freezing (and heating; temperature thresholds)

- standard allometric measures that indicate growth strategy and inform interpretation of ecophysiological variables, and which relate to water and temperature responses (eg. specific leaf area, wood density)

Bluebunch wheatgrass:

Prior to outplanting, we measured stable isotopes of carbon to estimate differences in photosynthetic water-use efficiency and specific leaf area (which entails a direct tradeoff of stress mitigation vs photosynthesis). Following outplanting, we are using three different sampling schemes across some or all of the 16 gardens established by Kilkenny et al.:

- 1) extensively across all 16 gardens, we are using stable isotopes of carbon to estimate differences in photosynthetic water-use efficiency, specific leaf area, and leaf width,
- 2) in four gardens that vary considerably in temperature, we finished (in 2016) measuring freezing avoidance (temperature causing ice formation, lowered in cold-adapted/acclimated plants), and freezing resistance (temperature causing a 50% reduction in chlorophyll fluorescence) (gardens from warmest to coldest are Central Ferry WA, Orchard ID, Richfield ID, Baker OR), and
- 3) an intensive effort at Orchard, ID has been completed to assess differences in photosynthesis, water status, phenology, chlorophyll fluorescence (a measure of stress response), and leaf curling (a stress avoidance mechanism).

Big sagebrush:

In fall 2012, we established five common gardens of young seedlings on five areas burned months earlier in the Birds of Prey National Conservation Area in Idaho, and performed the detailed assessment of survival in response to weather variation and the ecophysiological bases of the responses in Brabec et al. (2016). This study demonstrated how logistic modeling can supplement standard Cox survival models to enable learning how time variant factors affect survival.

New sagebrush common gardens:

Leveraging a grant applied for and received from the Joint Fire Sciences Program (JFSP) in 2016 and GBNPP resources, we established three common gardens with nearly 2000 plants across an elevation gradient in the 2015 Soda wildfire area (115K ha (250k acres)), using the following 35 seed sources (Figure 1, Table 1):

- Seed sources procured by BLM for aerial seeding of >60.7 ha (150K acres) of the Soda burn area, with sources ranging from the local county to hundreds of kilometers away.
- Seeds collected from large unburnt populations around the perimeter of the Soda Fire and the adjacent Treasure Valley by the Idaho Fish and Game volunteer group with USGS support and taxonomic verification.
- Seeds collected from unburnt relic plants within the burn area, including adjacent (within a km) of the common gardens.

Populations are seeded into the gardens and many were also outplanted (6 month old USFS Lucky Peak Nursery stock).

Additionally, a common garden was established in front of the Jack Wilson building at the National Interagency Fire Center (NIFC, in Boise) with some of the sources identified above, combined with seeds used for previous grow-outs at the Lucky Peak Nursery.



Figure 1. Photos of sagebrush seed sources applied by BLM on the 115K ha (285K acre) Soda Fire, and common gardens established in 2016 for the GBNPP and JFSP research effort. Analyses will combine information on seeding success across the burn area with insights from the common gardens. Elevations range from 914.4-1828.8 m (3000-6000 ft) across the varied topography of the Soda Fire. Our research efforts are closely integrated with the BLM's adaptive management of the burned area, including the monitoring led by the PI for BLM.

Table 1. Populations of big sagebrush used in common gardens on the 2015 Soda Fire. The number of seedlings outplanted per population is shown below. There are five replicate subplots in each garden where seeds of most populations were also sowed.

Seed Source	Collector	Species	Wilson (914.4m)	I95 (1219.2m)	Baltzor (1524m)
11	USGS	ATT/ATW	0	45	0
12	USGS	ATW	0	44	0
13 and 17 combo	USGS	ATW	47	51	51
14	USGS	ATT	0	45	0
16	USGS	ATT	0	45	0
18	USGS	ATT	0	44	0
19	USGS	ATT/ATW	0	40	0
21	USGS	ATT/ATW	0	19	0
22	USGS	ATW	9	18	18
3 and 4 combo	USGS	ATW	51	51	51
8	USGS	ATW	0	32	0
9	USGS	ATT	0	0	0
213	IDFG	ATT/X	0	40	0
216	IDFG	ARAR	51	51	51
217	IDFG	ATT	0	0	0
220	IDFG	ATW	46	33	33
Eagle	IDFG	ATT	0	45	0
Gravel	IDFG	ATW	0	29	0
High Wyoming	IDFG	ATW	0	0	0
1-13-Lot 2 B	BLM	ATT	0	40	0
1349	BLM	ATW	0	40	0
1501	BLM	ATW	0	40	0
1502	BLM	ATW	0	38	0
1550	BLM	ATW	0	40	0
351	BLM	ATW	0	40	0
ARTRT-O-OR 1520	BLM	ATT	0	45	0
ARTR-T-OW	BLM	ATT	0	40	0
ARTR-W-EL	BLM	ATW	0	42	0
ARTRW-N-NHV3	BLM	ATW	0	40	0
ARTRW-N-NHV5	BLM	ATW	0	34	0
ARTR-W-OW	BLM	ATW	0	39	0
ARTRW-TF	BLM	ATW	0	40	0
SIS5143	BLM	ATW	0	40	0
SIS5144	BLM	ATW	0	45	0
SIS5145	BLM	ATW	0	39	0
SIS5146	BLM	ATW	0	43	0
V85956	BLM	ATW	0	40	0
<u>Total</u>			<u>204</u>	<u>1357</u>	<u>204</u>

In Brabec et al. (2016), we report that: 1) Wyoming big sagebrush (*Artemisia tridentata* ssp. *Wyomingensis*) had the most growth and survival, and tetraploid populations had greater survival and height than diploids. Seasonal timing of mortality varied among the subspecies/cytotypes and was related more to minimum temperatures rather than water deficit, 2) Temperatures required to induce ice formation were up to 6° C more negative in 4n-big sagebrush and Wyoming big sagebrush than other subspecies/cytotypes, indicating greater freezing avoidance. In contrast, freezing resistance of photosynthesis varied only 1° C among subspecies/cytotypes,

being greatest in Wyoming big sagebrush and least in the subspecies normally considered most cold-adapted, mountain big sagebrush (*Artemisia tridentata ssp. vaseyana*). A large spectrum of reliance on freezing-avoidance vs. freezing-tolerance was observed and corresponded to differences in post-fire survivorship among subspecies/cytotypes. Differences in water-deficit responses among subspecies/cytotypes were not as strong and did not relate to survival patterns.

We (Brabec et al. 2016) concluded that low-temperature responses are a key axis defining climate adaptation in young sagebrush seedlings and vary more with cytotype than with subspecies, which contrasts the traditional emphases on 1) water limitations to explain establishment in these deserts, and 2) on subspecies in selecting restoration seedlings. These important and novel insights on climate adaptation are critical for seed selection and parameterizing seed transfer zones, and were made possible by incorporating weather data with survival statistics.

Management Applications and/or Seed Production Guidelines

Our combining of success of seedlings done by land managers where seed sources can be traced along with side-by-side comparisons of performance of the seed sources in common gardens (Fig 1, Table 1) is a powerful way to demonstrate if and how seed source variation matters for post-fire seeding success. In the case of the Soda gardens and monitoring, all seed sources were apparently within the correct provisional seed zone, although the seeded elevations ranged 914.4m and sources were from a wide range of locations and thus climates within the transfer zone.

Furthermore, our data on bluebunch wheatgrass can inform on fundamental differences in adaptation among cultivars compared to natural populations. Analyses of all gardens go beyond what can be learned from measurements of growth and survival alone to provide the physiological evidence the importance of the specific climate variables that generate the biggest variation among populations.

Finally, many plantings or seedlings in the Great Basin fail with no lessons learned, but the survival/weather statistics used here could be applied to any restoration plantings to enable adaptive management.

Presentations

Germino MJ. 2016. Ecophysiology Studies on Native Plant Common Gardens. Joint meeting of the Great Basin Native Plant Project and Great Basin Chapter of Society for Ecological Restoration; April 11-12; Boise ID.

Lazarus B, Germino MJ, Kilkenny F, et al. 2016. Low-Temperature Responses and Thresholds in Bluebunch Wheatgrass. Joint meeting of the Great Basin Native Plant Project and Great Basin Chapter of Society for Ecological Restoration; April 11-12; Boise ID.

Brabec M, Germino MJ, Richardson B. 2016. Low-Temperature Responses and Thresholds in Big Sagebrush. Joint meeting of the Great Basin Native Plant Project and Great Basin Chapter of Society for Ecological Restoration; April 11-12; Boise ID.

Davidson B, Germino MJ, Kilkenny F, et al. 2016. Drought Responses and Thresholds in Bluebunch Wheatgrass. Joint meeting of the Great Basin Native Plant Project and Great Basin Chapter of Society for Ecological Restoration; April 11-12; Boise ID.

Brabec M, Germino MJ. 2016. Weather effects on sagebrush establishment. Annual Meeting of Society for Rangeland Management; January 31 - February 4. Corpus Cristi TX.

Publications

Brabec, M.; Germino, M.; Richardson, B. 2016. Climate adaption and post-fire restoration of a foundational perennial in cold desert: insights from intraspecific variation in response to weather. *Journal of Applied Ecology* 54:293-302

Chaney, L.; Richardson, B. A.; Germino, M. J. 2016. Climate drives adaptive genetic responses associated with survival in big sagebrush (*Artemisia tridentata*). *Evolutionary Applications*.

Additional Products

- Co-organized the Joint meeting of the Great Basin Native Plant Project and Great Basin Chapter of Society for Ecological Restoration. Boise ID April 11-12; organized a special session entitled “Ecophysiological Studies on Native Plant Gardens for the meeting and organized and led a field tour of the Soda Fire.
- Received a grant from the Joint Fire Sciences Program to complement GBNPP efforts
- Gave many presentations to the BLM and participated in discussions
- Helped organize of the “All Hands/All Lands” meeting of Great Basin Consortium meeting (GBC#5), February 2016 in Salt Lake City.
- Quoted or featured in three articles on the topics of GBNPP common gardens of big sagebrush, sagebrush seeding, and climate change in rangelands, all through Associated Press, and disseminated in the Idaho Statesman newspaper (main paper for Boise ID) and others nationally.
- Serving on several committees regarding native plant materials for restoration for the Department of Interior secretarial order #3336. Co-led the program development for the GBC6 meeting (held in 2017).

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

Project Agreement No. 14-IA-11221632-013

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Project Description

Introduction

Native plant species are critical for wildlife habitat, livestock grazing, soil stabilization, and ecosystem function in the Western U.S. and the Great Basin. Current germplasm releases are often utilized without regard to their genetic suitability and adaptation to a given area. For this project, seed zones that match genetic variation in adaptive traits with source climates are developed. These zones guide seed source management decisions, ensure restoration with adapted plant material, and promote biodiversity needed for future natural selection with climate change. We have produced and published seed zones for numerous species including tapertip

onion (*Allium acuminatum* Hook.), Indian ricegrass (*Achnatherum hymenoides*), bluebunch wheatgrass (*Pseudoroegneria spicata*), Sandberg bluegrass (*Poa secunda*), and basin wildrye (*Leymus cinereus*). Seed zones for Thurber's needlegrass (*Achnatherum thurberianum*) have also been developed and a publication accepted in *Rangeland Ecology and Management*. In 2016, evaluations of taxonomy and adaptive plant traits were completed on 75 diverse populations of sulfur-flowered buckwheat with a view to determining adaptation to local climates and seed source recommendations for restoration projects.

Objectives

Determine and utilize the relationship between species variability in adaptive plant traits and seed source climates to develop seed transfer guidelines for key restoration species. Specifically:

- Collect populations of key Great Basin species and establish common garden studies quantifying adaptive genetic variation associated with phenology, production, and morphology traits.
- Uncover how plant trait variation relates to seed source climates and adaption,
- Develop seed zones based on genetic variation and source climates ensuring plant materials for restoration are adapted, ecologically suitable, and diverse.

Sulfur-flowered buckwheat - Sulfur-flowered buckwheat is an integral part of the Great Basin native plant community. Its seeds, leaves, and associated insects are important food sources for many small mammals and birds, including sage grouse. It also attracts many native bees and other pollinators important to sage-steppe communities (Young-Mathews, 2012). Yet a comprehensive determination of genetic variation in relation to climate has not been completed. Collection of sulfur-flowered buckwheat was completed by the Western Regional Plant Introduction Station (WRPIS) in 2012 resulting in 21 accessions and there has also been ongoing collection through the Bureau of Land Management (BLM) Seeds of Success (SOS) program (Figs 1 and 2). As a result, seeds from the WRPIS and SOS collections were used to grow 75 populations of sulfur-flowered buckwheat in the greenhouse in 2014.



Figure 1. Collecting sulfur-flowered buckwheat in the Great Basin, 2012

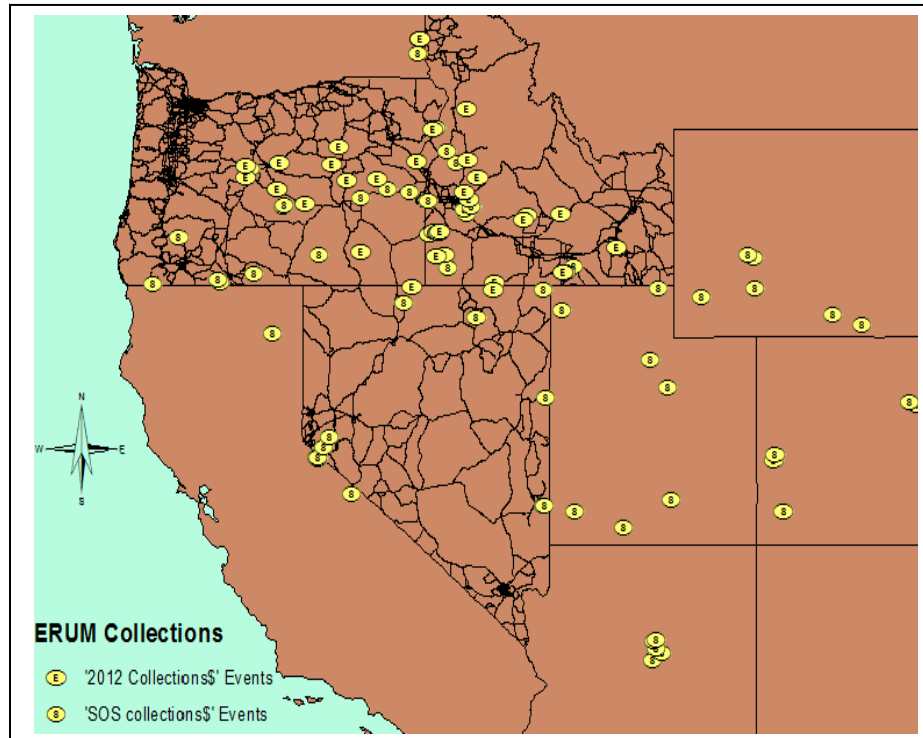


Figure 2. Collection locations of sulfur-flowered buckwheat populations established in a common garden at Pullman, WA.

In the fall of 2014, these populations were transplanted to a common garden at the WRPIS farm at Pullman, WA. Transplants established in 2015 and comprehensive data on adaptive plant traits and taxonomic variety were completed in 2016. Analyses of data collected in 2016 revealed strong genetic variation among population locations in adaptive phenology, production, and morphology traits (Table 1).

Table 1. Summary of analyses of variance of 75 sulfur-flowered buckwheat populations collected in the Great Basin and grown in a common garden at Pullman, WA, 2016.

Trait†	Population location	
Production	F-value	P-value
Survival, percent	2.68	<.0001
Umbel number, per plant	3.35	<.0001
Basal area, cm ²	8.53	<.0001
Phenology		
Bolting, day of year	9.37	<.0001
Blooming, day of year	54.15	<.0001
Maturity, day of year	40.84	<.0001
Morphology		
Stem length, cm	8.32	<.0001
Umbel length, cm	15.63	<.0001
Umbel width, cm	18.99	<.0001
Leaf area, cm ²	17.08	<.0001
Leaf weight, g	13.62	<.0001
Leaf aspect, length to width	4.99	<.0001
Petiole length, cm	6.92	<.0001
Specific leaf area, cm ² per g	5.56	<.0001

†Harvest mass, seed weight, and seed number are in process

We collaborated with Dr. Steve Love (University of Idaho) in a taxonomic evaluation of the study populations. Sulfur-flowered buckwheat varieties are extremely variable in morphological expression, especially if populations exist in geographical isolation at different elevations and habitats. Most, if not all varieties, will freely intercross. Where varieties share habitat locations, hybrid swarms will occur and intermediate types will be present. Since Dr. Love has previously observed and keyed most of the varieties in the Pullman common garden, he was able to identify most populations to variety with high to reasonably high confidence (Table 2). There was a range of varieties with *ellipticum* by far the largest group (Table 2). Still, given the complexity, identification of some populations were less certain and 3 were identified as parsnip-flower buckwheat (*Eriogonum heracleoides* Nutt.). Collection of evaluation data will continue in 2017. Taxonomic variety, source climate, and genetic variation will all be considered in seed source recommendations for restoration and seed zones.

Table 2. Taxonomic determinations for sulfur-flowered buckwheat collected in the Great Basin and growing in a common garden at Pullman, WA

†Species	Botanical variety	Number in common garden
<i>Eriogonum umbellatum</i>	<i>aureum</i>	5
<i>Eriogonum umbellatum</i>	<i>cognatum</i>	1
<i>Eriogonum umbellatum</i>	<i>desereticum</i>	1
<i>Eriogonum umbellatum</i>	<i>dichrocephalum</i>	4
<i>Eriogonum umbellatum</i>	<i>ellipticum</i>	23
<i>Eriogonum umbellatum</i>	<i>majus</i>	5
<i>Eriogonum umbellatum</i>	<i>modocense</i>	9
<i>Eriogonum umbellatum</i>	<i>nevadense</i>	6
<i>Eriogonum umbellatum</i>	<i>polyanthum</i>	1
<i>Eriogonum umbellatum</i>	<i>porteri</i>	1
<i>Eriogonum umbellatum</i>	<i>stragalum</i>	6
<i>Eriogonum umbellatum</i>	<i>subaridum</i>	5
<i>Eriogonum umbellatum</i>	<i>umbellatum</i>	2
<i>Eriogonum umbellatum</i>	<i>mixed, uncertain</i>	1
<i>Eriogonum heracleoides</i>	<i>heracleoides</i>	3
	total	73

†Taxonomic determinations were made by Dr. Steve Love, University of Idaho

Management Applications and Seed Production Guidelines

- Maps visualizing the interaction of genetic variability and climate are being utilized to guide seed sourcing for restoration projects in the Great Basin.
- 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 biodiversity needed for sustainable restoration and genetic conservation.
- Collections representing each seed zone for a given species should be released, grown, and used for ongoing restoration projects.

Publications

Johnson, R.C.; Vance-Borland, K. 2016. Linking Genetic Variation in Adaptive Plant Traits to Climate in Tetraploid and Octoploid Basin Wildrye [*Leymus cinereus*(Scribn. & Merr.) A. Love] in the Western U.S. PLoS ONE 11(2): e0148982. doi:10.1371/journal.pone.0148982

Johnson R.C.; Leger, EA; Vance-Borland, Ken. In press. Genecology of Thurber's needlegrass (*Achnatherum thurberianum* (Piper) Barkworth) in the Western U.S. (Accepted Rangeland Ecology and Management 9 January 2017)

Presentations

“Double Trouble: Ploidy, Adaptation, and Seed Zones for Basin Wildrye” The Great Basin Native Plant Project & the Society for Ecological Restoration meetings; 2016 April 11; Boise ID.

Additional Products

- Seed zones to ensure that seed sources for restoration are adapted and ecologically suitable.
- 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.
- Distribution of seeds of native species for research and development through the NPGS.

References

Johnson, R. C.; Cashman, M. J.; Vance-Borland, K. 2012. Genecology and seed zones for Indian Ricegrass across the Southwest USA. *Rangeland Ecology and Management* 65: 523-532.

Johnson, R. C.; Hellier, B. C.; Vance-Borland, K. W. 2013. Genecology and seed zones for tapertip onion in the U.S. Great Basin. *Botany* 91: 686-694.

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.

Johnson, R.C.; Vance-Borland, K. 2016. Linking Genetic Variation in Adaptive Plant Traits to Climate in Tetraploid and Octoploid Basin Wildrye [*Leymus cinereus*(Scribn. & Merr.) A. Love] in the Western U.S. *PLoS ONE* 11(2): e0148982. doi:10.1371/journal.pone.0148982

St. Clair, J. Bradley; Kilkenny, Francis F; Johnson, R.C.; Shaw, Nancy L; Weaver, George. 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.

Young-Mathews, A. 2012. Plant fact sheet for sulphur-flower buckwheat (*Eriogonum umbellatum*). USDA-Natural Resources Conservation Service, Plant Materials Center, Corvallis, OR.

Project Title Climate Niche Comparisons of Cold Desert Forbs Using Herbarium Records

Project Agreement No. 10-CR-11221632-174

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Project Description

Objectives

There is increasing interest in using native forbs for the restoration of degraded sagebrush communities that lack a native understory. Currently, there is little information available regarding the climate niches of many cold-desert forbs. This makes it challenging to design appropriate species mixes, or successfully locate and collect seeds from populations of herbaceous species growing in areas with similar climatic characteristics to areas in need of restoration.

Climate is a strong force shaping the distribution of plant species, with both spatial and inter-annual variation in climate characteristics influencing the geographic range where a species can grow. In arid environments, plant species may be especially sensitive to variability in the timing and quantity of precipitation, and may partition their use of this resource as a way to avoid competition and maintain species coexistence (Chesson et al. 2004). Because forb seeds are typically expensive, it is beneficial to narrowly define suitable habitat to avoid seeding in inappropriate habitats. This research aims to identify the climate niches of ten common, arid land forb species, with the goal of providing land managers with information that will aid in the selection of appropriate restoration species, based on the current and future environmental characteristics at the location being restored.

Methods

We used herbarium records for ten Great Basin forbs in combination with bioclimatic variables (Booth et al. 1989) created using PRISM data (Daly et al. 2008) for the past 64 years (Table 1) to model the potential habitat of our focal species using Maxent modeling. Focal species include bigflower agoseris (*Agoseris grandiflora*, AGGR), rough eyelashweed (*Blepharipappus scaber*,

BLSC), Douglas's duskymaiden (*Chaenactis douglasii*, CHDO), maiden blue eyed Mary (*Collinsia parviflora*, COPA), limestone hawksbeard (*Crepis intermedia*, CRIN), wingnut cryptantha (*Cryptantha pterocarya*, CRPT), shy gilia (*Gilia inconspicua*, GIIN), whitestem blazingstar (*Mentzelia albicaulis*, MEAL), slender phlox (*Microsteris gracilis*, MIGR), and silverleaf phacelia (*Phacelia hastata*, PHHA).

We obtained location information for our focal species from herbarium records (1950-present) downloaded from three websites: The Intermountain Region Herbarium Network, The Consortium of California Herbaria, and the Burke Museum herbarium at the University of Washington. We focused the extent of our study area on the western United States, as many of our focal species are confined to this region. For each species, we performed geographic filtering of the occurrence points by removing points within a 20 km buffer of another point included in the dataset. The number of records for each species ranged from 80 to 568, with a mean of 357.

We acquired monthly temperature and precipitation data from PRISM for the western United States from 1950 – 2014 (Daly et al. 2008). We then used ArcMap 10.1 software and map layers of monthly precipitation (mm), minimum temperature (C), and maximum temperature (C) that were downscaled to a 500 m² grid size to extract precipitation and temperature data for each occurrence point and month from 1950 to 2014. Using Pearson's correlation analysis, we selected a subset of ten variables with a correlation-coefficient of no greater than ± 0.70 to include in our model. Final variables included: mean maximum temperature, mean minimum temperature, temperature range, annual precipitation, summer precipitation, precipitation seasonality, fraction of AET from precipitation, soil water balance, AET:CWD, and spring water availability.

Table 1. Potential climate variables used to produce the ecological niche models for each of our focal species. All water-based variables are in units of millimeters and all temperature-based variables are in units of degrees Celsius.

Variable	Biological Relevance
AET - annual actual evapo-transpiration ^{1, 2}	Proxy for productivity
CWD - annual climate water deficit ^{1, 2}	Proxy for drought stress
PET - annual potential evapo-transpiration ^{1, 2}	Climatic demand for water, excluding water availability
SWB - annual soil water balance ^{1, 2}	Quantity of water stored in the soil from one month to the next
WS - annual water supply ^{1, 2}	Total water supply for the year
Coefficient of variation of annual precipitation	Seasonality of precipitation
AET:CWD ratio	Relative CWD; values > 1 are more mesic, values < 1 are more xeric
PET:AET ratio	Relative drought indicator; values > 1 indicate an unmet demand for water
SWB:AET ratio	Values > 1 indicate more soil water storage than AET
WS:AET ratio	Values > 1 indicate more water for soil water storage, runoff, or deep percolation than used in AET
Positive difference between AET and SWB	Fraction of AET from month's precipitation, not from soil water
Positive difference between WS and the greater of AET or SWB	Cumulative water available for runoff or deep percolation
Spring ratio of WS and the greater of AET or SWB	Spring water available for runoff or deep percolation
Precipitation - total and seasonal ^{2, 4}	¹ See Dilts et al. 2015 for method of calculation ² Summed for all months ³ Average for all months ⁴ Winter (Dec, Jan, Feb), Spring (Mar, Apr, May), Summer (Jun, Jul, Aug), Fall (Sep, Oct, Nov)
Temperature range ³	
Minimum temperature - total and seasonal ^{3, 4}	
Maximum temperature - total and seasonal ^{3, 4}	

We used Maxent (version 3.3.3k, Phillips et al. 2006) to identify the best model or models of the potential habitat for our focal species across the western United States, accounting for unequal sampling with a bias correction. We randomly partitioned the occurrence points for each species into a set used for model training (65%) and a set used for model validation (35%). Model selection involved two steps. First, we performed species-specific model optimization by adjusting the regularization parameter (1-5) and the Maxent feature types, using factorial combinations of linear, quadratic, product, and threshold feature types, or the hinge feature type on its own. We selected the best model or models for each species using Akaike's information criterion (AIC) score, calculated using ENMTools (Warren et al. 2010). We used the permutation importance and the ecological response curves from the Maxent output for the top model for each species to identify the climate variables most predictive of the distribution of our focal species (Phillips and Dudik 2008).

We also used the monthly temperature and precipitation data obtained from PRISM to estimate measures of climate mean and variability (inter-annual and across the geographic range) for each range. The coefficient of variation (CV) was used as a measure of climate variability. In order to account for differences in the number of herbarium records available for each species, we calculated an unbiased CV using the methods of Abdi (2010), as follows:

$$CV_{\text{unbiased}} = \left(1 + \frac{1}{4*N}\right) * CV$$

Where N is the number of samples from the group being measured.

We analyzed four variables of interest: mean annual precipitation (mm), mean summer precipitation (mm), mean annual maximum temperature (C), and mean annual minimum temperature (C), asking if there were significant differences between the mean or variation in climate conditions occupied by each of the species.

Results and Discussion

Based on our habitat models, a unique assemblage of climate variables was predictive of the potential habitat for each of our species (Table 2). Species differed in important variables as well as in the amount variables contributed to predicting their habitat (Table 2).

Table 2. Results of the permutation importance analysis performed in MaxEnt, indicating the percentage of variable contribution to the ecological niche model for A) perennial and B) annual species. Values can range from zero to 100, with values greater than eight presented in bold.

A)	Variable	<i>Agoseris grandiflora</i>	<i>Chaenactis douglasii</i>	<i>Crepis intermedia</i>	<i>Phacelia hastata</i>
	Maximum Temperature	0	22.9	24.1	56.7
	Minimum Temperature	5.5	12.3	22.4	20.7
	Temperature Range	0.1	0	0	3.6
	Annual Precipitation	2.3	1.3	5.4	0
	Summer Precipitation	37.7	32.4	46.1	6.5
	Precipitation Seasonality	1.5	18.2	1.1	1.5
	Fraction of AET from Precipitation	0	9.8	0	11
	Soil Water Balance	52.5	0.7	0.9	0
	AET:CWD	0	0	0	0
	Spring Water Availability	0.5	2.3	0	0

B)	Variable	<i>Blepharipappus scaber</i>	<i>Collinsia parviflora</i>	<i>Cryptantha pterocarya</i>	<i>Gilia inconsipua</i>	<i>Mentzelia albicaulis</i>	<i>Microsteris gracilis</i>
	Maximum Temperature	7.1	7.6	0.2	0	11.9	2.4
	Minimum Temperature	24.3	3.8	67	35.7	3.4	3.4
	Temperature Range	0	0.2	4	2.6	0	11.3
	Annual Precipitation	2.8	7.4	11.4	0	14.1	0
	Summer Precipitation	47.7	11.5	8.6	28.2	45.3	0
	Precipitation Seasonality	0.8	26.1	2.3	19.7	3.5	0
	Fraction of AET from Precipitation	10.8	14.4	3.4	4.6	0	0
	Soil Water Balance	3.2	24.9	0	6.8	21.7	78.9
	AET:CWD	0	0.2	0	0	0	0
	Spring Water Availability	3.2	3.9	3	2.3	0	3.9

The relationship between each of the model variables and the level of predicted habitat suitability also varied for each species (Figure 1 and Figure 2).

GENETICS AND CLIMATE CHANGE

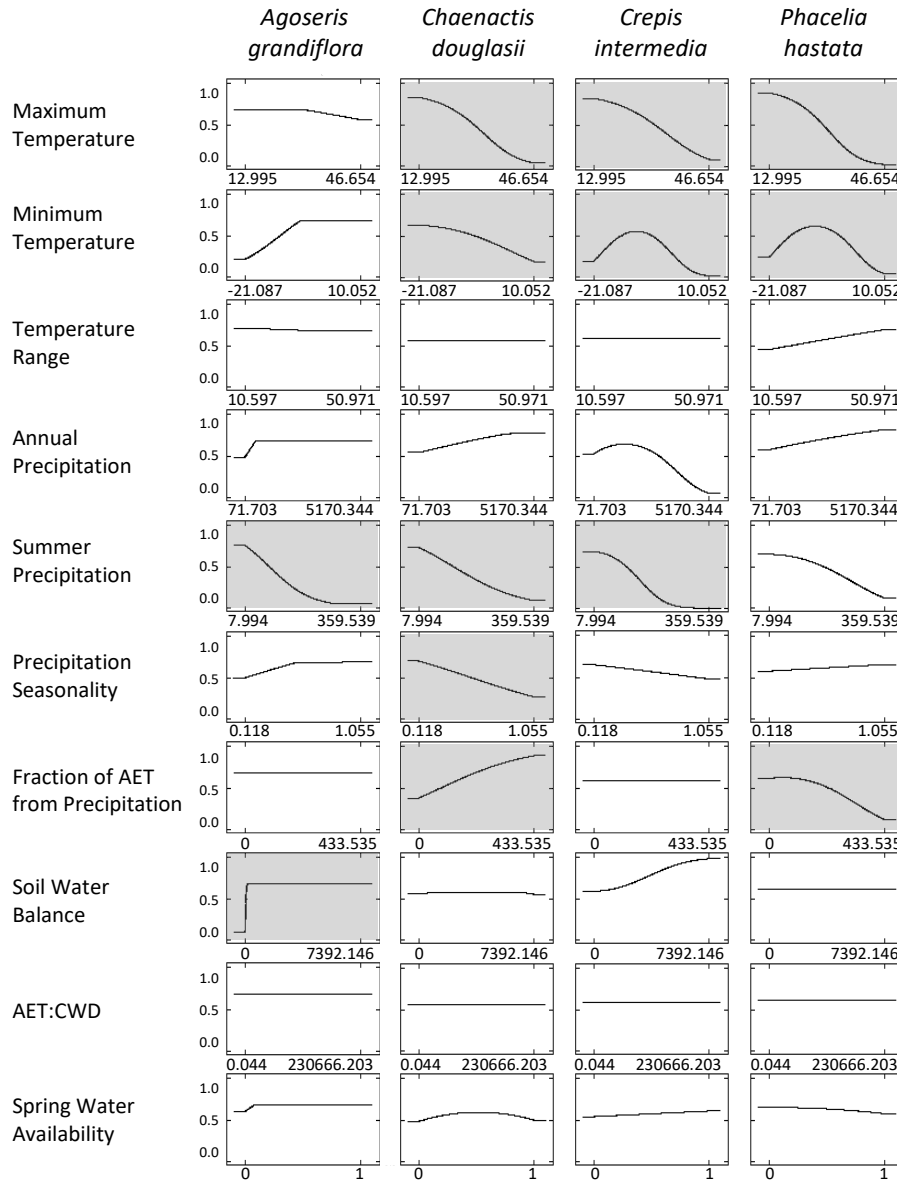


Figure 1. These ecological response curves show the relationship between each environmental variable and predicted habitat suitability for four perennial species. The x-axis represents the range of that variable across the study area (Western U.S.), with units described in Table 1, and the y-axis represents the predicted habitat suitability ranging from 0 (unsuitable) to 1 (suitable). Gray boxes indicate variables with a variable contribution greater than eight to predicting suitable habitat.

GENETICS AND CLIMATE CHANGE

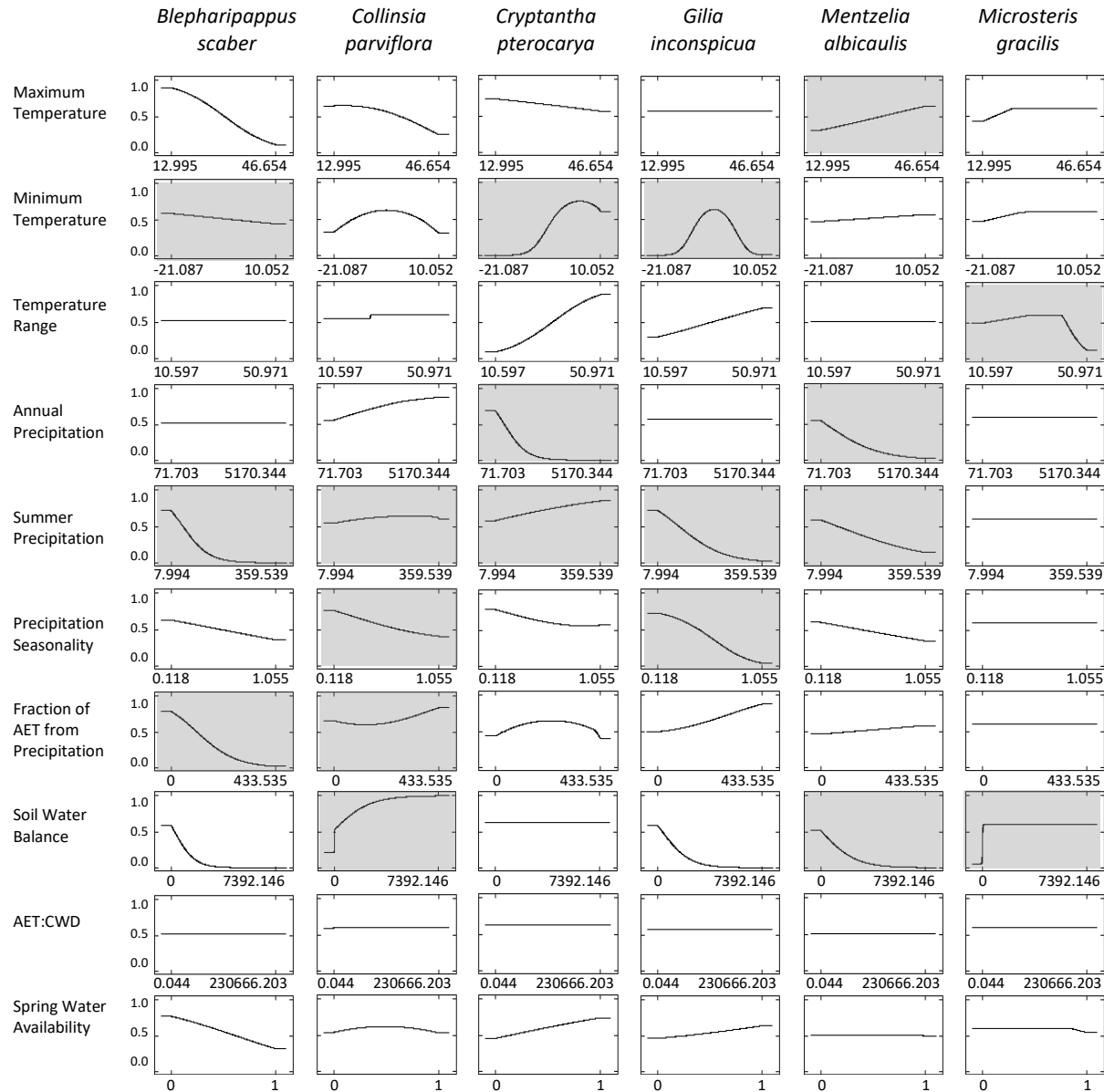


Figure 2. These ecological response curves show the relationship between the environmental variable and the predicted habitat suitability for six annual species. The x-axis for each variable represents the range of that variable across the study area (Western U.S.), with units as described in Table 1, and the y-axis represents the predicted habitat suitability ranging from 0 (unsuitable) to 1 (suitable). Gray boxes indicate variables with a variable contribution greater than eight to predicting suitable habitat.

In addition to the differences in the predicted climate niches of our species, they also demonstrated significant differences in both mean values and spatial (across their geographic range) and temporal (inter-annual) variability in annual precipitation and summer precipitation (Figure 3 and Figure 4).

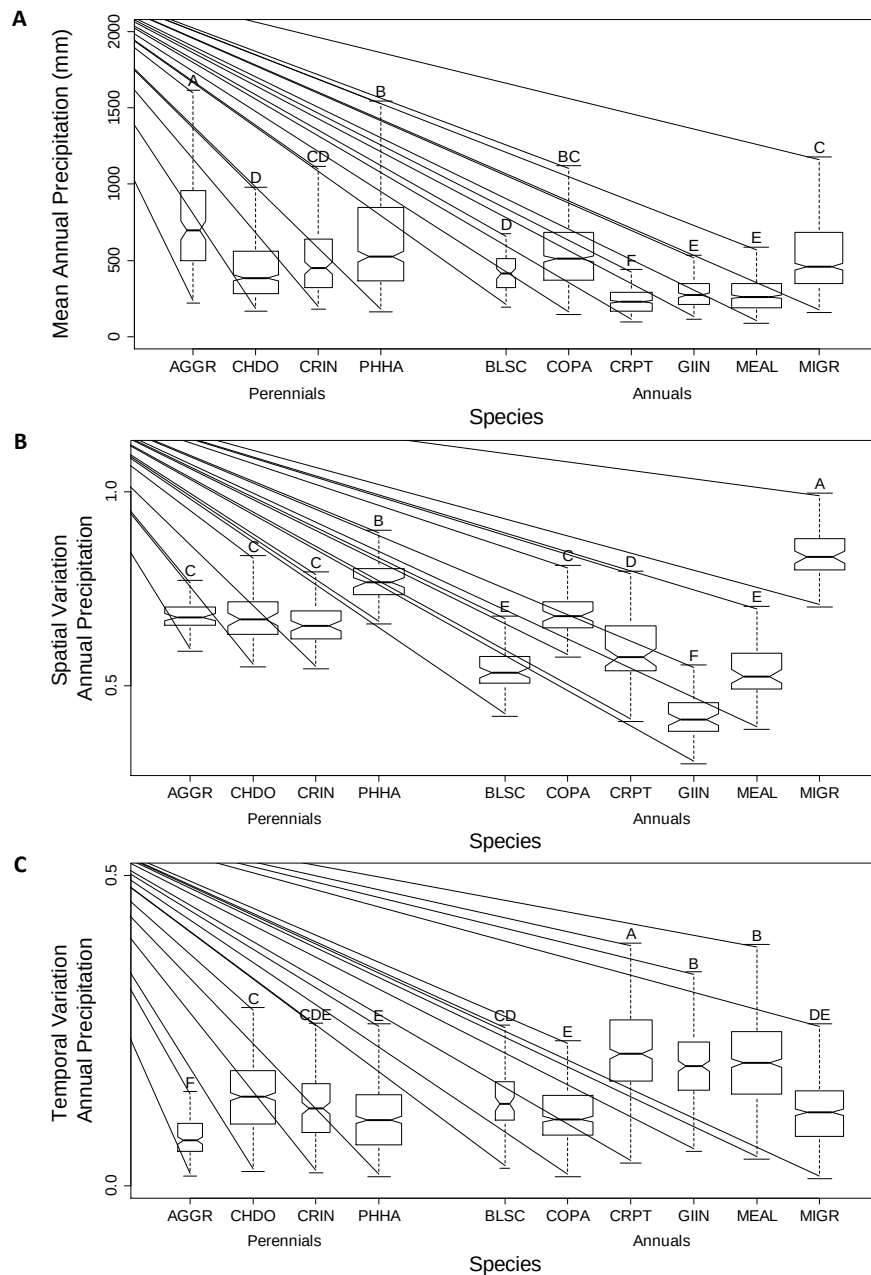


Figure 3. Boxplots of mean (A), spatial variation (B), and temporal variation (C) of annual precipitation. Variation is measured using the coefficient of variation (CV) for total annual precipitation for each year. Note the different y-axis scales. Spatial variation is measured across the collection locations for each species from 1950-2014 and temporal variation is measured across all years from 1950-2014 at each location. Letters that appear above each boxplot indicate the results of Tukey's tests that differentiate significant differences in means between species by assigning them a different letter. See Methods for a guide to plant species acronyms.

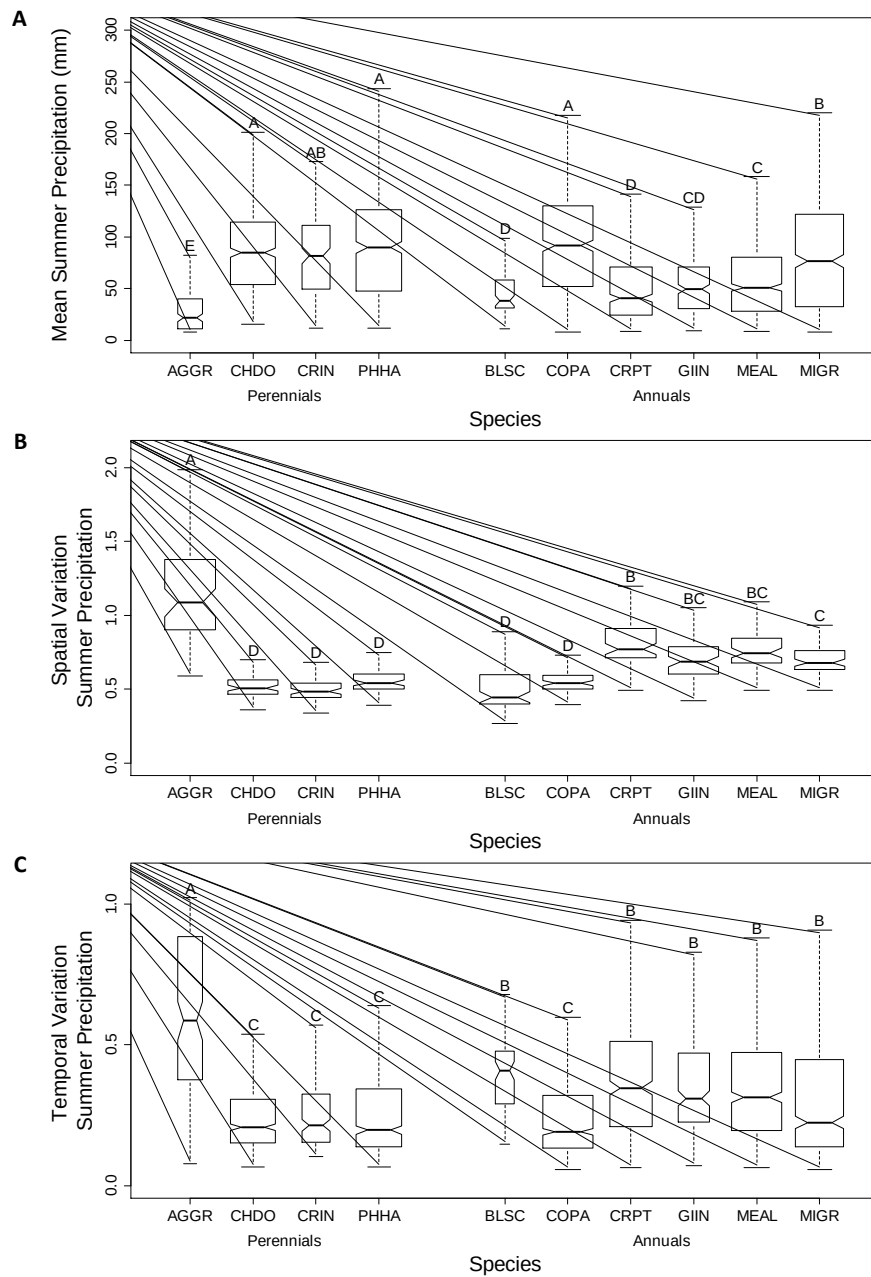


Figure 4. Boxplots of mean (A), spatial variation (B), and temporal variation (C) of summer precipitation. Variation is measured using the coefficient of variation (CV) for total summer precipitation for each year. Note the different y-axis scales. Spatial variation is measured across the collection locations (1950-2014) and temporal variation is variability measured across years at each location. Letters that appear above each boxplot indicate the results of Tukey's tests that differentiate significant differences in means between species by assigning them a different letter. See Methods for a guide to plant species acronyms.

Species also exhibited differences in the mean and variability of minimum annual temperature and maximum annual temperature in areas where they grow (data not shown), although the differences were less extreme than those exhibited by annual and summer precipitation.

These results demonstrate that herbarium records can be used to approximate climate preferences of Great Basin forbs. Although our study species displayed some overlap in the geographic areas where they grow (Figure 5 and Figure 6), they appear to possess different climate niches. Field collections and common garden studies could be used to verify these results, and understand whether species with larger climate niches are persisting in disparate areas through phenotypic plasticity, i.e. responding to local conditions by adaptive changes in phenotypes, or through local adaptation, i.e. populations from different climate areas are adapted to local conditions. Understanding the causes behind these species-level differences in range-wide spatial and temporal environmental variation could indicate which species may tolerate future climate variability better than others.

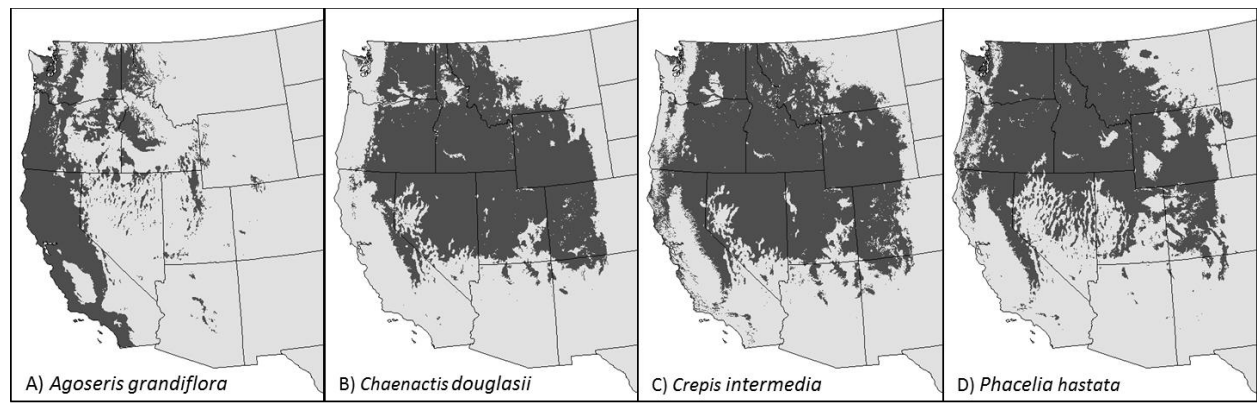


Figure 5. Maps of potential range for perennial species, including: A) bigflower agoseris, B) Douglas’s duskymaiden C) limestone hawksbeard, and D) silverleaf hastata. These maps represent areas with high environmental suitability and were created using Maxent modeling with the herbarium records and our collection of 29 environmental variables.

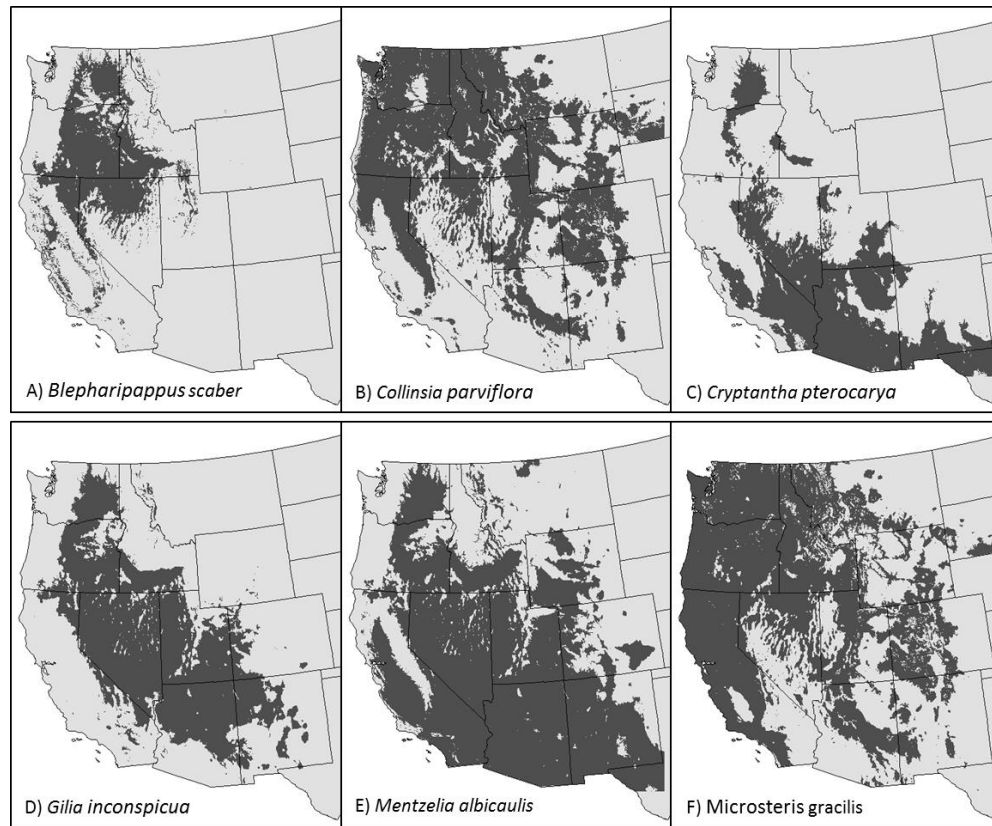


Figure 6. Maps of potential range for annual species, including: A) rough eyelashweed, B) maiden blue eyed Mary, C) wingnut cryptantha, D) shy gilia, E) whitestem blazingstar, and F) slender phlox. These maps represent areas with high environmental suitability and were created using Maxent modeling with the herbarium records and our collection 29 environmental variables.

Management Applications

Here we demonstrate that herbarium records can be used to create estimated habitat maps for species that lack common garden information. Land managers can use the results of this research to select appropriate restoration species based on the environmental conditions at the location being restored. For example, in our study, we found that bigflower agoseris grows in areas with soil that retains water and receives high amounts of annual rainfall, with little rain falling in the summer. In contrast, wingnut crypantha grows in areas with higher minimum temperatures and low levels of annual rainfall, with some summer rain. This type of information can be used to maximize the chances of restoration success, especially important for species where seed availability is limited. Additionally, species that have relatively little spatial and/or temporal variation in environmental characteristics may represent species that are specialized for growing in particular environmental conditions, and this should be considered when incorporating them into restoration protocols.

Presentations

Barga, Sarah; Dilts, Tom; Leger, Elizabeth A. 20 November 16. Climate niche comparisons using herbarium records. Oral presentation at the Ecology, Evolution, and Conservation Biology Program Ecolunch, University of Nevada - Reno, Reno, NV

Publications

Barga, Sarah; Dilts, Tom; Leger, Elizabeth A. In prep: submission expected Jan 2016. Climate niche comparisons using herbarium records for arid land forbs: how spatial climate data can inform the selection of restoration species. *Diversity and Distributions*.

References:

Abdi, H. 2010. Coefficient of variation. *Encyclopedia of research design*: 169-171.

Booth, T.H.; Searle, SD; Boland, DJ. 1989. Bioclimatic analysis to assist provenance selection for trials. *New forests* 3(3): 225-234.

Chesson, P.; Gebauer, R.L.; Schwinning, S.; Huntly, N.; Wiegand, K.; Ernest, M.S.; Sher, A.; Novoplansky, A.; Weltzin, J.F. 2004. Resource pulses, species interactions, and diversity maintenance in arid and semi-arid environments. *Oecologia* 141(2): 236-253.

Daly, Christopher; Halbleib, Michael; Smith, Joseph I; Gibson, Wayne P; Doggett, Matthew K; Taylor, George H; Curtis, Jan; Pasteris, Phillip P. 2008. Physiographically sensitive mapping of climatological temperature and precipitation across the conterminous United States. *International Journal of Climatology* 28(15): 2031-2064.

Dilts, Tom E.; Weisberg, Peter J.; Dencker, Camie M.; Chambers, Jeanne C. 2015. Functionally relevant climate variables for arid lands: a climate water deficit approach for modeling desert shrub distributions. *Journal of Biogeography* 42(10): 1986-1997.

Phillips, SJ. 2006. A brief tutorial on Maxent. AT & T Research. Available at: <http://www.cs.princeton.edu/~schapire/maxent/tutorial/tutorial.doc>

Phillips, S. J.; Dudík, M. 2008. Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. *Ecography* 31(2), 161-175.

Warren, Dan L; Glor, Richard E.; Turelli, Michael. 2010. ENMTools: a toolbox for comparative studies of environmental niche models. *Ecography* 33: 607-611.

Project Title Climate Change Effects on Native Plant Establishment and Annual Grass Invasion: Implications for Restoration

Project Agreement No. 15-IA-11221632-202

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Project Description

Introduction

Predicted climate changes in the Great Basin include increased temperature and altered precipitation, which are likely to increase wildfire and annual invasive grasses (Abatzaglou and Kolden 2011). Although research exists on the effects of elevated CO₂ on cheatgrass (Ziska et al. 2005) and red brome (Smith et al. 2000; Nagel et al. 2004), little is known about how warming or drought may affect either invasive grass. Red brome has been found to be as cold tolerant as cheatgrass but does not survive rapid temperature drops (Bykova and Sage 2012). Considering that red brome is currently dominant in warm deserts and sensitive to drastic temperature drops, increased temperatures in the cold desert, Great Basin, may result in further invasion. When growing individually, preliminary results found that drought and warming reduced cheatgrass emergence, specific leaf area, and biomass to a greater extent than squirreltail (*Elymus elymoides*) (Newingham et al. 2015); however, we do not know how this will affect plant competition.

Variable effects of altered climate may result in shifts in competitive abilities between native and invasive species. Previous studies have explored native species that may be resistant to invasion by cheatgrass (Leger 2008; Uselman et al. 2015) and red brome (Abella et al. 2012). These studies suggest that early seral natives (*Poa* and *Elymus* grasses for cheatgrass and early seral forbs for red brome) may be effective competitors. However, little is known about how these native species may perform under altered climate. Additionally, there have been no studies examining the potential competitiveness of sixweeks fescue (*Vulpia octoflora*), which is an early season, annual native, with cheatgrass. Although there are limited studies on competitive interactions between sixweeks fescue and red brome, a few studies evaluated the effects of elevated CO₂ (Nagel et al. 2004) and altered resource conditions (DeFalco et al. 2003) on these

two species. No studies have been conducted on the effects of precipitation and temperature on sixweeks fescue – red brome or sixweeks fescue – cheatgrass interactions to our knowledge.

Objectives

In a field experiment, we will:

- Determine the effects of warming and drought on invasive and native plant emergence, growth, and reproduction.
- Investigate what native species mixtures may compete with cheatgrass or red brome in future climate.

Methods

In a field experiment, we will examine the effects of increased temperature and altered precipitation on native and invasive plant growth, reproduction, and community dynamics. In field plots, we will establish three- 3x3 m plots with the following four treatments: control, warming, drought, and warming + drought (12 plots total). Passive warming chambers will be constructed to increase soil temperatures approximately 5°C. Rainout shelters will be constructed to reduce precipitation by 50%.

We will plant eight different seed treatments into 15x15 cm plots underneath each chamber/shelter; each treatment will have two subplots for a total of 16 plots in each chamber/shelter. We will use native species that occur at the Wyoming big sagebrush/mountain big sagebrush ecotone. Seed will be obtained from the BLM, commercial growers such as Benson Farms, and/or the Malheur Experiment Station. We will attempt to obtain species from similar seed zones to the greatest extent possible and avoid cultivars. Native species include: 1) native perennial grasses (*Poa secunda*; POSE / *Elymus elymoides*; ELEL5) 2) native annual grass (*Vulpia octoflora*; VUOC), and forbs (*Achillea millefolium*; ACMI2 / *Machaeranthera canescens*; MACA2). Native species will be planted with either of two invasive annual grasses: *Bromus tectorum* (BRTE) or *Bromus rubens* (BRRU2). *Poa secunda* and *Elymus elymoides* were chosen due to their competitive ability with *Bromus tectorum*, *Vulpia octoflora* is in a similar functional group to the invasive *Bromus* species, and the two forbs are adequately produced plant materials that are both competitive with *Bromus*.

Seeding treatments will include the following: 1) POSE-forbs-BRTE, 2) ELEL5-forbs-BRTE, 3) VUOC-forbs-BRTE, 4) POSE-forbs- BRRU2, 5) ELEL5-forbs- BRRU2, 6) VUOC-forbs- BRRU2, 7) BRTE alone, and 8) BRRU2 alone. Species mixtures will be planted in grids to track individual plants and randomized within subplot and plot. For each species, we will measure plant emergence, height, specific leaf area, biomass, reproduction, $\delta^{13}\text{C}$, $\delta^{15}\text{N}$, and C:N. Results will be analyzed in ANOVAs; dependent variables will include temperature and precipitation as fixed factors.

Results and Discussion

Due to a lack of adequate sites the previous year, we are still selecting an experimental site. We have eliminated two potential sites; however, we have identified the Virginia Fire Complex and the Red Rock area north of Reno as having potential sites. We have received GIS information from the Carson City Bureau of Land Management (BLM) for the Virginia Fire Complex and are working with them on site selection. We have collected cheatgrass and red brome seed from

various sites in Nevada. We are corresponding with the Ely BLM and associated seed warehouse for native seed.

Previous experimental studies (Suazo et al. 2015) revealed that the rainout shelters adequately reduced precipitation; however, the passive warming chambers only increased average minimum air temperatures by 0.6° C and maximum air temperatures by 1.4° C rather than the target of 3-5° C warming. Original warming chambers consisted of a wood frame with plastic slats on top that allowed precipitation in the plot (Figure 1). Control plots had only the wood framing material. In efforts to increase the amount of experimental warming, we designed alternative passive warming chambers. The new designs included control (Figure 2), 'clear' (Figure 3) and 'solar' (Figure 4) chambers. Clear chambers were framed with corrugated Plexiglas on all four sides of the frame. Solar chambers were framed with Plexiglas on the east, south, and west panels, while the north panel was a solar reflective material.



Figure 1. Original frame used in Suazo et al. 2015.



Figure 2. Control frame with soil moisture & temperature probes and RH sensor.



Figure 3. Clear frame with soil moisture & temperature probes and RH sensor. All four sides of the frame are made of corrugated Plexiglas



Figure 4. Solar frame with soil moisture & temperature probes and RH sensor. The east, south, and west sides of the solar frame are made of corrugated Plexiglas while the north panel is a reflective material.

We collected climate variables under each warming chamber: minimum and maximum soil temperatures at 5 cm and 10 cm, volumetric water content (VWC) in soil at 5 cm and 10 cm, air temperature, and relative humidity (RH). Results found that the clear chambers increased air temperatures by 0.44°C, while solar chambers increased air temperatures by only 0.39°C (Figure 5A). We also found that clear chambers increased soil temperatures either 1.21°C or 0.80°C from controls at 5 cm and 10 cm, respectively, and solar chambers increased soil temperatures 1.47°C and 1.00°C at 5 cm and 10 cm, respectively (Figure 5B). Volumetric water content increased relative to controls except in the clear frame at 10 cm where there was a slight decrease in VWC (Figure 5C). Relative humidity decreased with both clear and solar frames (Figure 5D). Time series for climate variables are shown in Figure 6.

Since these warming frame designs are still not elevating temperature to 3-5°C, we are trying one more round of modified warming chambers. Our new designs use non-corrugated acrylic Plexiglas on all four sides of both the solar and clear treatment, with the solar treatment retaining the reflective material on the inside of the north panel of Plexiglas. To further increase warming, slats of Plexiglas will be placed on top of the frame at a 30° angle and two inches apart, with a south facing aspect, as done in the original design. The new frames have a 17 cm gap from the ground to the bottom of the Plexiglas sides to increase airflow along the surface of the plot. If we cannot effectively achieve greater warming in plots with this combined design between the original and previous round of chambers, we will proceed with just the drought treatment.

Our study will 1) increase our understanding of the basic biology and ecology of several native species, 2) determine native plant sensitivity to altered climate, 3) provide recommendations on native plant material selections under future climate, and 4) offer insight into the resilience of native plant communities to climate change and resistance to invasion.

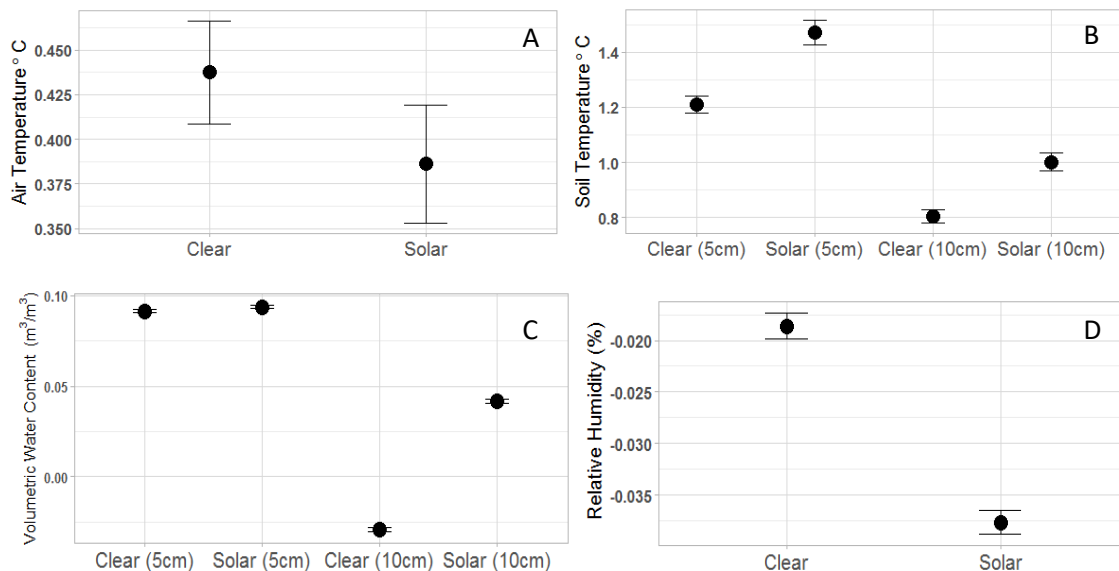


Figure 5. Difference between control chambers and either clear or solar chambers for air temperature (A), soil temperature (B), volumetric water content (C), and relative humidity (D).

Circles represent mean difference from control frame; bars represent 95% confidence intervals. All metrics were significantly different at $P < 0.05$.

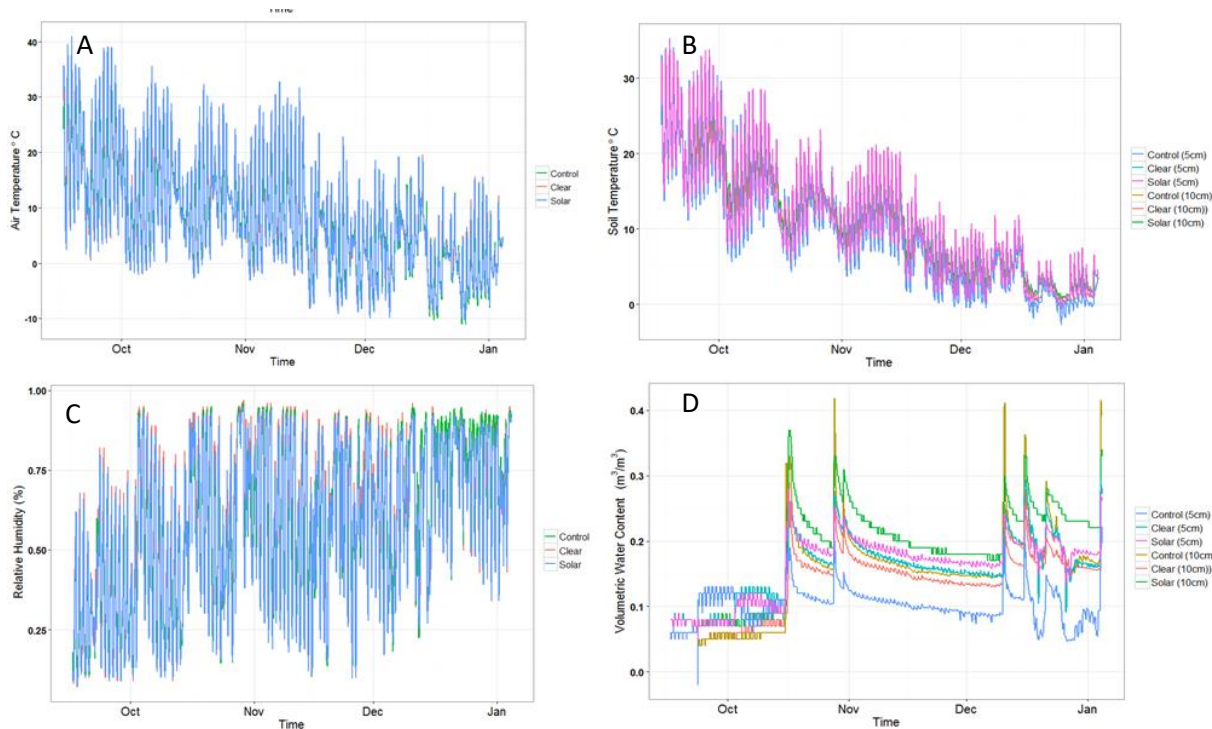


Figure 6. Time series of air temperature (A), soil temperature (B), volumetric water content (C), and relative humidity (D) for three different climate chambers: control, clear, and solar. Volumetric water content and soil temperature was captured at 5 and 10 cm soil depths.

Additional Products

We obtained additional project funds for a technician through the United State Department of Agriculture (USDA)-Agricultural Research CRIS project.

References

- Abatzoglou, J. T.; Kolden, C. A. 2011. Climate change in western US deserts: Potential for increased wildfire and invasive annual grasses. *Rangeland Ecology & Management* 64: 471-478.
- Abella, S. R.; Craig, D. J.; Smith, S. D.; Newton, A. C. 2012. Identifying native vegetation for reducing exotic species during the restoration of desert ecosystems. *Restoration Ecology* 20: 781-787.
- Bykova, O.; Sage, R.F. 2012. Winter cold tolerance and the geographic range separation of *Bromus tectorum* and *Bromus rubens*, two severe invasive species in North America. *Global Change Biology* 18: 3654-3663.

- DeFalco, L. A.; Bryla, D. R.; Smith-Longozo, V.; Nowak, R. S. 2003. Are Mojave Desert annual species equal? Resource acquisition and allocation for the invasive grass *Bromus madritensis* subsp. *rubens* (Poaceae) and two native species. *American Journal of Botany* 90: 1045-1053.
- Leger, E. A. 2008. The adaptive value of remnant native plants in invaded communities: an example from the great basin. *Ecological Applications* 18: 1226-1235.
- Nagel, J. M.; Huxman, T. E.; Griffin, K. L.; Smith, S. D. 2004. CO₂ enrichment reduces the energetic cost of biomass construction in an invasive desert grass. *Ecology* 85: 100-106.
- Newingham, B. A.; Suazo, A. A.; Germino, M. J. 2015. *Bromus tectorum* and native grass establishment under drought and warming in sagebrush steppe after fire. Great Basin Consortium Meeting; 2015 February 17-19; Boise, ID.
- Smith, S. D.; Huxman, T. E.; Zitzer, S. F.; Charlet, T. N.; Housman, D. C.; Coleman, J. S.; Fenstermaker, L. K.; Seemann, J. R.; Nowak, R. S. 2000. Elevated CO₂ increases productivity and invasive species success in an arid ecosystem. *Nature* 408: 79-82.
- Uselman, S. M.; Snyder, K. A.; Leger, E. A.; Duke, S. E. 2015. Emergence and early survival of early vs. late seral species in Great Basin restoration in two different soil types. *Applied Vegetation Science*. 18:624-636.
- Ziska, L. H.; Reeves, J. B.; Blank, B. 2005. The impact of recent increases in atmospheric CO₂ on biomass production and vegetative retention of cheatgrass (*Bromus tectorum*): implications for fire disturbance. *Global Change Biology* 11: 1325-1332.

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

Introduction

Land managers face numerous challenges when maintaining and restoring healthy ecosystems that are resilient to climate change. One challenge is determining and procuring the appropriate plant material to restore an area. In the western United States, plant species span a wide range of climates from arid desert to temperate rainforest to alpine areas. Climatic extremes can lead to natural selection on populations leading to improved survival and reproduction in local environments, i.e. local adaptation. Adaptation can occur on a regional level particularly along climatic gradients. To ensure success in restoration activities and healthy ecosystems, federal agencies have directives to use genetically appropriate materials that are locally adapted. Seed zones have been developed to guide the movement of appropriate plant materials in restoration and reforestation (Campbell and Sorensen 1978; Johnson et al. 2004). Seed zones separate areas by plant performance and/or climatic conditions important to plant growth, survival, and reproduction. Provisional seed zones combine minimum winter temperature with aridity (mean

annual temperature/mean annual precipitation) to delineate areas of similar climate (Bower et al. 2014). Empirical seed zones are delineated for a particular species and incorporate climatic data related to genetically differentiated traits important to survival and reproduction. Empirical seed zones have been developed for over 20 species in the western United States.

Bluebunch wheatgrass (*Pseudoroegneria spicata*) is an ecologically important restoration species (Daubenmire 1942; Harris 1967) that occurs in a wide range of habitats in the western United States. Populations of bluebunch wheatgrass differ in several traits important for adaptation to precipitation and temperature (St.Clair et al. 2013). Seed zones for bluebunch wheatgrass demarcate areas with similar climate and populations with climate-associated genetic variation. To examine if populations are locally or regionally adapted requires comparing performance of local and non-local populations in a reciprocal manner (Kawecki and Ebert 2004). We are using a reciprocal transplant experiment to investigate the efficacy of bluebunch wheatgrass seed zones. Results from this experiment will determine if seed zones for bluebunch wheatgrass are delineated appropriately or if they need modification.

Objectives

1. Evaluate adaptation of bluebunch wheatgrass populations from local seed zones relative to non-local seed zones.
2. Model adaptation as a function of source location and common garden climates.
3. Characterize traits and climatic factors important for adaptation.
4. Model effects of climate change on native populations and consequences of assisted migration for responding to climate change.

Methods

Bluebunch wheatgrass is a cool-season, long-lived perennial bunchgrass native to the western United States. This grass thrives in a variety of habitats that range in mean annual temperature (3-11°C), annual precipitation (21-187 cm), and elevation (230-2460 m). We investigate the effectiveness of empirical seed zones for bluebunch wheatgrass by comparing establishment, survival, and reproduction of populations from local seed zones 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 at 16 sites located in two broad regions (i.e. transects) (Figure 1). The two broad regions include (1) a transect through hot, dry climates of the lower Snake River Plain to the cool, relatively wet climates of the higher elevations of the Great Basin Ranges to the cold, dry climates of the upper Snake River Plain, and (2) a transect from hot, dry climates of the Columbia Plateau to cool, wet climates of the Blue Mountains to the cold, dry climates east of the Blue Mountains. Within each transect, we reciprocally planted native populations from eight seed zones into eight sites that represent the climate of each seed zone (Figure 1). In addition, we planted two propagated lines at all sites and one propagated line at sites at the two extremes of the seed zones.

Seed was collected from 78 populations throughout the two broad regions in 2013. The University of Idaho was contracted to produce containerized planting stock for the study in 2014. Federal, state and private collaborators provided land for common garden sites. The 16 common gardens were identified, prepared and established in 2014. Several common gardens were fenced to protect plants from herbivory. Each common garden was planted with 39 populations and two

propagated lines (Anatone and Goldar) for a total of 820 plants surrounded by two rows of buffer plants. A few common garden sites had an additional treatment included: (1) a seed zone from the other transect, or (2) an extra propagated line (Wahluke) for a total of 1000 plants per common garden. The experimental design at each common garden is a split-plot design with populations planted by seed zone into subplots and all seed zones present within a plot. Each site includes four replicate plots. Each subplot has 25 plants: five replicates of five populations or all one propagated line. However, only four populations were available from the hottest, driest seed zone within each transect and had additional replicates to reach 25 plants per subplot. Spacing is 0.6 m x 0.8 m between plants.

Each site was visited in spring and summer of 2015, 2016, and 2017 to record various traits including: leaf length, width and roll; survival; reproductive phenology; herbivory; root crown diameter; and number of reproductive stalks. In 2015 and 2016 reproductive stalks were collected from a subset of individuals per population at each site to estimate seed production. In the summer 2017 after reproductive stalk production, biomass was harvested from a subset of individuals per populations at each site. Weather data loggers were installed at plant height and at 2 m at each site to record local temperature for comparison with regional weather stations and climate interpolation models. Common gardens are managed to control weeds to ensure establishment and to reduce the effect of competing vegetation to allow better evaluation of differences in plant growth, survival, and reproduction associated with local climates.

Expected Results and Discussion

Among populations of bluebunch wheatgrass there is genetic differentiation (St. Clair et al. 2013) and these populations exist in a wide range of environmental conditions. Thus we expect that populations of bluebunch wheatgrass are locally adapted. We focus on the regional level of adaptation (ref. regional adaptation) since restoration on this level is logistically and financially more feasible since costs to procure, produce and disseminate native seeds are reduced in comparison to a local or population level.

Across 16 common garden sites survival was high (>80%) through the first growing season. One site was completely lost with the majority of plants dying a month after transplant due to an extreme weather event. This site was re-planted, but subsequently lost due to repeated vandalism. Of the remaining 15 sites, plant survival declined over time to 54% in spring 2017. Plants varied in survival, leaf morphology, reproductive phenology and reproduction among common garden sites and among seed sources. At many sites genetic variation among populations was found for survival and reproductive phenology (Fig 2A,B). At sites with more than 30% survival, plants with late reproductive phenology were less likely to survive in the future (Fig 2A,B). In 2016, reproductive stalk production per plant varied among seed sources across common garden sites (Fig. 3). In 2017, mean population survival to spring 2017 varied among seed sources across common garden sites (Fig. 4). Bluebunch wheatgrass is a perennial plant that can live for decades (over 30 years). With these data we see differences in reproduction and survival of seed sources across common garden sites, indicating that at some sites local plants outperform non-local plants. Additional analyses will follow based on the 2017 data to look at responses as a function of climatic distance between sources and planting sites. We plan to access these sites in the future to see if local plants continue to outperform non-local plants. In addition we will

conduct analyses to determine if the current seed zone delineation for bluebunch wheatgrass is appropriate considering these data or if it needs a modification to improve restoration success.

Management Applications and/or Seed Production Guidelines

Since bluebunch wheatgrass is an ecologically important restoration species (Daubenmire 1942; Harris 1967), it is essential to have effective seed-transfer zones to improve restoration success. This study is examining 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 to 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 various 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. Plant material movement guidelines and associated seed zones can be adjusted based on results from this study and management objectives.

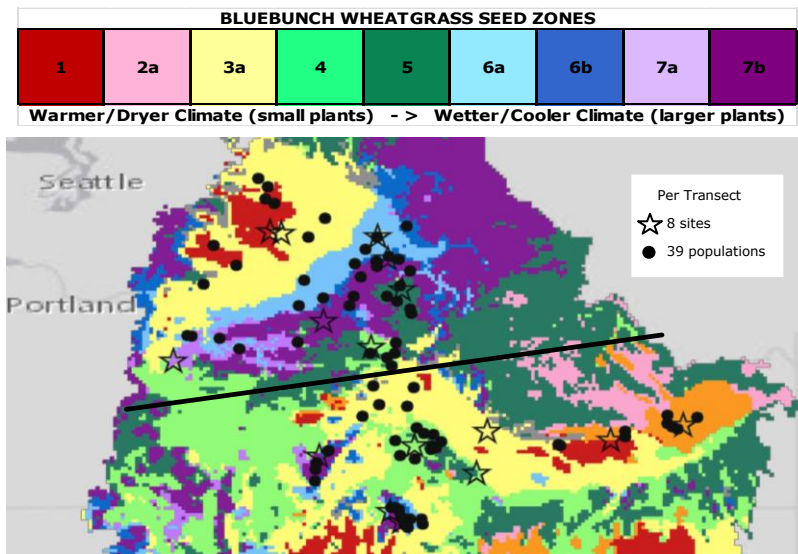


Figure 1. Map of bluebunch wheatgrass populations (black circles) used in eight common gardens (stars) in each transect (delineated) in the northwest US.

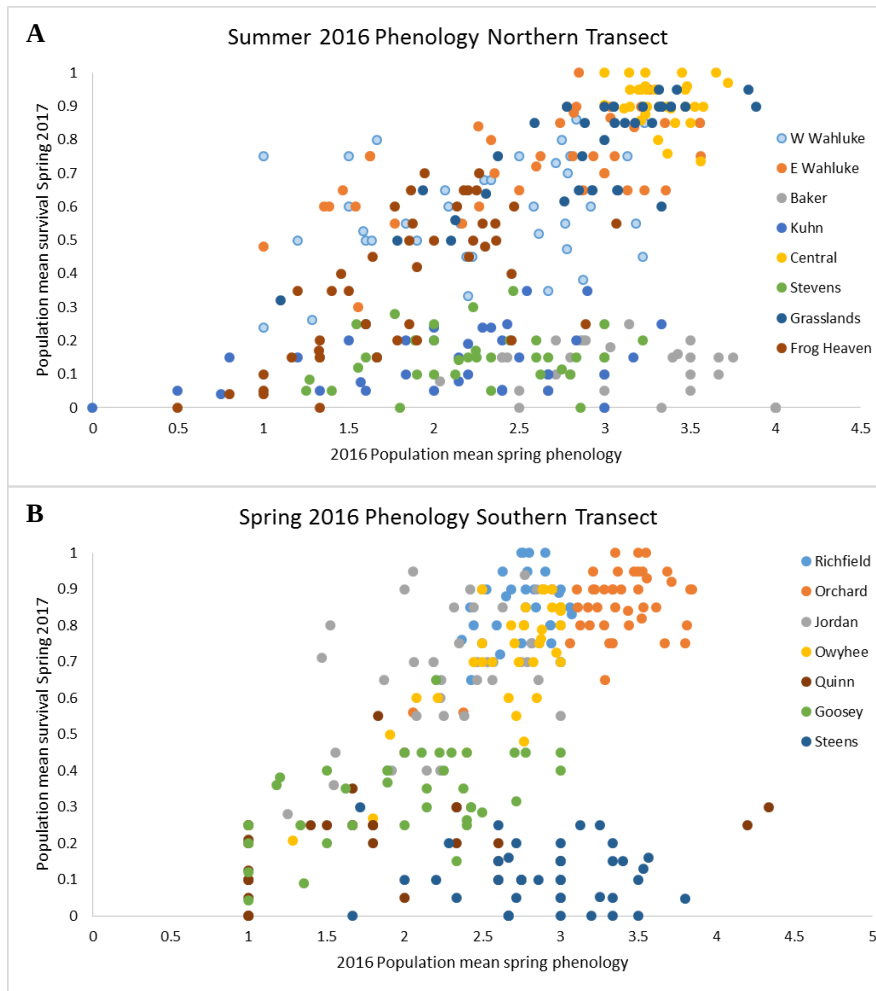


Figure 2. Population mean reproductive phenology scores during the spring 2016 survey plotted with population mean survival during the spring 2017 survey for the A) northern and B) southern transects. Phenology scores represent plants in the vegetative state at 0 and in anthesis at 4. Each common garden site is represented by a color with each population mean represented by a dot.

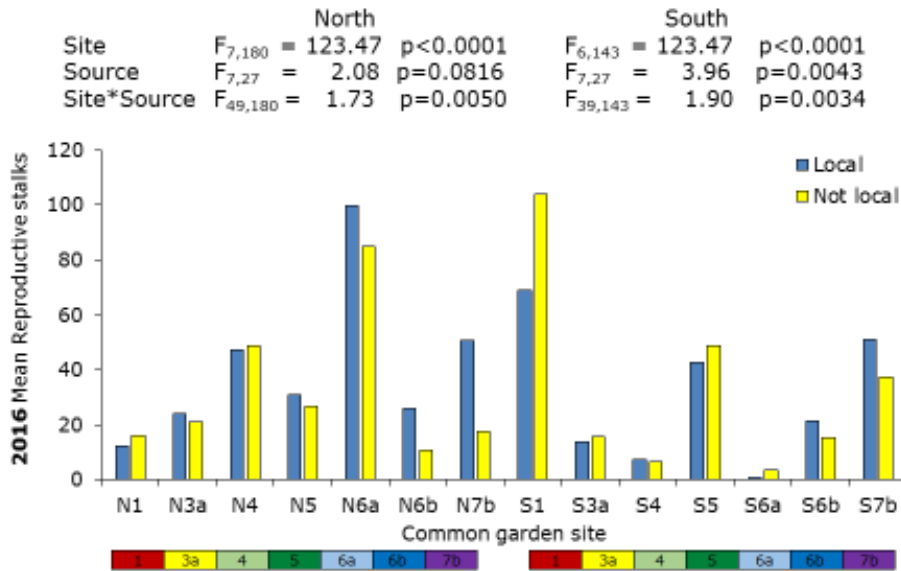


Figure 3. Mean reproductive stalks per plant for local (blue bar) and non-local (yellow bar) plants for each common garden site grouped by transect. Color bars below the figure indicate seed zones of bluebunch wheatgrass.

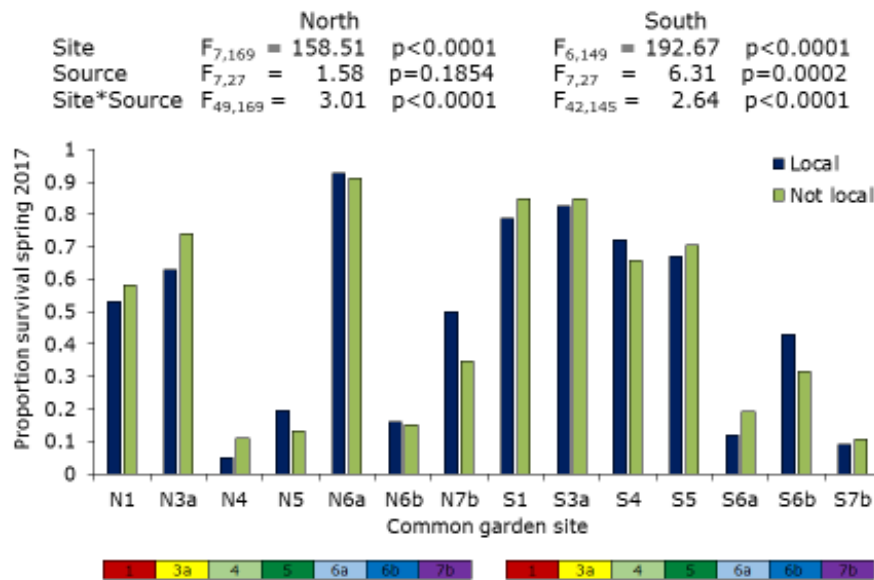


Figure 4. Proportion of plants surviving until spring 2017 for local (dark blue bars) and non-local (green bars) plants for each common garden site grouped by transect. Color bars below the figure indicate seed zones of bluebunch wheatgrass.

References

Campbell, R. K; Sorensen, F.C. 1978. Effect of test environment on expression of clines and on delimitation of seed zones in Douglas-fir. *Theoretical Applied Genetics* 51: 233-246.

Daubenmire, R. F. 1942. An ecological study of the vegetation of southeastern Washington and adjacent Idaho. *Ecological Monographs*. 12: 53-79.

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

Johnson, G. R.; Sorensen, F.C.; St. Clair, J.B; Cronn, R.C. 2004. Pacific Northwest Forest Tree Seed Zones: A template for native plants? *Native Plants Journal* 5: 131-140.

Kawecki, T.J.; Ebert, D. 2004. Conceptual issues in local adaptation. *Ecology Letters* 7: 1225-1241.

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 Morphological and Genetic Characterization of Blue Penstemon (*Penstemon cyaneus*)

Project Agreement No. 15-JV-11221632-181

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Project Description

Introduction

Blue penstemon (*P. cyaneus*) is considered a valuable forb for revegetation and restoration uses in the Great Basin region (Winslow 2002; Shaw et al. 2004). Research on blue penstemon irrigation, and propagation has been conducted to develop cultural practices that contribute to seed production (Winslow 2002; Tilley et al. 2012; Shock et al. 2014); however, to our knowledge, there has not been a systematic assessment of blue penstemon genetic diversity across the landscape.

Blue penstemon has a latitudinal range over 563.3 km, and has a reported elevational distribution between 944.9 and 3048 m. (SEINet 2016). The species as a whole has adapted across a broad and varied ecological range occurring from sagebrush steppe to spruce-fir forest. These adaptations can potentially impact restoration success if seed origins are not considered and genetic ecotypes not defined. It is important to identify appropriate germplasm sources of blue penstemon for restoration use within specific Great Basin regions to: 1) maximize potential establishment success by matching appropriate genotypes with restoration sites 2) ensure sufficient genetic variation to allow for natural selection and adaptation post revegetation (e.g., climate change effects), 3) minimizing the possibility of out-breeding depression (genetic swamping), and 4) identifying collections with greatest potential for commercial seed production (McKay et al. 2005; Broadhurst et al. 2008; Bushman et al. 2010).

Objectives

- 1) Characterize the morphological variation in blue penstemon accessions through common garden studies.
- 2) Gain an understanding of the genetic variation within the taxon through molecular analyses.

Methods

Using species distribution and location data from herbarium specimens as geographic references, we located blue penstemon populations where we were able to collect voucher specimens, which will be deposited at the Stanley L. Welch Herbarium, Brigham Young University (BYU). At each site we collected four to six young healthy leaves from typically eight individual plants and preserving them in silica gel desiccant, lyophilizing them, and then freezing them until DNA extractions were made. During the late summer and early fall we returned to as many blue penstemon sites as possible and collected seed from up to 100 separate plants. Seed collections were not made at every site due to constraining conditions such as livestock/wildlife grazing, drought, and wildfire. In addition to blue penstemon, we also collected from closely related *Penstemon* species that share areas of geographic sympatry with blue penstemon as they share taxonomic characteristics. This was done to gain a deeper insight into the taxonomy of this group of penstemons as some of these species are easily confused with blue penstemon (Holmgren 1984).

Information relating to the genetic population structure and diversity of blue penstemon is critical to wisely proceed in the germplasm development for seed production and reseeding uses in revegetation projects. In this study we are presently preparing to use a sequence capture technique (Ali et al. 2016) to investigate the population genetics of blue penstemon. In preparation for this study DNA has been extracted from lyophilized leaf tissue using the method described by Todd and Vodkin (1996). Extracted DNA was stored in the freezer at -20°C until used in molecular evaluations.

Between 30-40 seed collections of blue penstemon will be planted in at least two common garden locations. One will be at the Aberdeen, ID Research and Extension Center, which is located within the geographic distribution of blue penstemon, and second at the BYU Life Science Greenhouse field plot in Provo, UT. The differences between the common garden sites will allow us to quantify the genotype by environment interaction for each phenotypic trait. The

measurements taken will include survival, days to flower, flowering stem counts, flowers per inflorescence counts, seed production, leaf area of last vegetative node, and plant height at maturity.

Results and Discussion

In addition to the populations sampled and seed collections made in 2015, we identify 67 additional populations, from which tissue samples were taken from eight individual plants from 66 of these populations. In total we have tissue samples from 125 blue penstemon and related species that will be included in our molecular evaluations (Figure 1). We were able to make an additional 25 seed collections, making the total seed collections in our repository 68 (Figure 2). With few exceptions most populations were field identified as blue penstemon. However, after detailed examination of plant vouchers many of these populations have been verified to be a species other than blue penstemon.

The taxonomic identification of blue penstemon has been difficult to determine, as there are several closely related species sharing sympatric areas of their respective distributions. For example, the Minidoka penstemon (*P. perpulcher*) has a purported distribution almost encompassed within the reported distribution of blue penstemon. They both share many floral and stamen features (used as taxonomic differentiation in *Penstemon*). In fact, Crosswhite, who was a leading expert in *Penstemon* taxonomy and systematics, confused these two species (Holmgren, 1984). We have reason to believe that some of the plant material being developed as blue penstemon may be Minidoka penstemon. We have also made collections of Wasatch penstemon (*P. cyananthus*) varieties in Utah, because this species was also field identified as blue penstemon in many instances in Idaho and Wyoming (Table 1). We will be using these accessions for comparative purposes in our molecular evaluations.

Seedlings of 42 accessions (Table 1) are being prepared and planted in Cone-tainers™ in our greenhouse. All lines with sufficient plants will be planted in a completely randomized block design that will consist of four replications, or blocks into black weed barrier fabric in our common gardens early spring of 2017. Each replication will have five individual plants of each population. Although 42 populations are being prepared for use in our common garden trials, there is the potential that not all will be included due to uneven germination and diseases (damping off, root rot, etc.). We expect this number to be between 30 and 40 accessions.

DNA has been extracted from all plant samples collected in 2015/16, yielding approximately 1,000 samples for molecular evaluations. We sequenced a single sample from Accession 376 using the Illumina Hi-Seq platform to obtain reference sequences for comparison of loci within the blue penstemon genome during the sequence capture or genome reduction technique in our molecular evaluations.

The molecular evaluations in combination with the common garden results planned in this study will allow for the identification of morphological and genetic differences of blue penstemon populations. We will then correlate genetic, morphology, and geography aspects of this study in population genetic studies. It is anticipated that the common garden evaluations combined with molecular characterization, followed by the population genetic studies will allow us to make recommendations for approaches to seed collecting, germplasm development, and seed increases

for use in land reclamation and native community restoration throughout the northern Great Basin.

Management Applications and Seed Production Guidelines

Blue penstemon and Mikidoka penstemon occur sympatrically throughout much of their distribution on the Snake River Plain. Both share many floral and stamen features (used in taxonomic differentiation in *Penstemon*). We have reason to believe that some of the plant material being developed as blue penstemon may be Minidoka penstemon.

Presentations

Stevens, Mikel R.; Johnson, Robert L.; Stettler, Jason M. 2016. Morphological and Genetic Characterization of Blue Penstemon. Great Basin Native Plant Project Annual Meeting; April 11-12; Boise, ID.

Additional Products

Although we are still in the initial stages of our research, we expect the following products will be available at the conclusion of this project:

- Detailed map of blue penstemon proposed seed zones, areas of local adaptation, based on common garden plant traits, climatic variables, and molecular population structures.
- Recommendations for germplasm releases and uses.
- Peer-reviewed publications.

GENETICS AND CLIMATE CHANGE

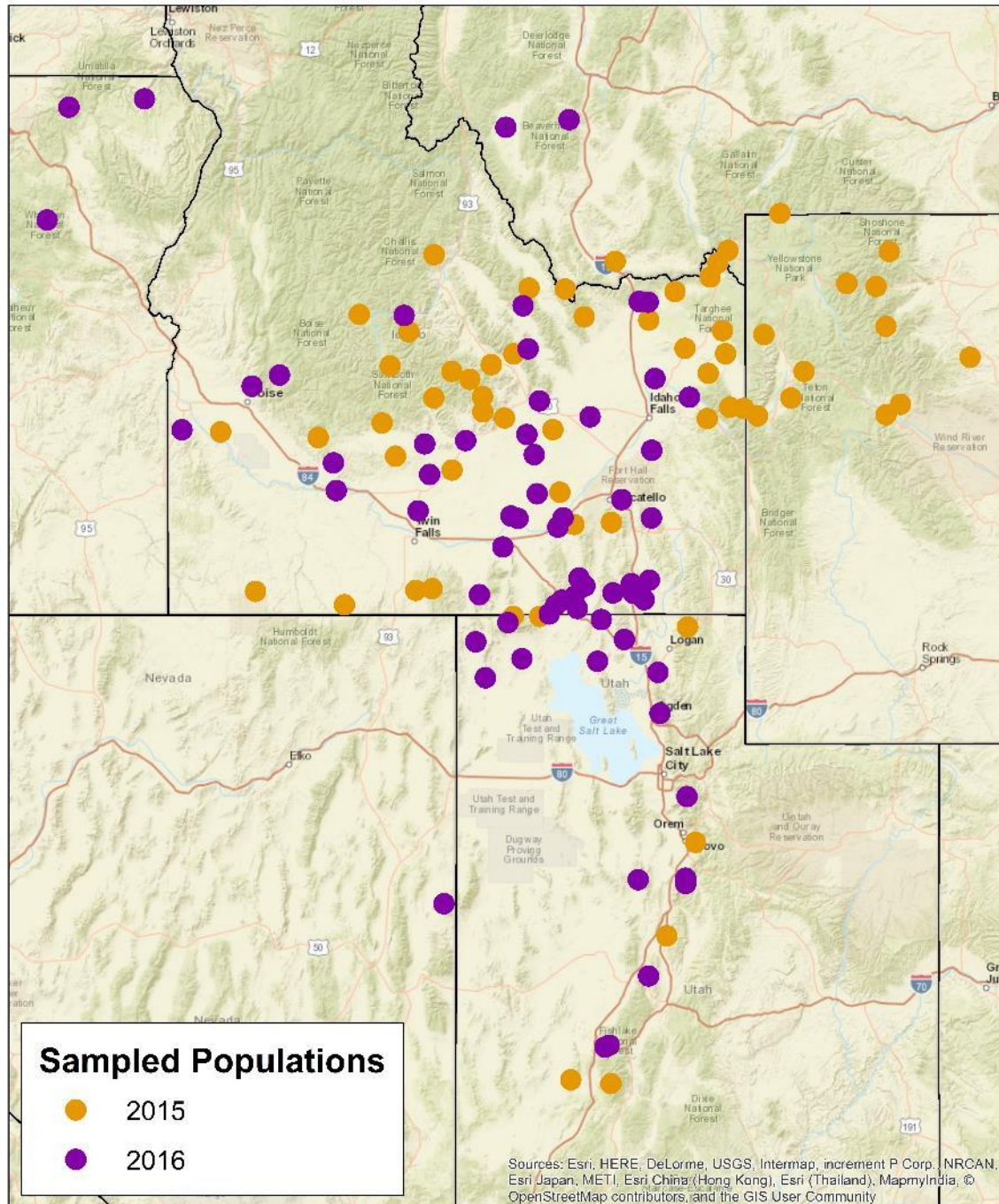


Figure 1. Map of all populations sampled in 2015/16 that will be included in our molecular evaluations.

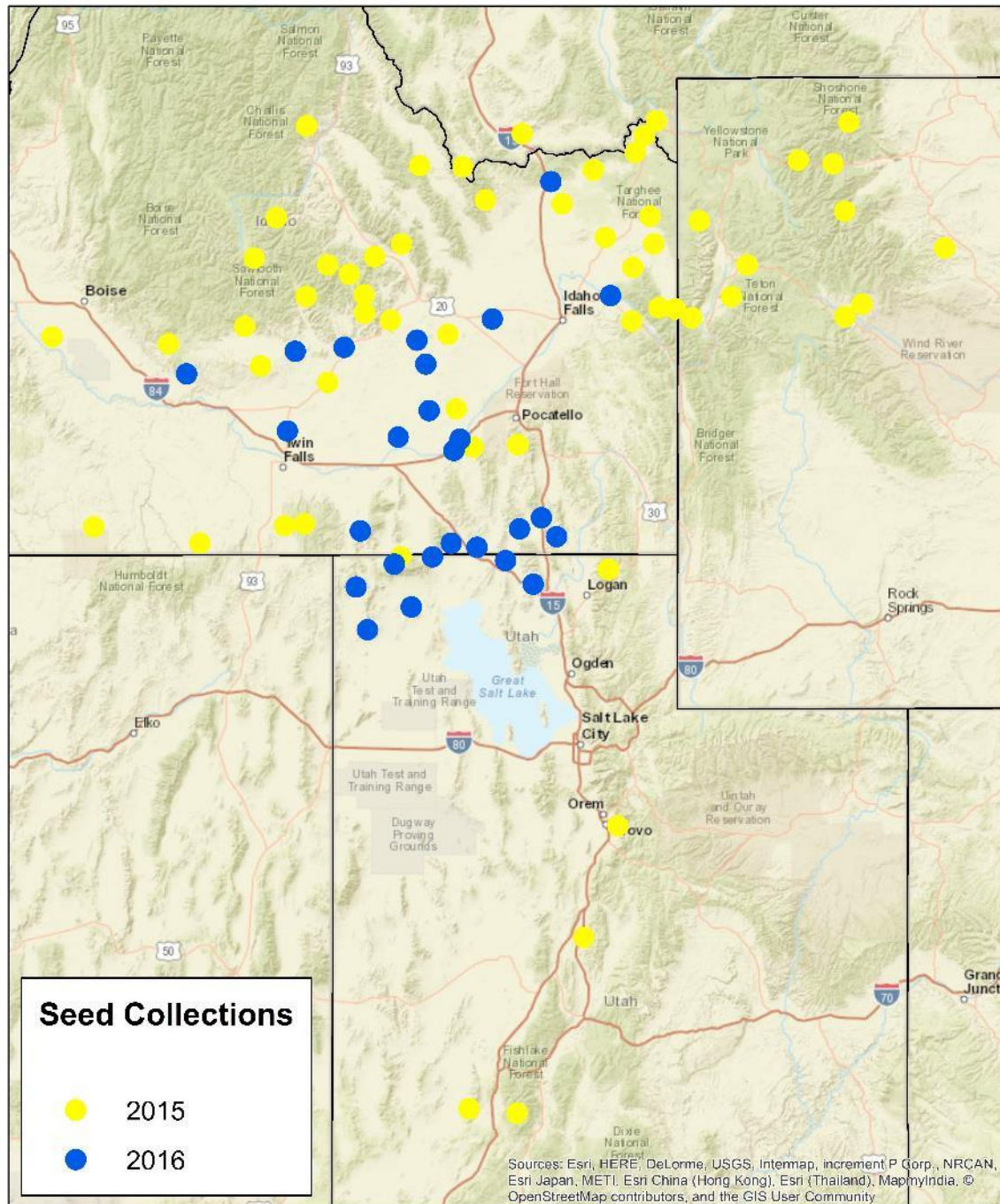


Figure 2. Map of all seed collections made in 2015/16.

Table 1. Accessions included in our molecular and common garden evaluations of blue penstemon with limited location information.

Taxon	Accession no.	Tissue Samples	Seed Collections	Common Garden	State	County	Elevation (feet)
<i>P. longiflorus</i>	66	Y	Y	N	Utah	Beaver	8451
<i>P. tidesstromii</i>	128	Y	Y	N	Utah	Juab	5805
<i>P. cyananthus</i> var. <i>subglaber</i>	159	Y	Y	N	Utah	Box Elder	6499
<i>P. cyananthus</i> var. <i>subglaber</i>	160	Y	Y	Y	Utah	Box Elder	5255
<i>P. compactus</i>	188	Y	Y	N	Utah	Cache	8381
<i>P. cyananthus</i> var. <i>cyananthus</i>	189	Y	Y	Y	Utah	Cache	8395
<i>P. perpulcher</i>	360	Y	Y	N	Idaho	Twin Falls	6842
<i>P. perpulcher</i>	361	Y	Y	Y	Idaho	Twin Falls	5718
<i>P. speciosus</i>	362	Y	Y	N	Idaho	Owyhee	5505
<i>P. speciosus</i>	363	Y	Y	N	Idaho	Owyhee	5356
<i>P. perpulcher</i>	364	Y	Y	Y	Idaho	Ada	2843
<i>P. cyaneus</i>	365	Y	Y	Y	Idaho	Elmore	4794
<i>P. cyaneus</i>	366	Y	Y	Y	Idaho	Camas	5571
<i>P. payettensis</i>	367	Y	Y	Y	Idaho	Camas	5525
<i>P. cyaneus</i>	368	Y	Y	N	Idaho	Blaine	6070
<i>P. perpulcher</i>	369	Y	Y	Y	Idaho	Lincoln	4508
<i>P. cyaneus</i>	370	Y	Y	N	Idaho	Blaine	5990
<i>P. cyaneus</i>	371	Y	Y	Y	Idaho	Butte	5686
<i>P. cyaneus</i>	373	Y	Y	N	Idaho	Butte	6413
<i>P. cyananthus</i>	374	Y	Y	N	Idaho	Madison	6004
<i>P. cyananthus</i>	375	Y	Y	N	Idaho	Fremont	5981
<i>P. cyaneus</i>	376	Y	Y	Y	Idaho	Fremont	5730
<i>P. cyaneus</i>	377	Y	Y	N	Idaho	Fremont	6586
<i>P. cyaneus</i>	378	Y	Y	Y	Idaho	Fremont	7835
<i>P. cyaneus</i>	379	Y	Y	N	Idaho	Clark	6451
<i>P. cyananthus</i>	380	Y	Y	N	Idaho	Clark	5708
<i>P. cyaneus</i>	381	Y	Y	Y	Montana	Beaverhead	6499
<i>P. cyaneus</i>	382	Y	N	N	Montana	Park	5576
<i>P. cyaneus</i>	383	Y	Y	Y	Montana	Gallatin	6547
<i>P. perpulcher</i>	384	Y	Y	Y	Idaho	Bingham	4662
<i>P. cyananthus</i>	385	Y	Y	N	Idaho	Power	5237
<i>P. cyananthus</i>	386	Y	Y	N	Idaho	Bannock	5677
<i>P. cyaneus</i>	387	Y	Y	Y	Idaho	Bonneville	5353
<i>P. cyananthus</i>	388	Y	Y	N	Idaho	Teton	6491
<i>P. subglaber</i>	389	Y	Y	Y	Wyoming	Teton	6750
<i>P. glaber</i>	390	Y	Y	N	Wyoming	Fremont	6845
<i>P. glaber</i>	391	Y	Y	Y	Wyoming	Fremont	7142
<i>P. glaber</i>	392	Y	Y	N	Wyoming	Hot Springs	5913
<i>P. glaber</i>	393	Y	Y	N	Wyoming	Park	6241
<i>P. cyaneus</i>	394	Y	Y	N	Wyoming	Park	6917
<i>P. glaber</i>	395	Y	Y	Y	Wyoming	Park	6437
<i>P. strictus</i>	396	Y	Y	Y	Wyoming	Park	6085
<i>P. cyaneus</i>	397	Y	N	N	Idaho	Fremont	5042
<i>P. cyaneus</i>	398	Y	Y	N	Wyoming	Teton	7491
<i>P. cyananthus</i>	399	Y	Y	Y	Wyoming	Teton	6870
<i>P. cyananthus</i>	400	Y	Y	N	Wyoming	Teton	7715

Table 1. (cont.) Accessions included in our molecular and common garden evaluations of blue penstemon with limited location information.

Taxon	Accession no.	Tissue Samples	Seed Collections	Common Garden	State	County	Elevation (feet)
<i>P. strictus</i>	401	Y	Y	N	Idaho	Teton	6690
<i>P. cyaneus</i>	402	Y	Y	Y	Montana	Beaverhead	7535
<i>P. cyaneus</i>	403	Y	Y	Y	Idaho	Clark	6292
<i>P. cyaneus</i>	404	Y	Y	N	Idaho	Lemhi	7710
<i>P. cyaneus</i>	405	Y	Y	N	Idaho	Custer	7220
<i>P. cyaneus</i>	406	Y	Y	Y	Idaho	Custer	8224
<i>P. cyaneus</i>	407	Y	Y	N	Idaho	Custer	7318
<i>P. cyaneus</i>	408	Y	Y	Y	Idaho	Custer	7895
<i>P. cyaneus</i>	410	Y	Y	Y	Idaho	Butte	6581
<i>P. cyaneus</i>	411	Y	Y	Y	Idaho	Custer	7445
<i>P. strictus</i>	412	Y	N	N	Idaho	Custer	6527
<i>P. cyaneus</i>	413	Y	Y	Y	Idaho	Blaine	8236
<i>P. cyaneus</i>	419	Y	Y	Y	Idaho	Custer	5678
<i>P. longiflorus</i>	426	Y	Y	N	Utah	Beaver	8133
<i>P. cyananthus</i> var. <i>cyananthus</i>	430	Y	Y	Y	Utah	Utah	8362
<i>P. cyaneus</i>	437	Y	Y	N	Idaho	Oneida	4741
<i>P. rydbergii</i>	438	Y	N	N	Idaho	Oneida	4741
<i>P. cyaneus</i>	440	Y	N	N	Idaho	Jefferson	4954
<i>P. cyananthus</i>	441	Y	Y	N	Idaho	Madison	5810
<i>P. cyaneus</i>	442	Y	Y	Y	Idaho	Bingham	5753
<i>P. cyaneus</i>	443	Y	Y	Y	Idaho	Blaine	5028
<i>P. cyaneus</i>	444	Y	Y	Y	Idaho	Power	4927
<i>P. cyaneus</i>	445	Y	Y	Y	Idaho	Power	4351
<i>P. perpulcher</i>	446	Y	N	N	Idaho	Blaine	4258
<i>P. perpulcher</i>	447	Y	Y	Y	Idaho	Minidoka	4285
<i>P. perpulcher</i>	448	Y	N	N	Idaho	Elmore	2558
<i>P. cyaneus</i>	450	Y	Y	Y	Idaho	Elmore	4935
<i>P. speciosus</i>	452	Y	N	N	Idaho	Owyhee	3733
<i>P. payettensis</i>	453	Y	N	N	Idaho	Boise	4907
<i>P. payettensis</i>	454	Y	N	N	Idaho	Boise	3847
<i>P. cyaneus</i>	455	Y	N	N	Idaho	Custer	5702
<i>P. cyaneus</i>	456	Y	N	N	Idaho	Butte	5507
<i>P. cyaneus</i>	457	Y	Y	Y	Idaho	Blaine	4815
<i>P. cyaneus</i>	458	Y	Y	Y	Idaho	Blaine	5148
<i>P. cyaneus</i>	459	Y	N	N	Idaho	Lincoln	4273
<i>P. perpulcher</i>	460	Y	Y	Y	Idaho	Jerome	3936
<i>P. cyaneus</i>	461	Y	Y	Y	Idaho	Power	4316
<i>P. cyananthus</i>	462	Y	N	N	Idaho	Oneida	4904
<i>P. cyananthus</i>	463	Y	Y	N	Idaho	Oneida	5237
<i>P. cyananthus</i> var. <i>cyananthus</i>	464	Y	N	N	Utah	Weber	4686
<i>P. cyananthus</i> var. <i>cyananthus</i>	465	Y	N	N	Utah	Cache	5866
<i>P. cyananthus</i>	466	Y	Y	N	Utah	Box Elder	5164
<i>P. cyananthus</i>	467	Y	Y	N	Idaho	Oneida	5052
<i>P. cyananthus</i>	468	Y	Y	N	Idaho	Cassia	5227
<i>P. cyananthus</i>	469	Y	N	N	Idaho	Oneida	5514
<i>P. cyananthus</i>	470	Y	N	N	Idaho	Oneida	5230

Table 1. (cont.) Accessions included in our molecular and common garden evaluations of blue penstemon with limited location information.

Taxon	Accession no.	Tissue Samples	Seed Collections	Common Garden	State	County	Elevation (feet)
<i>P. cyananthus</i>	471	Y	N	N	Idaho	Oneida	4941
<i>P. cyananthus</i>	472	Y	Y	N	Idaho	Franklin	5495
<i>P. cyananthus</i>	473	Y	N	N	Idaho	Franklin	5297
<i>P. cyananthus</i>	474	Y	N	N	Idaho	Caribou	5389
<i>P. cyananthus</i>	475	Y	N	N	Idaho	Bingham	4537
<i>P. cyananthus</i>	476	Y	N	N	Idaho	Bannock	5835
<i>P. cyaneus</i>	485	Y	Y	N	Idaho	Butte	5250
<i>P. cyananthus</i>	486	Y	N	N	Idaho	Oneida	4900
<i>P. cyananthus</i>	487	Y	N	N	Idaho	Cassia	5150
<i>P. perpulcher</i>	488	Y	Y	Y	Idaho	Cassia	5470
<i>P. cyaneus</i>	489	Y	N	N	Idaho	Cassia	4425
<i>P. tdestromii</i>	496	Y	N	N	Utah	Millard	6175
<i>P. longiflorus</i>	497	Y	N	N	Utah	Sevier	7088
<i>P. longiflorus</i>	498	Y	N	N	Utah	Juab	5935
<i>P. longiflorus</i>	499	Y	N	N	Utah	Sevier	7143
<i>P. speciosus</i>	501	Y	N	N	Oregon	Grant	7195
<i>P. pennellianus</i>	505	Y	N	N	Oregon	Union	4960
<i>P. pennellianus</i>	506	Y	N	N	Oregon	Wallowa	4521
<i>P. lemhiensis</i>	509	Y	N	N	Montana	Beaverhead	7404
<i>P. cyananthus</i>	511	Y	Y	N	Utah	Box Elder	4900
<i>P. lemhiensis</i>	516	Y	N	N	Montana	Beaverhead	6076
<i>P. cyananthus</i>	522	Y	N	N	Idaho	Clark	6111
<i>P. cyananthus</i>	523	Y	Y	Y	Idaho	Clark	5971
<i>P. cyananthus</i> var. <i>cyananthus</i>	525	Y	N	N	Utah	Salt Lake	8307
<i>P. subglaber</i>	534	Y	N	N	Utah	Utah	7200
<i>P. cyananthus</i> var. <i>cyananthus</i>	535	Y	N	N	Utah	Utah	8600
<i>P. cyananthus</i> var. <i>subglaber</i>	536	Y	N	N	Utah	Box Elder	5320
<i>P. cyananthus</i> var. <i>subglaber</i>	537	Y	Y	N	Utah	Box Elder	5640
<i>P. cyananthus</i> var. <i>subglaber</i>	538	Y	N	N	Utah	Box Elder	6060
<i>P. longiflorus</i>	539	Y	N	N	Nevada	White Pine	7020
<i>P. cyaneus</i>	540	Y	N	N	Idaho	Butte	7040
<i>P. cyaneus</i>	541	Y	N	N	Idaho	Lemhi	6760
<i>P. cyananthus</i> var. <i>subglaber</i>	542	Y	Y	N	Utah	Box Elder	6650
<i>P. cyananthus</i> var. <i>subglaber</i>	543	N	Y	N	Utah	Box Elder	5290

References

Ali, Omar A.; O'Rourke, Sean M.; Amish, Stephen J.; Meek, Mariah H.; Luikhart, Gordon; Jeffres, Carson; Miller, Micheal R. 2016. RAD capture (Rapture): flexible and efficient sequence-based genotyping. *Genetics*. 202(2): 389-400.

Broadhurst, Linda M.; Lowe, Andrew; Coates, David J.; Cunningham, Saul A.; McDonald, Maurice; Vesk, Peter A.; Yates, Colin. 2008. Seed supply for broadscale restoration: maximizing evolutionary potential. *Evolutionary Applications* 1(4): 587-597.

Bushman, B. Shaun; Bhattarai, Kishor; Johnson, Douglas A. 2010. Population structures of *Astragalus filipes* collections from western North America. *Botany-Botanique* 88(6): 565–574.

Holmgren, Noel H. 1984. *Penstemon*. In: Cronquist, Arthur; Holmgren, Arthur H.; Holmgren, Noel H.; Reveal, James L.; Holmgren, Patricia K., eds. Intermountain flora: Vascular plants of the Intermountain west. Bronx, NY: New York Botanical Garden: 370-457.

McKay, John K.; Christian, Caroline E.; Harrison, Susan; Rice, Kevin J. 2005. “How local is local?” - A review of practical and conceptual issues in the genetics of restoration. *Restoration Ecology* 13(3): 432-440.

Shaw, Nancy L.; Lambert, Scott M.; DeBolt, Ann M.; Pellant, Mike 2005. Increasing native forb seed supplies for the Great Basin. In: Dumroese, R.K.; Riley, L.E.; Landis, T.D., tech coords. National proceedings: Forest and Conservation Nursery Associations-2004. RMRS-P-35. USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO. p. 94-102.

SOUTHWEST ENVIRONMENTAL INFORMATION NETWORK, SEINet – Arizona Chapter. 2016. Available: <http://swbiodiversity.org/seinet/index.php> October 29.

Shock, Clinton C.; Feibert, Erik B.G.; Saunders, Lamont D.; Shaw, Nancy; Sampangi, Ram S. 2014. Irrigation requirements for native perennial wildflower seed production in a semi-arid environment. Ann. Rep. 2013. Corvallis, OR: Oregon State University Agricultural Experiment Station, Malheur Experiment Station: 166-183.

Tilley, Derek; St. John, Loren; Ogle, Dan; Shaw, Nancy 2012. Plant Guide: Blue penstemon, *Penstemon cyaneus* Pennell. Aberdeen, ID: U.S. Department of Agriculture, Natural Resources Conservation Service, Aberdeen Plant Materials Center. 3 p.

Todd, Joselyn J.; Vodkin, Lila O. 1996. Duplications that suppress and deletions that restore expression from a chalcone synthase multigene family. *The Plant Cell* 8(4): 687-699.

Winslow, Susan R. (2002). Propagation protocol for production of *Penstemon cyaneus* seeds, [Propagation Protocol Database]. Reforestation, Nurseries, and Genetic Resources. Available: [http://www.nativeplantnetwork.org/Network/ViewProtocols.aspx?ProtocolID=1173/?searchterm=penstemon cyaneus](http://www.nativeplantnetwork.org/Network/ViewProtocols.aspx?ProtocolID=1173/?searchterm=penstemon%20cyaneus) [accessed 23 December 2015]



PLANT MATERIALS AND CULTURAL PRACTICES



Project Title Developing Protocols to Maximize Seedling
Establishment and Seed Production for Utah Trefoil
(*Lotus utahensis* Ottley)

Project Agreement No. 15-IA-11221632-200

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Project Description

Introduction

Rangeland ecosystems in the western U.S. are increasingly vulnerable to wildfires, weed invasion, mismanagement, and soil erosion (Pierson et al. 2011). Many western rangelands suffer from long-term reductions in biodiversity, altered nutrient and water cycling, diminished livestock and wildlife forage production, increased wildfire frequency, and increased soil erosion and stream sedimentation (Sheley et al. 2008). Concerns related to biodiversity as well as food and habitat resources for sage-grouse and native pollinators are particularly important for sagebrush-steppe rangelands (Rowland et al. 20068; Cane 2011). Degraded rangelands or rangelands vulnerable to weed invasion after wildfires may not recover for decades (or longer) without human intervention, so restoration may be required to improve conditions, speed recovery, and prevent further erosion and degradation. Land managers, ecologists, the commercial seed trade, and the public have considerable interest in the development, production, buying/selling seed, and utilization of rangeland plant materials. Leguminous forbs are of particular interest because they biologically fix nitrogen as well as provide high quality food for wildlife and native pollinators. Our research group has focused on providing germplasm sources of native legumes for rangeland use in the semi-arid western USA, including research on best practices for seed production and rangeland planting. However, few North American forb species (including legumes) are available for use in restoration projects in the southern Great Basin.

Utah trefoil (*Lotus utahensis*) is a legume that naturally occurs in the southern Great Basin and the Mojave Basin and Range. In 2012, we made 19 seed collections across the range of distribution for Utah trefoil in southern Nevada, southern Utah, and northern Arizona. Common gardens of these collections were established in 2013 at three locations in northern Utah, and these replicated plantings were evaluated for plant establishment, collection/population genetic diversity and gene-flow, and a wide range of morphological and physiological characteristics. During this last year, genetically differentiated groups were selected and brought together for seed production to enable further analyses.

Objectives and Methods

1) Determine the best seed treatments to maximize germination: Hard seededness is a common feature in legume species, which limits initial, uniform germination and subsequent establishment. The effects of scarification, boiling water treatment, and age of seed on germination percentage and rate will be investigated to find the most promising accessions of Utah trefoil.

2) Identify planting depths and seasons that will give the best success: Once optimal seed treatments are determined, the best treatment combination will be used in field evaluations of fall dormant and spring plantings at several locations. First and second year establishment/survival will be recorded at each of the test sites to identify best seeding practices.

Results

Nineteen putative Utah lotus collections were made across the southern Great Basin and Mojave Desert. The five collections from Arizona were later classified as scrub lotus (*Lotus wrightii*) (Figure 1). All phenotypic and morphological traits showed significant variation across collections, albeit less so within Utah lotus than between Utah and scrub lotus. Scrub lotus had a later flowering time, and lower seed and dry matter yields (Figures 2 and 3). Utah lotus showed generally greater seed and dry matter yields, with collections LU-5 and LU-20 exhibiting the highest values (Figures 2 and 3).

In addition, we used AFLP molecular markers to evaluate relationships among collections. Collections tended to group by geographic provenance, with a Mantels correlation coefficient of 0.88 ($P = 0.001$). However, phenotypic measures were not significantly correlated with collection site temperatures or elevation, indicating little if any evidence of local adaptation. This is likely a result of the relatively narrow geographic and climatic distribution of this species. Given these data, collections LU-5 and LU-20, which had high seed production potential and biomass production, but with intermediate flowering times, were selected for further studies. Seed of these collections will be harvested summer of 2017.

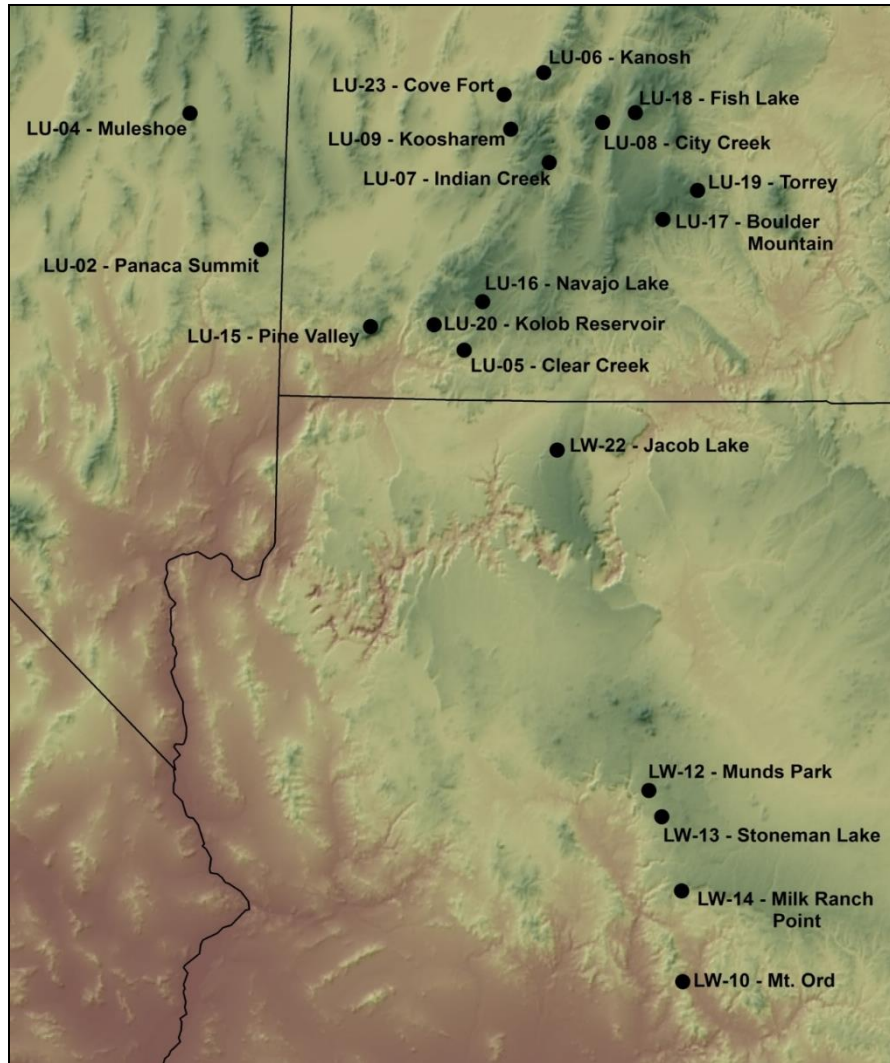


Figure 1. Seed collection sites for Utah lotus (LU) and scrub lotus (LW).

PLANT MATERIALS AND CULTURAL PRACTICES

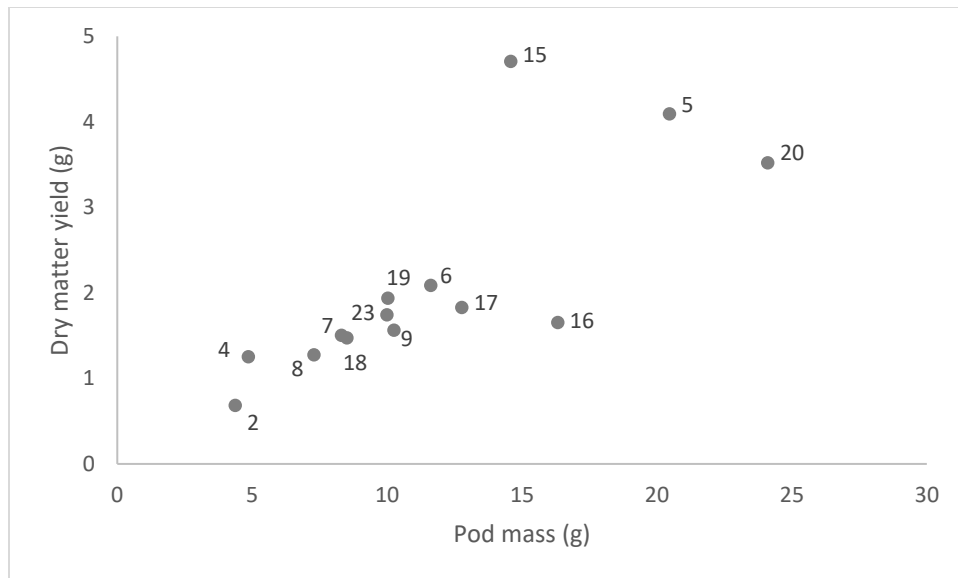


Figure 2. Dry matter yield and pod mass (indirect estimate of seed production potential) in 14 Utah lotus collections. Labels on dots correspond to collection sites identified in Figure 1.

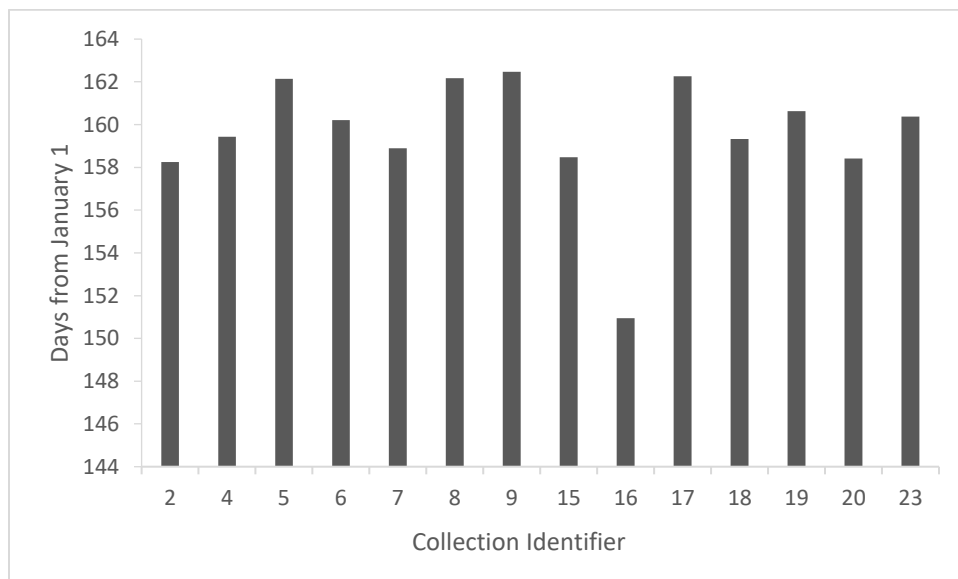


Figure 3. Flowering date of 14 Utah lotus collections. Collection identifiers correspond to collection sites identified in Figures 1 and 2.

Management Applications

- Germplasm release for Utah lotus.
- Seed production guidelines and planting guide
- Peer reviewed publications

Presentations

Johnson, D. A.; MacAdam, J. W.; Connors, K. J.; Stettler, J. M.; Bushman, B. S.; Jones, T. A. High concentrations of condensed tannins in Utah trefoil (*Lotus utahensis* Ottley). Society for Range Management Annual Meeting; 2015 February; Sacramento, CA.

Johnson, D. A.; Stettler, J. M.; Bushman, B. S.; Connors, K. J.; MacAdam, J. W.; Jones, T. A. Utah trefoil (*Lotus uathensis* Ottley): North American legume for rangeland restoration/revegetation in the southern Great Basin and Colorado Plateau of the western U.S.A. National Native Seed Conference; 2015 April; Santa Fe, NM.

Johnson, D. A.; Stettler, J. M.; MacAdam, J. W.; Bushman, B. S.; Connors, K. J.; Jones, T. A. Evaluation of Utah trefoil collections for rangeland restoration in the southern Great Basin. Society for Range Management Annual Meeting; 2016 February; Corpus Christi, TX.

References

Cane, J. H. 2011. Meeting wild bees' needs on western US rangelands. *Rangelands* 33: 27-32.

Pierson, F. B.; Williams, C. J.; Hardegree, S. P.; Weltz, M. A.; Stone, J. J.; Clark, P. E. 2011. Fire, plant invasions, and erosion events on western rangelands. *Rangeland Ecology and Management* 64: 439-449.

Rowland, M. M.; Wisdom, M. J.; Suring, L. H.; Meinke, C. W. 2006. Greater sage-grouse as an umbrella species for sagebrush-associated vertebrates. *Biological Conservation* 129: 323-335.

Sheley, R.; Mangold, J.; Goodwin, K.; Marks J. 2008. Revegetation guidelines for the Great Basin: considering invasive weeds. ARS-168. Washington, D.C.: U.S. Department of Agriculture, Agricultural Research Service: 1-52.

Project Title Great Basin Research Center Seed Increase

Project Agreement No. 16-JV-11221632-052

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Highlights

- Continued growout for increase of native plant materials. Expanded existing increase plots of thistleleaf beardtongue (*Penstemon pachyphyllus*), Nevada goldeneye (*Heliomeris multiflora nevadensis*), and Lewis flax (*Linum lewisii*) in spring 2016. Implemented new increase plots of scarlet gilia (*Ipomopsis aggregata*) and increase fields of basalt milkvetch (*Astragalus fillips*) and Searls' prairie clover (*Dalea searlsiae*) in spring 2016. Implemented new increase plots of firecracker penstemon (*P. eatonii*), Palmer's penstemon (*P. palmeri*), Rocky Mountain beeplant (*Cleome serrulata*), and barestem biscuitroot (*Lomatium nudicaule*) in fall 2016.
- Harvest of seed for distribution for further research and commercial increase. Successfully harvested seed from thistleleaf beardtongue, Nevada goldeneye, Lewis flax, needle and thread (*Heterostipa comata*), nakedstem sunray (*Enceliopsis nudicaulis*) and Searls' prairie clover.
- Distribution of thistleleaf beardtongue seed to grower for commercial scale increase. Distribution of thistleleaf beardtongue seed for further research.
- Installed infrastructure for a further 80 increase plots.

Project Description

Introduction

This project directly supports the National Seed Strategy Goal 1, Objective 1.3 and provides a supportive role for Goal 2 (2015). It is well recognized in these goals that there is a need for the increase of seed for native species both at the commercial scale for restoration efforts, but also to meet research needs. This project is designed to help further both objectives through the increase of small scale wildland collections of native species for release to larger scale commercial production or to researchers for further testing. Work for this project is accomplished by the Utah Division of Wildlife Resources (UDWR) Great Basin Research Center (GBRC) in conjunction with the United States Forest Service (USFS) Rocky Mountain Research Station (RMRS) Provo Shrub Sciences Lab wildland seed collection project.

Objectives

1. Increase seed from wildland collections to support further research and increase distribution of native seed to commercial growers.

2. Keep detailed records of practices and plant growth and production to assess methods to increase seed production of native species in agronomic settings.

Methods

Selected species and accessions of wildland collected seed were planted on the UDWR farms in Fountain Green, UT or the Snow College farm in Ephraim, UT for the purpose of seed increase. Seed was either direct seeded into fields or propagated in the greenhouse for plug transplanting depending on the amount of seed available.

Production fields were maintained and harvested to maximize seed production of native species. When opportunities arose, development of propagation protocols and research for increased establishment and production were conducted. Detailed records were kept on growth traits and production techniques to further assess best practices for seed production.

Results and Discussion

The project continued to expand the number of species and accessions for the increase of native plant materials. In the spring of 2016 we expanded the number of plants in existing increase plots of 16 accessions of thistleleaf beardtongue, four accessions of Nevada goldeneye, and seven accessions of Lewis flax. We also implemented new increase plots of five accessions of scarlet gilia and increase fields of 'NBR-1' basalt milkvetch and 'Fanny' Searls' prairie clover in spring 2016. New increase plots of four accessions of firecracker penstemon, 11 accessions of Palmer's penstemon, six accessions of Rocky Mountain beeplant, and two accessions of barestem biscuitroot were established in the fall of 2016. All other existing increase plots and fields were maintained (Table 1).

Table 1. Native species grown for increase by the GBRC in 2016.

Code	Species	# of Accessions	Location
ASFI	<i>Astragalus filipes</i>	1**	Ephraim
ASTER	<i>Aster sp.</i>	1	Ft. Green
CLSE	<i>Cleome serrulata</i>	6*	Ft. Green
CRAC2	<i>Crepis acuminata</i>	2	Ft. Green
CRIN4	<i>Crepis intermedia</i>	3	Ft. Green
DASE3	<i>Dalea searlsiae</i>	1**	Ephraim & Ft. Green
ENNUN	<i>Enceliopsis nudicaulis</i>	3	Ft. Green
HEMUN	<i>Heliomeris multiflora nevadensis</i>	5*	Ft. Green
IPAG	<i>Ipomopsis aggregate</i>	5**	Ft. Green
LECI4	<i>Leymus cinereus</i>	30***	Ephraim
LILE2	<i>Linum lewisii</i>	9*	Ft. Green
LONU2	<i>Lomatium nudicaule</i>	2**	Ft. Green
HECO26	<i>Hesperostipa comata</i>	7	Ft. Green
PEEA	<i>Penstemon eatonii</i>	4**	Ft. Green
PEPA6	<i>Penstemon pachyphyllus</i>	21*	Ft. Green
PEPA8	<i>Penstemon palmeri</i>	11**	Ft. Green

*Number of plants was increased in 2016.

**New increase plots were established in 2016.

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

The project accomplished the harvest of seed for distribution for further research and commercial increase. We successfully harvested seed from 21 accessions of thistleleaf beardtongue, five

accessions of Nevada goldeneye, nine accessions of Lewis flax, seven accessions of needle and thread, two accessions of nakedstem sunray, one germplasm ('Fanny') of Searls' prairie clover, and one selected release ('UDWR Tetra') of basin wildrye (*Leymus cinereus*). Growth and harvest information are noted in Table 2.

The project distributed 24 pooled sources of thistle beardtongue seed to a grower for commercial scale increase, 15 of which were grown through the increase project. The pooled sources all came from the 15-20 Deg. F./3-6 provisional seed zone (PSZ) for the Great Basin. The project also distributed pooled sources of accessions from three PSZs of thistle beardtongue for research to test their establishment and persistence on a restoration project.

The project continued to expand its capacity with the installation of infrastructure for a further 80 increase plots.

Table 2. Growth and harvest information for native species grown for increase by the GBRC in 2016.

Species/Collection	Peak Bloom Date	Harvest Date(s)	Plant Height (cm) $\pm$ SE	No. of Plants	Cleaned Seed (g)	1000 seed wt. (g) $\pm$ SE
<i>Aster sp.*</i>						
Gold Creek	5/19	7/12	50.1 $\pm$ 2.2	105	800.0	na
<i>Dalea searlsiae</i>						
'Fanny'	na	7/28-9/6	na	na	189.5	3.4733 $\pm$ 0.0657
<i>Enceliopsis nudicaulis*</i>						
Crystal Peak	6/13	6/20-7/13	37.1 $\pm$ 1.3	180	500.0	5.9802 $\pm$ 0.0497
Painted Pot Road	6/13	6/20-7/13	42.9 $\pm$ 1.8	103	520.0	6.2850 $\pm$ 0.1124
<i>Heliomeris multiflora nevadensis</i>						
Jackrabbit Mine	6/23	8/1-8/29	46.2 $\pm$ 3.3	128	462.3	0.4340 $\pm$ 0.0098
Patterson Pass	6/23	8/1-9/6	51.8 $\pm$ 2.7	85	305.4	0.4829 $\pm$ 0.0130
Silverhorn Wash	6/23	8/1-9/28	51.6 $\pm$ 2.8	101	183.0	0.5045 $\pm$ 0.0180
Newcastle	6/23	9/6-9/28	46.1 $\pm$ 3.1	245	112.5	0.5163 $\pm$ 0.0108
Patterson Pass 2	6/23	8/8-9/28	45.9 $\pm$ 4.2	167	150.0	0.5208 $\pm$ 0.0114
<i>Leymus cinereus</i>						
UDWR Tetra	na	na	na	na	94,800	na
<i>Linum lewisii</i>						
Side Hill Pass	6/13	7/5-7/25	54.6 $\pm$ 4.9	29	46.9	2.5741 $\pm$ 0.0254
Jackrabbit Mine	6/13	7/5-7/25	43.6 $\pm$ 3.5	32	40.2	2.4357 $\pm$ 0.0224
Long Hill	6/13	7/5-7/25	65.2 $\pm$ 4.9	117	538.2	2.0428 $\pm$ 0.0100
Patterson Pass	6/13	7/5-7/25	55.9 $\pm$ 4.5	210	1299.2	2.3967 $\pm$ 0.0105
Crystal Peak	6/13	7/5-7/25	71.1 $\pm$ 6.6	242	555.3	2.0111 $\pm$ 0.0287
Wilson Reservoir	6/13	7/5-7/25	52.8 $\pm$ 5.3	63	73.8	2.0935 $\pm$ 0.0221
Majors Place	6/13	7/5-7/25	70.4 $\pm$ 4.4	228	619.5	2.2952 $\pm$ 0.0317
Rice Mountain	6/13	7/5-7/25	65.4 $\pm$ 6.1	159	653.8	2.0229 $\pm$ 0.0112
Halfway Hills	6/13	7/5-7/25	84.5 $\pm$ 4.9	87	489.7	1.9455 $\pm$ 0.0079
<i>Hesperostipa comata*</i>						
Fish Springs Ranch	na	6/20	103.1 $\pm$ 3.8	358	1200.0	2.7348 $\pm$ 0.0221 $\dagger$
Century Peak	na	6/20	107.7 $\pm$ 4.4	163	360.0	2.3784 $\pm$ 0.0330 $\dagger$
Sand Pass 1	na	6/20	101.1 $\pm$ 3.2	219	340.0	2.4344 $\pm$ 0.0334 $\dagger$
Blind Valley-Side Valley	na	6/20	108.6 $\pm$ 4.6	281	740.0	2.5805 $\pm$ 0.0341 $\dagger$
Proctor Flat	na	6/20	92.1 $\pm$ 2.5	303	780.0	2.4809 $\pm$ 0.0387 $\dagger$
South Osgood	na	6/20	101.0 $\pm$ 4.4	248	400.0	3.5969 $\pm$ 0.0812 $\dagger$
Black Rock Road	na	6/20	92.6 $\pm$ 6.0	132	116.8	2.5999 $\pm$ 0.0419 $\dagger$

Table 2. (cont.) Growth and harvest information for native species grown for increase by the GBRC in 2016.

Species/Collection	Peak Bloom Date	Harvest Date(s)	Plant Height (cm) $\pm$ SE	No. of Plants	Cleaned Seed (g)	1000 seed wt. (g) $\pm$ SE
<i>Penstemon pachyphyllus</i>						
Upper Moonshine	5/19	8/1	71.7 $\pm$ 3.4	93	1926.6	2.7029 $\pm$ 0.0178
Applegarth Spring	5/19	7/25	59.4 $\pm$ 3.1	36	380.3	2.5246 $\pm$ 0.0213
Triple 7's	5/19	7/25	73.8 $\pm$ 3.0	54	242.0	2.4667 $\pm$ 0.0030
Cave Creek	5/19	7/25	76.2 $\pm$ 2.5	146	1496.3	2.1956 $\pm$ 0.0192
Cave Lake 2011	5/19	7/25	87.2 $\pm$ 3.8	97	804.6	2.3124 $\pm$ 0.0267
Eberhardt	5/19	7/25	68.9 $\pm$ 4.4	201	1573.2	2.1850 $\pm$ 0.0088
Step toe Creek	5/19	7/25	85.1 $\pm$ 3.5	86	904.7	2.4754 $\pm$ 0.0222
Beaver/Millard Border	5/19	8/1	66.6 $\pm$ 3.6	45	520.1	2.3749 $\pm$ 0.0098
Treasure	5/19	7/25	69.2 $\pm$ 4.0	84	341.8	2.6684 $\pm$ 0.0144
Cottonwood Wash	5/19	8/1	74.1 $\pm$ 3.1	115	1481.9	2.4496 $\pm$ 0.0535
Gubler Canyon	5/19	7/25	76.2 $\pm$ 5.7	88	754.9	2.5023 $\pm$ 0.0205
Paris Creek	5/23	7/25	82.1 $\pm$ 3.0	79	862.2	2.4734 $\pm$ 0.0293
Sand Spring	5/23	8/1	72.5 $\pm$ 2.5	82	1265.7	2.5833 $\pm$ 0.0086
Jockey Road	5/23	7/25	97.9 $\pm$ 3.1	80	798.1	2.6702 $\pm$ 0.0191
Rosebud Spring	5/19	7/25	78.4 $\pm$ 2.0	58	333.4	2.4383 $\pm$ 0.0224
Mount Zeppelin	5/19	8/1	57.1 $\pm$ 2.7	60	560.7	2.5307 $\pm$ 0.0174
Fisher's Wash	5/23	7/25	89.0 $\pm$ 1.5	32	463.5	2.5893 $\pm$ 0.0145
North Cave Lake Turn Off	5/19	7/25	71.2 $\pm$ 2.6	14	217.9	2.6103 $\pm$ 0.0148
Cave Lake 2010*	5/25	7/21	52.3 $\pm$ 2.8	230	153.1	2.0196 $\pm$ 0.0095
Robinson Pass*	5/25	7/21	58.8 $\pm$ 3.6	322	744.1	1.8769 $\pm$ 0.0096
Sacramento Summit*	5/25	7/21	49.7 $\pm$ 2.5	348	653.0	1.5841 $\pm$ 0.0065
Goshute Canyon*	5/25	7/21	55.2 $\pm$ 2.8	225	684.6	1.5766 $\pm$ 0.0158

*Received no additional irrigation.

†500 seed weight.

References

Plant Conservation Alliance and U.S. Department of the Interior, Bureau of Land Management. 2015. National Seed Strategy for Rehabilitation and Restoration 2015-2020. 50 p.

Project Title Plant Material Work at the Provo Shrub Science Lab

Project Agreement No. 17-IA-11221632-180

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Project Descriptions

Forb Islands: Possible Techniques to Improve Forb Seedling Establishment for Diversifying Sagebrush-Steppe Communities

This multiagency cooperative study assessing seed and ground treatments to improve forb establishment was repeated with modification in 2016. The Rocky Mountain Research Station (RMRS) maintains the Spanish Fork test site, developed 44 forb treatment combinations, deployed weather stations and supplied a tractor and seeder to install the study at three Utah and Idaho sites. For complete details see Douglas A. Johnson's write up in this report.

Growing native grasses and forbs with aquaponics, a pilot study.

In an aquaponics system waste produced from farmed fish supply nutrients for plants grown hydroponically. Deseret Peak Aquaponics in Grantsville, Utah has been producing vegetable crops for personal consumption and farmers markets for several years. This novel approach to agriculture offers an alternative and potentially low cost method for producing container plant materials. We partnered with Deseret Peak Aquaponics to evaluate the suitability of aquaponics for growing a test group of native forbs and grasses.

Objectives

Assess the suitability of aquaponics for starting plants from seed, finishing plants started in a traditional greenhouse, dormant bunchgrass root division, and non-dormant bunchgrass root division.

Methods

In this aquaponics system a wood fueled rocket stove provides heat to maintain water in the fish tank and grow beds at approximately 15.6 °C. Styrofoam rafts floating on the grow beds contain plants and insulate the water. For our trials plants were housed in Hortiblock 128/42 LDH-R containers (www.stuewe.com) fitted with 30/50 Qplugs (www.ihort.com).

Our pilot study included four trials.

1. Starting plants from seed.

Four species; gooseberryleaf globemallow (*Sphaeralcea grossulariifolia*), bigflower agoseris (*Agoseris grandiflora*), hairy bigleaf lupine (*Lupinus prunophilus*), and thickleaf

beardtongue (*Penstemon pachyphyllus*) primed with gibberellic acid were sown in Qplugs on aquaponics rafts the third week of March. Plants were removed the first week of May.

2. Finishing plants started in a greenhouse.

Three species; Lewis flax (*Linum lewisii*), thistle beardtongue, and Nevada showy goldeneye (*Helianthus multiflorus* var. *nevadensis*) started in a greenhouse in January were translocated to the aquaponics greenhouse the third week of March where they remained until the first week of May when transplanted to the field site.

3. Dormant bunchgrasses root division.

An individual plant of four dormant bunchgrass species; Basin wildrye (*Leymus cinereus*), Sandberg bluegrass (*Poa secunda*), Indian ricegrass (*Achnatherum hymenoides*), needle and thread (*Hesperostipa comata*) were partitioned into 25 sections and placed within split Qplugs the third week of March where they remained until the first week of May when transplanted to the field site.

4. Non-dormant bunchgrass root division.

Individual plants of two bunchgrasses; muttongrass (*Poa fendleriana*) and bluebunch wheatgrass (*Pseudoroegneria spicata*) that had broken dormancy and were actively growing were partitioned into 25 sections and placed within split Qplugs the third week of May where they remained until the final week of June when they were transplanted to the field site.

Results

Trial 1. Establishment was poor for all four species germinated in the rafts. Globemallow and beardtongue were primed using methods that typically offer moderate to good germination while the lupine and agoseris are non-dormant and generally germinate at high rates. We presume the continuous moist environment was detrimental to establishment.

Trial 2. All three translocated species persisted well in the aquaponic environment. Top growth was slow and roots were sparse but elongated to nearly 30 cm. Long intertwined roots made plant extraction from the rafts time consuming. For each species plants were separated into 3 groups with $\frac{1}{3}$ of the plants transplanted with full length roots (30 cm), $\frac{1}{3}$ planted with roots trimmed to half length (15 cm) and $\frac{1}{3}$ trimmed at the plug. Plants with full and half-length roots were planted to the depth of the plug (5 cm) with the root trailing horizontally in the trough created by a model 5000 mechanical transplanter. Plants were periodically irrigated initially by overhead means then subsurface drip and grew indistinguishable from traditional greenhouse grown plants. Survival on all three groups was near 100%.

Trial 3. Basin wildrye failed to grow in the aquaponic system. The three remaining species put on little top growth but elongate root growth similar to the forbs. Similar to the previous trial roots were trimmed to three lengths and similarly planted. Survival was similar and subsequent growth good for all three species and root groups.

Trial 4. Bunchgrasses that were actively growing remained green in the aquaponic system but completely failed when transplanted.

While top growth was marginal for all species in the aquaponic system translocating traditional greenhouse grown stock and divided dormant bunchgrasses to aquaponics was successful for the trial species. Our curiosity in evaluating dormant and non-dormant bunchgrasses came from an interest in speeding the availability of stock seed supplies. We wondered if plants from desired

wildland stands could be dug, divided, grown, and then transplanted into production fields. This provides an opportunity to advance seed increase if seed harvest had been missed from a desired stand. It appears dormant plants can be propagated in this manner. We didn't evaluate if there is a benefit to the aquaponic step over simply dividing and planting dormant bunchgrasses. The number of root portions that can be sectioned from an individual depends on the size of the root but in this trial we were able to partition each root into at least 25 plants.

Presentations

Jensen, S. L. 2016. The changing face of plant materials; can a new approach improve restoration success? Utah Central Region Watershed Restoration Meeting; 2016 February 2; Springville, Utah.

Jensen, S. L. 2016. The changing face of plant materials; can a new approach improve restoration success? Western North American Invasive Plant Conference; 2016 September 28; Salt Lake City, Utah.

Jensen, S. L. 2016. The changing face of plant materials; can a new approach improve restoration success? Northern Rockies Invasive Plant Conference; 2016 October 20; Boise, Idaho.

Jensen, S. L. 2016. The effect of seed characteristics and sowing depth on emergence of 20 Great Basin forbs. Intermountain Native Plant Summit; 2016 November 2; Boise, Idaho.

Jensen, S. L.; Anderson, Val Joe. 2016. Can restoration success be improved by using local seed sources? BYU Graduate student conclave; 2016 November 17; Provo, Utah.

Publications

Eldredge, Sean D.; Geary, Brad; Jensen, Scott L. 2016. Seed isolates of *Alternaria* and *Aspergillus* fungi increase germination of *Astragalus utahensis*. Native Plants Journal. 17(2): 89-94. <http://www.treesearch.fs.fed.us/pubs/53266>

Jones, Covy D.; Stevens, Mikel R.; Jolley, Von D.; Hopkins, Bryan G.; Jensen, Scott L.; Turner, Dave; Stettler, Jason M. 2016. Evaluation of thermal, chemical, and mechanical seed scarification methods for 4 Great Basin lupine species. Native Plants Journal. 17(1): 5-17. <http://www.treesearch.fs.fed.us/pubs/53267>

Additional Products

▪ *Wildland seed collection*

Seed collection efforts in 2016 were limited to a request to aid the Nevada state office of the US Fish and Wildlife Service (USFWS) in harvesting seed zone specific populations of Sandberg bluegrass (*Poa secunda*). Two populations, one near Wells and the second near Elko, Nevada were harvested yielding 0.85 and 6.9 kg. respectively.

PLANT MATERIALS AND CULTURAL PRACTICES

▪ *Seed Distributed under Contract for Commercial Production*

Species	Source	Quantity	Producer	Contract
Thickleaf penstemon	15-20 Deg F / 3-6 CBR	20 lbs.	Quarter Circle J	USFS R4
Thickleaf penstemon	15-20 Deg F / 6-12 CBR	20 lbs.	Quarter Circle J	USFS R4
Thickleaf penstemon	5-10 Deg F / 6-12 CBR	20 lbs.	Quarter Circle J	USFS R4
whitestem blazingstar	20-25 Deg F / 6-12 CBR	1 lb.	BFI	BLM ELY NV
flatbud pricklypoppy	15-20 Deg F / 6-12 CBR	0.8 lbs	BFI	BLM ELY NV
coyote tobacco	15-20 Deg F / 3-6 CBR	8.8 lbs	BFI	BLM ELY NV
coyote tobacco	15-20 Deg F / 6-12 CBR	2 lbs	BFI	BLM ELY NV

▪ *Internal Seed Increase*

In cooperation with the Utah Division of Wildlife Resources (UDWR) Great Basin Research Center (GBRC) the following materials were planted in increase beds at Fountain Green, Utah.

Species	Source	# populations	1st crop
Rocky Mountain beeplant	5 - 10 Deg. F. / 6 – 12	6	2017
barestem biscuitroot	15 - 20 Deg. F. / 6 – 12	2	2019
Palmer's penstemon	15 - 20 Deg. F. / 6 – 12	11	2018
firecracker penstemon	15 - 20 Deg. F. / 3 – 6	6	2018
gooseberryleaf globemallow	15 - 20 Deg. F. / 6 – 12	12	2018

▪ *Seed Distribution or Conditioning*

Seed of three species, cleftleaf wildheliotrope (*Phacelia crenulata* var. *corrugata*), Beckwith's milkvetch (*Astragalus beckwithii*), and silvery lupine (*Lupinus argenteus*) were provided to Malheur Experiment Station for cultural practice studies.

22.7kg of Munro's globemallow (*Sphaeralcea munroana*) was scarified for Quarter Circle J Seeds to increase the size of an existing production field.

PLANT MATERIALS AND CULTURAL PRACTICES

▪ *Commercial Seed Produced from Seed Stock Distributed by GBNPP Provo.*

Species	Source	Quantity	Producer	Contract
Thickleaf penstemon	14-24 in. /70-80 CBR*	3,510 lbs.	Quarter Circle J	None
Nevada Showy goldeneye	15-20 Deg. F. / 6-12 CBR	1,205 lbs.	Quarter Circle J	None
Gooseberryleaf globemallow	15-20 Deg. F. / 6-12 CBR	500 lbs.	Quarter Circle J	None
Gooseberryleaf globemallow	15-20 Deg. F. / 6-12 CBR	33 lbs.	BFI	USFWS, NV
Munro's globemallow	10-15 Deg. F. / 6-12 CBR	23 lbs.	BFI	USFWS, NV
bigflower agoseris	20-25 Deg. F. / 3-6 CBR	107 lbs.	BFI	USFWS, NV
Yellow spiderflower	15-20 Deg. F. / 6-12 CBR	75 lbs.	BFI	USFWS, NV
Erigeron speciosus	15-20 Deg. F. / 3-6 CBR	19 lbs.	BFI	USFWS, NV
Leymus cinereus	10-15 Deg. F. / 6-12 CBR	438 lbs.	BFI	USFWS, NV
Leymus cinereus	15-20 Deg. F. / 3-6 CBR	286 lbs.	BFI	USFWS, NV
Leymus cinereus	15-20 Deg. F. / 6-12 CBR	345 lbs.	BFI	USFWS, NV
Leymus cinereus	20-25 Deg. F. / 6-12 CBR	136 lbs.	BFI	USFWS, NV
		6,677 total lbs.		

*Original provisional seed zone designation, no longer in use.

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 seed production using small amounts of supplemental water, and seeding practices.

Seven reports follow here, six reports on seed production responses to irrigation for six groups of forb species, plus a single report on plant establishment over species.

1. Irrigation Requirements for Native Buckwheat Seed Production in a Semi-arid Environment

Clinton C. Shock, Erik B. G. Feibert, Alicia Rivera, and Lamont D. Saunders, Malheur Experiment Station, Oregon State University (OSU), Ontario, OR, 2016

Nancy Shaw and Francis Kilkenney, U.S. Forest Service (USFS), Rocky Mountain Research Station (RMRS), Boise, ID

Summary

Native buckwheats (*Eriogonum* spp.) are important perennials in the Intermountain West. Buckwheat seed is desired for rangeland restoration activities, but little cultural practice information is available for seed production of native buckwheat. The seed yield of sulphur-flower buckwheat (*Eriogonum umbellatum*) and parsnipflower buckwheat (*E. heracleoides*) were evaluated over multiple years in response to four biweekly irrigations applying either 0, 1 or 2 inches of water (0, 4, or 8 inches/season). Seed yield of sulphur-flower buckwheat responded to irrigation plus spring precipitation in 10 of the 11 years, with 5 to 11 inches of water applied plus spring precipitation maximizing yields, depending on year. Averaged over 11 years, seed yield of sulphur-flower buckwheat showed a quadratic response to irrigation rate plus spring precipitation and was estimated to be maximized at 232 lbs/acre/year by applying 5.4 inches of water with average spring precipitation of 2.8 inches. Over six seasons, seed yield of parsnipflower buckwheat was responsive to irrigation only in 2013, a dry year when seed yield was maximized by 4.9 inches of applied water. Averaged over 6 years, seed yield of parsnipflower buckwheat showed a quadratic response to irrigation rate with the highest yield achieved with 5 inches of water applied.

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 because they often are not competitive with crop weeds in cultivated fields, which could 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 designed experiments 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 sulphur-flower buckwheat and parsnipflower buckwheat.

Materials and Methods

Plant Establishment

Seed of sulphur-flower buckwheat was received in late November 2004 from the Rocky Mountain Research Station (RMRS) (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% by volume solution of 13% 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 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% 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/100 ft at 8 psi with emitters spaced 16 inches apart, resulting in a water application rate of 0.66 inch/hour.

On March 3, 2005, seed of sulphur-flower buckwheat was planted in 30 inches rows using a custom-made small plot grain drill with disc openers. All seed was planted at 20-30 seed/ft of row at 0.25 inch depth. The trial was irrigated with a minisprinkler system (R10 Turbo Rotator, Nelson Irrigation Corp., Walla Walla, WA) from March 4 to April 29 for even stand establishment. 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. Sulphur-flower buckwheat started emerging on March 29. 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 sulphur-flower buckwheat were uneven, and it did not flower in 2005. In early October, 2005 more seed was received from the RMRS for replanting. The empty lengths of rows were replanted by hand. The seed was replanted on October 26, 2005. In the spring of 2006, the plant stands were excellent.

In early November 2009, drip tape was buried as described above in preparation for planting parsnipflower buckwheat. On November 25, 2009 seed of parsnipflower buckwheat was planted in 30 inch rows using a custom-made small-plot grain drill with disc 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 lbs/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.

After parsnipflower buckwheat emerged, the row cover was removed in April, 2010. The irrigation treatments were not applied to parsnipflower buckwheat in 2010, and stands were not adequate for yield estimates. Gaps in the rows were replanted by hand on November 5, 2010. The replanted seed was covered with a thin layer of a mixture of 50% sawdust and 50% hydro-seeding mulch (Hydrostraw LLC, Manteno, IL) by volume. The mulch mixture was sprayed with water using a backpack sprayer.

Irrigation for Seed Production

The planted strips were divided into plots 30 ft long (sulphur-flower buckwheat in April 2006 and parsnipflower buckwheat in April 2011). 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 four irrigations that were applied approximately every 2 weeks starting at bud formation and flowering. 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. Irrigation dates are found in Table 1.

Flowering, Harvesting, and Seed Cleaning

Flowering dates for each species were recorded annually (Table 1). The sulphur-flower buckwheat plots produced seed in 2006, in part because they had emerged in the spring of 2005. Parsnipflower buckwheat started flowering in 2011. Each year, the middle two rows of each plot were harvested when seed of each species was mature (Table 1). Seed was harvested with a small-plot combine every year, except 2013 and 2016 when seed was harvested manually. Sulphur-flower buckwheat and parsnipflower buckwheat seeds did not separate from the flowering structures in the combine. In 2006, the unthreshed seed of parsnipflower buckwheat was taken to the USFS Lucky Peak Nursery (Boise, ID) and run through a dewinger to separate seed. The seed was further cleaned in a small clipper seed cleaner. In subsequent years, the unthreshed seed of both species was run through a meat grinder to separate the seed. The seed was further cleaned in a small clipper seed cleaner.

Table 1. Sulphur-flower buckwheat and parsnipflower buckwheat flowering, irrigation, and seed harvest dates by species in 2006-2016, Malheur Experiment Station, OSU, Ontario, OR.

Species	Year	Flowering dates			Irrigation dates		Harvest
		Start	Peak	End	Start	End	
sulphur-flower buckwheat	2006	19-May		20-Jul	19-May	30-Jun	3-Aug
	2007	25-May		25-Jul	2-May	24-Jun	31-Jul
	2008	5-Jun	19-Jun	20-Jul	15-May	24-Jun	24-Jul
	2009	31-May		15-Jul	19-May	24-Jun	28-Jul
	2010	4-Jun	12-19 Jun	15-Jul	28-May	8-Jul	27-Jul
	2011	8-Jun	30-Jun	20-Jul	20-May	5-Jul	1-Aug
	2012	30-May	20-Jun	4-Jul	30-May	11-Jul	24-Jul
	2013	8-May	27-May	27-Jun	8-May	19-Jun	9-Jul
	2014	20-May	4-Jun	1-Jul	13-May	24-Jun	10-Jul
	2015	13-May	26-May	25-Jun	29-Apr	10-Jun	2-Jul
	2016	16-May	26-May	25-Jun	27-Apr	7-Jun	1-Jul
parsnipflower buckwheat	2011	26-May	10-Jun	8-Jul	27-May	6-Jul	1-Aug
	2012	23-May	30-May	25-Jun	11-May	21-Jun	16-Jul
	2013	29-Apr	13-May	10-Jun	24-Apr	5-Jun	1-Jul
	2014	1-May	20-May	12-Jun	29-Apr	10-Jun	3-Jul
	2015	24-Apr	5-May	17-Jun	15-Apr	27-May	24-Jun
	2016	26-Apr	6-May	16-Jun	18-Apr	31-May	23-Jun

Cultural Practices 2006

On October 27, 50 lbs phosphorus/acre and 2 lbs zinc/acre were injected through the drip tape to all plots of sulphur-flower buckwheat. November 17, all plots of sulphur-flower buckwheat had Prowl® at 1 lb ai/acre broadcast on the soil surface for weed control. In addition to herbicides, weeds were controlled with hand weeding as necessary.

Cultural Practices 2007

On November 9, all plots of sulphur-flower buckwheat had Prowl® at 1 lb ai/acre broadcast on the soil surface for weed control. In addition to herbicides, weeds were controlled with hand weeding as necessary.

Cultural Practices 2008

On April 15, all plots of sulphur-flower buckwheat had Prowl® at 1 lb ai/acre broadcast on the soil surface for weed control. In addition to herbicides, weeds were controlled with hand weeding as necessary.

Cultural Practices 2009

On March 18, Prowl at 1 lb ai/acre and Volunteer® at 8 oz/acre were broadcast on all sulphur-flower buckwheat plots for weed control. On December 4, all plots of sulphur-flower buckwheat had Prowl® at 1 lb ai/acre broadcast on the soil surface for weed control. In addition to herbicides, weeds were controlled with hand weeding as necessary.

Cultural Practices 2010

On November 17, all plots of sulphur-flower buckwheat had Prowl® at 1 lb ai/acre broadcast on the soil surface for weed control. In addition to herbicides, weeds were controlled with hand weeding as necessary.

Cultural Practices 2011

On November 9, Prowl at 1 lb/acre was broadcast on all plots of both species. In addition to herbicides, weeds were controlled with hand weeding as necessary.

Cultural Practices 2012

On November 7, Prowl at 1 lb/acre was broadcast on all plots of both species. In addition to herbicides, weeds were controlled with hand weeding as necessary.

Cultural Practices 2013

On April 3, Select Max® at 2 lbs/acre was broadcast for grass weed control on all plots of sulphur-flower buckwheat. In addition to herbicides, weeds were controlled with hand weeding as necessary.

Cultural Practices 2014

On February 26, Prowl at 1 lb/acre and Select Max at 2 lbs/acre were broadcast on all plots of both species. In addition to herbicides, weeds were controlled with hand weeding as necessary.

Cultural Practices 2015

On March 13, Prowl at 1 lb/acre was broadcast on all plots of both species. On November 11, Prowl at 1 lbs/acre and Poast at 30 oz/acre were broadcast on all plots of sulphur-flower buckwheat. In addition to herbicides, weeds were controlled with hand weeding as necessary.

Statistical Analysis

Seed yield means were compared by analysis of variance and by linear and quadratic regression. Seed yield (y) in response to irrigation or irrigation plus precipitation (x , inches/season) was estimated by the equation $y = a + b \cdot x + c \cdot x^2$. For the quadratic equations, the amount of irrigation (x') that resulted in maximum yield (y') was calculated using the formula $x' = -b/2c$, where a is the intercept, b is the linear parameter, and c is the quadratic parameter. For the linear regressions, the seed yield responses to irrigation were based on the actual highest amount of water applied plus precipitation and the measured average seed yield.

For each species, seed yields for each year were regressed separately against 1) applied water; 2) applied water plus spring precipitation; 3) applied water plus spring and winter precipitation; and 4) applied water plus spring, winter, and fall precipitation. Winter and spring precipitation occurred in the same year that yield was determined; fall precipitation occurred the prior year.

Adding the seasonal precipitation to the irrigation response equation would have the potential to provide a closer estimate of the amount of water required for maximum seed yields of the *Eriogonum* species. Regressions of seed yield each year were calculated on all the sequential seasonal amounts of precipitation and irrigation, but only some of the regressions are reported below. The period of precipitation plus applied water that had the lowest standard deviation for

irrigation plus precipitation over the years was chosen as the most reliable independent variable for predicting seed yield.

Results and Discussion

Precipitation from January through June in 2009, 2012, and 2014 was close to the average of 5.8 inches (Table 2). Precipitation from January through June in 2006, 2010, and 2011 was higher than the average and precipitation from January through June in 2007, 2008, 2013, 2015, and 2016 was lower than the average of 5.8 inches. The accumulated growing degree-days (50-86°F) from January through June in 2006, 2007, 2013, 2014, 2015, and 2016 were higher than average (Table 2). Both buckwheats flowered and were harvested earlier in 2013-2016 than in 2011-2012 (Table 1), consistent with more early season growing degree-days (Table 2).

Seed Yields Sulphur-flower Buckwheat

In 2006, seed yield of sulphur-flower buckwheat increased with increasing water application, up to 8 inches, the highest amount tested (Tables 3 and 4). In 2007-2009, and 2012-2016 seed yield showed a quadratic response to irrigation rate. In 2010, there was no significant difference in yield between the irrigation treatments. In 2011, seed yield was highest with no irrigation. The 2010 and 2011 seasons had unusually cool and wet weather; accumulated precipitation in April through June of 2010 and 2011 was the highest over the years of the trial (Table 2). The relatively high seed yield of sulphur-flower buckwheat in the nonirrigated 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 compounded by the presence of rust. Irrigation could have exacerbated the rust and resulted in lower yields.

Averaged over the 11 years, seed yield showed a quadratic response to irrigation rate plus spring precipitation and was estimated to be maximized at 232 lbs/acre/year by applying 5.4 inches of water with average spring precipitation of 2.8 inches.

Parsnipflower buckwheat

For parsnipflower buckwheat, there was only one year where a yield response to irrigation existed, so yield responses to only water applied are reported.

In 2013, seed yields showed a quadratic response to irrigation with a maximum seed yield at 4.9 inches of water applied. Seed yields did not respond to irrigation in 2011, 2012, 2014, 2015, and 2016 (Tables 3 and 4). Averaged over 6 years, seed yield of parsnipflower buckwheat showed a quadratic response to irrigation rate with the highest yield achieved with 5 inches of water applied.

Conclusions

The total irrigation requirements for these arid-land species were low and varied by species. parsnipflower buckwheat responded to irrigation only in 2013, a drier than average year. In the other years, natural rainfall was sufficient to maximize seed production in the absence of weed competition. Seed yield of sulphur-flower buckwheat responded to irrigation plus spring precipitation in 10 of the 11 years, with 5 to 11 inches of water applied plus spring precipitation maximizing yields, depending on year. Buckwheat flowering and harvests have been earlier in 2013-2016 than in previous years, probably due to warmer weather.

Acknowledgements

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Table 2. Early season precipitation and growing degree-days at the Malheur Experiment Station, Ontario, OR, 2006-2016.

Year	Precipitation (inches)		Growing degree-days (50-86°F)
	Jan-Jun	Apr-Jun	Jan-Jun
2006	9	3.1	1,273
2007	3.1	1.9	1,406
2008	2.9	1.2	1,087
2009	5.8	3.9	1,207
2010	8.3	4.3	971
2011	8.3	3.9	856
2012	5.8	2.3	1,228
2013	2.6	1.4	1,319
2014	5.1	1.6	1,333
2015	4.8	2.7	1,610
2016	4.4	2.1	1,458
72-year average	5.8	2.7	1,196 ^a

^a23-year average.

Table 3. Sulphur-flower buckwheat and parsnipflower buckwheat seed yield in response to irrigation rate (inches/season) in 2006 through 2016. Malheur Experiment Station, OSU, Ontario, OR.

		Irrigation rate			
Species	Year	0 inches	4 inches	8 inches	LSD (0.05)
lb/acre					
Sulphur-flower buckwheat	2006	155.3	214.4	371.6	92.9
	2007	79.6	164.8	193.8	79.8
	2008	121.3	221.5	245.2	51.7
	2009	132.3	223	240.1	67.4
	2010	252.9	260.3	208.8	NS ^a
	2011	248.7	136.9	121	90.9
	2012	61.2	153.2	185.4	84.4
	2013	113.2	230.1	219.8	77.5
	2014	257	441.8	402.7	82.9
	2015	136.4	124.4	90.7	NS
	2016	183.4	204.3	140.8	NS
	Average	96.3	173.0	165.8	40.9
Parsnipflower buckwheat	2011	55.2	71.6	49	NS ^a
	2012	252.3	316.8	266.4	NS
	2013	287.4	516.9	431.7	103.2
	2014	297.6	345.2	270.8	NS
	2015	83.6	148.2	122.3	NS
	2016	421.6	486.9	437.2	NS
	Average	211.4	311.0	279.4	72.5

^a Not significant. There was no statistically significant trend in seed yield in response to amount of irrigation.

Table 4. Regression analysis for sulphur-flower buckwheat and parsnipflower buckwheat seed yield (y) in response to irrigation (x) (inches/season) using the equation $y = a + b \cdot x + c \cdot x^2$. For the quadratic equations, the amount of irrigation that resulted in maximum yield was calculated using the formula: $x = -b/2c$, where a is the intercept, b is the linear parameter and c is the quadratic parameter. Malheur Experiment Station, OSU, Ontario, OR.

Sulphur-flower buckwheat								
Year	intercept	linear	quadratic	R ²	P	Maximum yield lb/acre	Water applied plus spring precipitation for maximum yield inches/season	Spring precipitation inch
2006	66.6	22.9		0.52	0.05	328.0	11.4	3.4
2007	18.7	35.0	-1.8	0.69	0.05	193.8	10.0	1.9
2008	66.9	41.4	-2.4	0.73	0.01	246.6	8.7	1.4
2009	-35.6	50.6	-2.3	0.6	0.05	242.7	11.0	4.1
2010	178.5	25.2	-1.8	0.08	NS ^a	264.4	6.8	4.3
2011	308.9	-16.0		0.58	0.01	232.7	4.8	4.8
2012	-30.7	40.2	-1.9	0.65	0.01	185.4	10.7	2.6
2013	71.9	51.9	-4.0	0.62	0.05	241.3	6.5	0.9
2014	107.7	98.4	-7.0	0.76	0.01	453.7	7.0	1.7
2015	-35.7	70.4	-5.3	0.55	0.10	199.4	6.7	3.2
2016	96.3	48.9	-4.4	0.47	0.10	233.5	5.6	2.2
Average	71.0	39.1	-2.4	0.75	0.01	231.8	8.2	2.8

Parsnipflower buckwheat								
Year	intercept	linear	quadratic	R ²	P	Maximum yield lb/acre	Water applied for maximum yield 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			
2015	83.6	27.5	-2.8	0.29	NS			
2016	421.6	30.7	-3.6	0.06	NS			
Average	211.4	41.3	-4.1	0.57	0.05	315.4	5.0	

^a Not significant, indicating that there was no statistically significant trend in seed yield in response to amount of irrigation in that year.

2. Irrigation Requirements for Seed Production of Five *Lomatium* species in a Semi-arid Environment

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Summary

Lomatium species are important botanical components in the rangelands of the Intermountain West. Relatively little is known about the cultural practices necessary to produce *Lomatium* seed for use in rangeland restoration activities. The seed yield response to four biweekly irrigations applying either 0, 1, or 2 inches of water (total of 0, 4, or 8 inches/season) was evaluated for four *Lomatium* species over multiple years starting in 2007. In order to improve the accuracy of estimated irrigation water requirements, seed yield responses to irrigation plus precipitation during the previous spring; spring and winter; and spring, winter and fall were also evaluated. On average, over eight seed production seasons, fernleaf biscuitroot (*L. dissectum*) seed yield was maximized by 9.8 inches of water, including applied water and natural spring precipitation (7 inches of water applied plus 2.8 inches of spring precipitation). On average, over ten seed production seasons, Gray's biscuitroot (*L. grayi*) seed yield was maximized by 14 inches of water, including applied water plus spring, winter, and fall precipitation (5.1 inches of water applied plus 8.9 inches of spring, winter, and fall precipitation). On average, over ten seed production seasons, nineleaf biscuitroot (*L. triternatum*) seed yield was maximized by 10.6 inches of water, including applied water plus spring precipitation (7.8 inches of water applied plus 2.8 inches of spring precipitation). Over five seed production seasons, barestem biscuitroot (*L. nudicaule*) seed yield did not respond to irrigation. In three seed production seasons, seed yield of Suksdorf's desertparsley (*L. suksdorfii*) responded to irrigation in one year.

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 production over years.

In native rangelands, the natural variation in spring rainfall and soil moisture results 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 and often are not competitive with crop weeds in cultivated fields, which could limit wildflower seed production. Supplemental water can be provided by sprinkler or furrow irrigation systems, but these irrigation systems risk further encouraging weeds. Sprinkler and furrow irrigation can lead to the loss of plant stand and seed production due to fungal pathogens. Burying drip tapes at 12 inch depth and avoiding wetting the soil surface could help 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 five *Lomatium* species (Table 1).

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.

Table 1. *Lomatium* species planted in the drip irrigation trials at the Malheur Experiment Station, OSU, Ontario, OR.

Species	Common names
<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>Lomatium nudicaule</i>	barestem biscuitroot, barestem lomatium
<i>Lomatium suksdorfii</i>	Suksdorf's desertparsley

Materials and Methods

Plant Establishment

Seed of fernleaf biscuitroot, Gray's biscuitroot, and nineleaf biscuitroot was received in late November 2004 from the RMRS (Boise, ID). The plan was to plant the seed in fall 2004, but due to excessive rainfall in October, 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% by volume solution of 13% 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 Gray's biscuitroot and nineleaf biscuitroot 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% 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/100 ft at 8 psi with emitters spaced 16 inches apart, resulting in a water application rate of 0.066 inch/hour.

On March 3, 2005, seed of the three species (fernleaf biscuitroot, Gray's biscuitroot, and nineleaf biscuitroot) 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 at 0.5 inch depth. The trial was irrigated from March 4 to April 29 with a minisprinkler system (R10 Turbo Rotator, Nelson Irrigation Corp., Walla Walla, WA) for even stand establishment. Risers were spaced 25 ft apart along the flexible polyethylene hose laterals that were spaced 30 ft apart and the water application rate was 0.1 inch/hour. A total of 1.72 inches of water was applied with the minisprinkler system. Nineleaf biscuitroot and Gray's biscuitroot started emerging on March 29. Beginning on June 24, the field was irrigated with the drip irrigation 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 nineleaf biscuitroot and Gray's biscuitroot were uneven; fernleaf biscuitroot did not emerge. None of the species flowered in 2005. In early October, 2005 more seed was

received from the RMRS for replanting. The entire row lengths were replanted using the planter on October 26, 2005. In spring 2006, the plant stands were excellent.

On November 25, 2009 seed of barestem biscuitroot, Suksdorf's desertparsley, and three selections of fearnleaf biscuitroot (LODI 38, LODI 41, and seed from near Riggins, ID) was planted in 30 inch rows using a custom-made plot grain drill with disc 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 lbs/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.

Irrigation for Seed Production

In April 2006 (April 2010 for the species and selections planted in 2009) each planted strip of each species was divided into plots 30 ft long. 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 four irrigations applied approximately every 2 weeks starting with flowering. 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.

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.

Flowering, Harvesting, and Seed Cleaning

Flowering dates for each species were recorded (Table 2). Each year, the middle two rows of each plot were harvested manually when seed of each species was mature (Table 2). Seed was cleaned manually.

Cultural Practices in 2006

On October 27, 2006, 50 lbs phosphorus (P)/acre and 2 lbs zinc (Zn)/acre were injected through the drip tape to all plots. On November 11, 100 lbs nitrogen (N)/acre, as urea, was broadcast to all plots. On November 17, all plots 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.

Cultural Practices in 2007

Irrigations for each species were initiated and terminated on different dates (Table 2).

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.

Cultural Practices in 2009

On March 18, Prowl at 1 lb ai/acre and Volunteer® at 0.2 kg/acre were broadcast on all plots for weed control. On April 9, 50 lbs N/acre and 10 lbs P/acre were applied through the drip irrigation system to the three *Lomatium* spp. On December 4, 2009, Prowl at 1 lb ai/acre was broadcast for weed control on all plots.

Cultural Practices in 2010

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 lbs N/acre was applied to all *Lomatium* spp. plots as URAN (urea ammonium nitrate) injected through the drip tape. On November 9, Prowl at 1 lb ai/acre was broadcast on all plots for weed control.

Cultural Practices in 2012

Iron deficiency symptoms were prevalent in 2012. Liquid fertilizer was injected containing 50 lbs N/acre, 10 lbs P/acre, and 0.3 lb iron (Fe)/acre using a brief pulse of water through the drip irrigation system to all plots on April 13. On November 7, Prowl at 1 lb ai/acre was broadcast on all plots for weed control.

Cultural Practices in 2013

Liquid fertilizer was injected containing 20 lbs N/acre, 25 lbs P/acre, and 0.3 lb Fe/acre using a brief pulse of water through the drip irrigation system to all plots on March 29. On April 3, Select Max at 32 oz/acre was broadcast for grass weed control on all plots.

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 for weed control. Liquid fertilizer was injected containing 20 lbs N/acre, 25 lbs P/acre, and 0.3 lb Fe/acre using a brief pulse of water through the drip irrigation system to all plots on April 2.

Cultural Practices in 2015

On March 13, Prowl at 1 lb ai/acre was broadcast on all plots for weed control. Liquid fertilizer was injected containing 20 lbs N/acre, 25 lbs P/acre, and 0.3 lb Fe/acre using a brief pulse of water through the drip irrigation system to all plots on April 15. On November 6, Prowl at 1 lb ai/acre and Roundup at 24 oz/acre were broadcast on all plots for weed control.

Cultural Practices in 2016

Liquid fertilizer was injected containing 20 lbs N/acre, 25 lbs P/acre, and 0.3 lb Fe/acre using a brief pulse of water through the drip irrigation system to all plots on March 31.

Statistical Analysis

Seed yield means were compared by analysis of variance and by linear and quadratic regression. Seed yield (y) in response to irrigation or irrigation plus precipitation (x, inches/season) was estimated by the equation $y = a + b \cdot x + c \cdot x^2$. For the quadratic equations, the amount of irrigation (x') that resulted in maximum yield (y') was calculated using the formula $x' = -b/2c$, where a is the intercept, b is the linear parameter, and c is the quadratic parameter. For the linear regressions, the seed yield responses to irrigation were based on the actual highest amount of water applied plus precipitation and the measured average seed yield.

For each species, seed yields for each year were regressed separately against 1) applied water; 2) applied water plus spring precipitation; 3) applied water plus spring and winter precipitation; and 4) applied water plus spring, winter, and fall precipitation. Winter and spring precipitation occurred in the same year that yield was determined; fall precipitation occurred the prior year.

Adding the seasonal precipitation to the irrigation response equation would have the potential to provide a closer estimate of the amount of water required for maximum seed yields of the *Lomatium* species. Regressions of seed yield each year were calculated on all the sequential seasonal amounts of precipitation and irrigation, but only some of the regressions are reported below. The period of precipitation plus applied water that had the lowest standard deviation for irrigation plus precipitation over the years was chosen as the most reliable independent variable for predicting seed yield. For the species where there were few years where a yield response to irrigation existed, yield responses to only water applied are reported.

Results and Discussion

Spring precipitation in 2012, 2015, and 2016 was close to the average of 2.8 inches (Table 3). Spring precipitation in 2009, 2010, and 2011 was higher, and spring precipitation in 2007, 2008, 2013, and 2014 was lower than average. The accumulated growing degree-days (50-86°F) from January through June in 2006, 2007, 2013, 2014, 2015, and 2016 were higher than average (Table 2). The high accumulated growing degree-days in 2015 probably caused early harvest dates (Table 2).

Flowering and Seed Set

Gray's biscuitroot and nineleaf biscuitroot started flowering and producing seed in 2007 (second year after fall planting in 2005, Tables 2 and 4). Fernleaf biscuitroot started flowering and producing seed in 2009 (fourth year after fall planting in 2005). Barestem biscuitroot started flowering and produced seed in 2012 (third year after fall planting in 2009), and Suksdorf's deserts parsley started flowering and produced seed in 2013 (fourth year after fall planting in 2009).

Seed Yields

Fernleaf Biscuit Root

Fernleaf biscuitroot 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 fernleaf biscuitroot selection planted in this trial. This infection delayed fernleaf biscuitroot plant development. In 2009, vegetative growth and flowering of fernleaf biscuitroot were improved.

Seed yields of fernleaf biscuitroot showed a quadratic response to irrigation rate plus spring precipitation from 2009 to 2011 and 2013 to 2015 (Tables 4 and 6). In 2012, seed yields of fernleaf biscuitroot did not respond to irrigation. In 2016, seed yield increased linearly with increasing irrigation rate plus spring precipitation. Averaged over the 8 years, seed yield showed a quadratic response to irrigation rate plus spring precipitation and was estimated to be maximized at 1034 lbs/acre/year by applying 9.5 inches of water with average spring precipitation of 2.8 inches.

Fernleaf Biscuitroot Riggins Selection

The Riggins selection fernleaf biscuitroot started flowering in 2013, but only in small amounts. Seed yields of Riggins selection fernleaf biscuitroot showed a quadratic response to irrigation rate plus spring precipitation in 2014 and 2016 (Tables 5 and 7). Seed yields were estimated to be maximized by 4.8 inches of applied water plus 4.3 inches of spring precipitation in 2014. Seed was inadvertently not harvested in 2015. In 2016, seed yields were estimated to be maximized by 5.3 inches of applied water plus 2.2 inches of spring precipitation

Fernleaf Biscuitroot Selections 38 and 41

Fernleaf biscuitroot 38 and 41 started flowering in 2013, but only in small amounts. Seed yields of fernleaf biscuitroot 38 did not respond to irrigation in 2014, 2015, and 2016 (Tables 5 and 7) and seed yields of fernleaf biscuitroot 41 did not respond to irrigation in 2014 and 2016. In 2015, seed yields of fernleaf biscuitroot 41 showed a quadratic response to irrigation rate (Tables 5 and 7). Seed yields of fernleaf biscuitroot 41 were estimated to be maximized by 4.9 inches of applied water plus 3.2 inches of spring precipitation in 2015.

Gray's Biscuitroot

Seed yields of Gray's biscuitroot showed a quadratic response to irrigation rate plus spring, winter, and fall precipitation in all years from 2007 through 2016, except in 2007, 2009, and 2013 (Tables 4 and 6). In 2007, 2009, and 2013, seed yield showed a positive linear response to water applied plus precipitation. In 2010, seed yield was not responsive to irrigation, possibly caused by the unusually wet spring of 2010. Rodent damage was a further complicating factor in 2010 that compromised seed yields. Extensive vole damage occurred over the 2009-2010 winter. The affected areas were transplanted with 3-year-old Gray's biscuitroot 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. On average, seed yields of Gray's biscuitroot were maximized at 778 lbs/acre by 5.1 inches of applied water plus 8.9 inches of spring, winter, and fall precipitation.

Nineleaf Biscuitroot

Seed yields of nineleaf biscuitroot showed a quadratic response to irrigation rate plus spring precipitation from 2008 through 2013 (Tables 4 and 6). In 2007, and 2014 through 2016, seed yield showed a positive linear response to water applied plus spring precipitation. On average, seed yields of nineleaf biscuitroot were maximized at 1206 lbs/acre by 7.8 inches of applied water plus 2.8 inches of spring precipitation.

Barestem Biscuitroot

Seed yields did not respond to irrigation in the 5 years seed was harvested (Tables 4 and 6). Seed yields in the range of 350 to 700 lbs/acre/year were harvested in 2013, 2014, 2015, and 2016, the fourth, fifth, sixth, and seventh year after planting.

Suksdorf's Deserparsley

Suksdorf's desert parsley started flowering in 2013, but only in small amounts. In the three years that seed was harvested, seed yields of Suksdorf's deserparsley only responded to irrigation in 2015 (Tables 5 and 7). In 2015, seed yield increased linearly with increasing water applied up to 8 inches, the highest amount of water applied.

Management Applications

This report describes irrigation practices that can be immediately implemented by seed growers. Multi-year summaries of research findings are found in Tables 4-8.

Conclusions

The *Lomatium* species were relatively slow to produce ample seed. Gray's biscuitroot and nineleaf biscuitroot had reasonable seed yields starting in the second year, fernleaf biscuitroot and barestem biscuitroot were productive in their fourth year, while Suksdorf's deserparsley was only moderately productive in the fifth year after planting. The delayed maturity affects the cost of seed production, but these species have proven to be strong perennials, especially when protected from rodent damage.

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 8). Barestem biscuitroot did not respond to irrigation in these trials; natural rainfall was sufficient to maximize its seed production in the absence of weed competition. Fernleaf biscuitroot required approximately 6 inches of irrigation. Gray's biscuitroot and nineleaf biscuitroot responded quadratically to irrigation with the optimum varying by year.

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Table 2. *Lomatium* flowering, irrigation, and seed harvest dates by species in 2006-2016, Malheur Experiment Station, OSU, Ontario, OR.

Species	Year	Flowering			Irrigation		Harvest
		Start	Peak	End	Start	End	
fernleaf biscuitroot	2006	No flowering			19-May	30-Jun	
	2007	No flowering			5-Apr	24-Jun	
	2008	Very little flowering			10-Apr	29-May	
	2009	10-Apr		7-May	20-Apr	28-May	16-Jun
	2010	25-Apr		20-May	15-Apr	28-May	21-Jun
	2011	8-Apr	25-Apr	10-May	21-Apr	7-Jun	20-Jun
	2012	9-Apr	16-Apr	16-May	13-Apr	24-May	4-Jun
	2013	10-Apr		25-Apr	4-Apr	16-May	4-Jun
	2014	28-Mar		21-Apr	7-Apr	20-May	2-Jun
	2015	1-Apr		24-Apr	1-Apr	13-May	26-May (0 in), 1-Jun (4, 8 in)
	2016	25-Mar		24-Apr	31-Mar	9-May	26-May
Gray's biscuitroot	2006	No flowering			19-May	30-Jun	
	2007	5-Apr		10-May	5-Apr	24-Jun	30-May, 29-Jun
	2008	25-Mar		15-May	10-Apr	29-May	30-May, 19-Jun
	2009	10-Mar		7-May	20-Apr	28-May	16-Jun
	2010	15-Mar		15-May	15-Apr	28-May	22-Jun
	2011	1-Apr	25-Apr	13-May	21-Apr	7-Jun	22-Jun
	2012	15-Mar	25-Apr	16-May	13-Apr	24-May	14-Jun
	2013	15-Mar		30-Apr	4-Apr	16-May	10-Jun
	2014	28-Mar		2-May	7-Apr	20-May	10-Jun
	2015	1-Mar		28-Apr	1-Apr	13-May	1-Jun
	2016	7-Mar		29-Apr	31-Mar	9-May	1-Jun
nineleaf biscuitroot	2006	No flowering			19-May	30-Jun	
	2007	25-Apr		1-Jun	5-Apr	24-Jun	29-Jun, 16-Jul
	2008	25-Apr		5-Jun	10-Apr	29-May	3-Jul
	2009	10-Apr	7-May	1-Jun	20-Apr	28-May	26-Jun
	2010	25-Apr		15-Jun	15-Apr	28-May	22-Jul
	2011	30-Apr	23-May	15-Jun	21-Apr	7-Jun	26-Jul
	2012	12-Apr	17-May	6-Jun	13-Apr	24-May	21-Jun
	2013	18-Apr		10-May	4-Apr	16-May	4-Jun
	2014	7-Apr	29-Apr	2-May	7-Apr	20-May	4-Jun
	2015	10-Apr	28-Apr	20-May	1-Apr	13-May	7-Jun (0 in), 15-Jun (4, 8 in)
	2016	11-Apr	28-Apr	20-May	31-Mar	9-May	15-Jun
barestem biscuitroot	2011	No flowering					
	2012	12-Apr	1-May	30-May	18-Apr	30-May	22-Jun
	2013	11-Apr		20-May	12-Apr	22-May	10-Jun
	2014	7-Apr		13-May	7-Apr	20-May	16-Jun
	2015	25-Mar		5-May	1-Apr	13-May	8-Jun
	2016	5-Apr		5-May	11-Apr	23-May	6-Jun
Suksdorf's desert-parsley	2013	18-Apr		23-May			
	2014	15-Apr		20-May	7-Apr	20-May	30-Jun
	2015	3-Apr	27-Apr	10-May	1-Apr	13-May	23-Jun
	2016	5-Apr	27-Apr	31-May	11-Apr	23-May	28-Jun

Table 3. Early season precipitation and growing degree-days at the Malheur Experiment Station, Ontario, OR, 2006-2016.

Year	Precipitation (inches)		Growing degree-days (50-86°F)
	spring	spring, winter, fall	Jan-Jun
2007	1.9	6.2	1,406
2008	1.4	6.7	1,087
2009	4.1	8.8	1,207
2010	4.3	11.7	971
2011	4.8	14.5	856
2012	2.6	8.4	1,228
2013	0.9	5.3	1,319
2014	1.7	8.1	1,333
2015	3.2	10.4	1,610
2016	2.2	9.1	1,458
Average	2.8	8.9	1,196 ^a

^a23-year average.

Table 4. Seed yield response to irrigation rate (inches/season) for four *Lomatium* species in 2006 through 2016. Malheur Experiment Station, OSU, Ontario, OR.

Species	Year	Irrigation Rate			LSD (0.05)	Species	Year	Irrigation Rate			LSD (0.05)
		0 inches	4 inches	8 inches				0 inches	4 inches	8 inches	
fernleaf biscuitroot		----- lb/acre -----				Gray's biscuitroot		----- lb/acre -----			
2006		---- no flowering ----				2006		---- no flowering ----			
2007		---- no flowering ----				2007		36.1	88.3	131.9	77.7 ^b
2008		- very little flowering -				2008		393.3	1287	1444.9	141
2009		50.6	320.5	327.8	196.4 ^b	2009		359.9	579.8	686.5	208.4
2010		265.8	543.8	499.6	199.6	2010		1035.7	1143.5	704.8	NS
2011		567.5	1342.8	1113.8	180.9	2011		570.3	572.7	347.6	NS
2012		388.1	460.3	444.4	NS	2012		231.9	404.4	377.3	107.4
2013		527.8	959.8	1166.7	282.4	2013		596.7	933.4	1036.3	NS
2014		353.4	978.9	1368.3	353.9	2014		533.1	1418.1	1241.3	672
2015		591.2	1094.7	1376.0	348.7	2015		186.4	576.7	297.6	213.9
2016		1039.4	1612.7	1745.4	564.2	2016		483.7	644.2	322.9	218.7
8-year average		473.0	950.8	1005.3	143.0	10-year average		449.1	764.8	659.1	220.4

Species	Year	Irrigation Rate			LSD (0.05)	Species	Year	Irrigation Rate			LSD (0.05)
		0 inches	4 inches	8 inches				0 inches	4 inches	8 inches	
barestem biscuitroot		----- lb/acre -----				nineleaf biscuitroot		----- lb/acre -----			
						2006		---- no flowering ----			
						2007		2.3	17.5	26.7	16.9 ^b
						2008		195.3	1060.9	1386.9	410
						2009		181.6	780.1	676.1	177
2010		---- no flowering ----				2010		1637.2	2829.6	3194.6	309.4
2011		---- no flowering ----				2011		1982.9	2624.5	2028.1	502.3 ^b
2012		53.8	123.8	61.1	NS	2012		238.7	603	733.2	323.9
2013		357.6	499.1	544	NS	2013		153.7	734.4	1050.9	425
2014		701.3	655.6	590.9	NS	2014		240.6	897.1	1496.7	157
2015		430.6	406.1	309.3	NS	2015		403.2	440.8	954.9	446.6
2016		363.0	403.7	332.5	NS	2016		395.0	475.7	638.4	175.7
5-year average		381.3	417.7	367.6	NS	10-year average		543.0	1046.4	1206.2	147.9

^bLSD (0.10)

Table 5. Seed yield response to irrigation rate (inches/season) for two *Lomatium* species in 2014 - 2016. Malheur Experiment Station, OSU, Ontario, OR.

Species	Year	Irrigation Rate			LSD (0.05)
		0 inches	4 inches	8 inches	
		----- lb/acre -----			
fernleaf biscuitroot 'Riggins'	2014	276.8	497.7	398.4	163
	2016	299.1	679.5	592.4	247.4
2-year average		288.0	588.6	495.4	184.5
fernleaf biscuitroot '38'	2014	281.9	356.4	227.1	NS
	2015	865.1	820.9	774.6	NS
	2016	474.8	634.5	620.0	70.3
3-year average		540.6	603.9	508.2	NS
fernleaf biscuitroot '41'	2014	222.2	262.4	149.8	NS
	2015	152.2	561.9	407.4	181.4
	2016	238.1	297.7	302.0	NS
3-year average		204.2	374.0	286.4	148.8 ^a
Suksdorf's deserparsley	2014	162.6	180.0	139.8	NS
	2015	829.6	1103.9	1832.0	750.2
	2016	692.6	898.8	467.5	NS
3-year average		561.6	727.6	918.5	NS

Table 6. Regression analysis for native wildflower seed yield (y) in response to irrigation (x) (inches/season) using the equation $y = a + bx + cx^2$ in 2006 - 2016, and 8- to 10-year averages. For the quadratic equations, the amount of irrigation that resulted in maximum yield was calculated using the formula: $x = -b/2c$, where a is the intercept, b is the linear parameter and c is the quadratic parameter. Malheur Experiment Station, Ontario, OR.

Fernleaf biscuitroot						Water applied plus spring precipitation for maximum yield		
Year	intercept	linear	quadratic	R^2	P	Maximum yield lb/acre	inches/season	Spring precipitation inch
2009	-922.0	307.9	-16.9	0.60	0.05	478	9.1	4.1
2010	-178.3	128.3	-5.9	0.51	0.05	514	10.8	4.3
2011	-1669.6	618.7	-31.4	0.86	0.001	1380	9.9	4.8
2012	293.9	43.4	-2.8	0.07	NS			2.6
2013	407.0	148.1	-7.0	0.68	0.01	1186	10.5	0.9
2014	9.7	211.4	-7.4	0.83	0.001	1524	14.3	1.7
2015	24.5	198.4	-6.9	0.78	0.01	1441	14.3	3.2
2016	916.9	88.2		0.42	0.05	1623	10.2	2.2
Average	-156.6	250.9	-13.2	0.90	0.001	1034	9.5	2.8
Gray's biscuitroot						Water applied plus spring, winter, and fall precipitation for maximum yield		
Year	intercept	linear	quadratic	R^2	P	Maximum yield lb/acre	inches/season	Spring, winter, fall precipitation inch
2007	-36.6	12.0		0.26	0.10	59	14.2	6.19
2008	-2721.1	621.3	-23.0	0.93	0.001	1475	13.5	6.65
2009	17.8	40.8		0.38	0.05	344	16.8	8.8
2010	-2431.4	495.9	-17.1	0.22	NS			11.7
2011	-1335.1	234.7	-7.1	0.07	NS			14.5
2012	-778.8	172.8	-6.2	0.66	0.01	418	13.8	8.4
2013	344.3	55.0		0.25	0.10	1075	13.3	5.3
2014	-4502.3	890.8	-33.2	0.64	0.05	1477	13.4	8.1
2015	-3980.4	617.7	-20.9	0.71	0.01	579	14.8	10.4
2016	-2046.2	403.1	-15.1	0.66	0.01	651	13.4	9.1
Average	-1806.4	368.7	-13.1	0.58	0.05	778	14.0	9.5
nineleaf biscuitroot						Water applied plus spring precipitation for maximum yield		
Year	intercept	linear	quadratic	R^2	P	Maximum yield lb/acre	inches/season	Spring precipitation inch
2007	-2.6	3.1		0.52	0.01	28	9.9	1.92
2008	-245.1	332.1	-16.9	0.77	0.01	1390	9.8	1.43
2009	-1148.3	416.1	-22.0	0.83	0.001	824	9.5	4.1
2010	-586.2	625.4	-25.9	0.83	0.001	3196	12.1	4.3
2011	-400.3	684.1	-38.7	0.45	0.10	2623	8.8	4.8
2012	-123.6	158.4	-7.3	0.52	0.05	734	10.8	2.6
2013	-3.8	192.2	-8.3	0.68	0.01	1115	11.6	0.9
2014	-22.7	157.4		0.97	0.001	1509	9.7	1.7
2015	101.8	69.0		0.51	0.01	875	11.2	3.2
2016	313.9	30.4		0.29	0.10	624	10.2	2.2
Average	5.9	226.9	-10.7	0.84	0.001	1206	10.6	2.8

^aNot significant. There was no statistically significant trend in seed yield in response to the amount of irrigation.

Table 7. Regression analysis for seed yield response to irrigation rate (inches/season) in 2012-2016 for barestem biscuitroot, Suksdorf's desertparsley, and three selections of fernleaf biscuitroot planted in 2009. 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, OSU, Ontario, OR.

barestem biscuitroot								
Year	intercept	linear	quadratic	R^2	P	Maximum yield lb/acre	Water applied for maximum yield inches/season	
2012	53.8	34.1	-4.1	0.18	NS			
2013	357.6	47.5	-3.0	0.11	NS			
2014	704.5	-13.8		0.08	NS			
2015	430.6	2.9	-2.3	0.15	NS			
2016	363.0	24.1	-3.5	0.07	NS			
Average	399.2	-1.2		0.01	NS			
Suksdorf's desertparsley								
Year	intercept	linear	quadratic	R^2	P	Maximum yield lb/acre	Water applied for maximum yield inches/season	
2014	162.6	11.5	-1.8	0.01	NS			
2015	753.9	125.3		0.43	0.05	1756	8.0	
2016	692.6	131.2	-19.9	0.17	NS			
Average	171.7	-2.5		0.01	NS			
fernleaf biscuitroot 'Riggins'								
Year	intercept	linear	quadratic	R^2	P	Maximum yield lb/acre	Water applied plus spring precipitation for maximum yield inches/season	Spring precipitation inch
2014	82.1	129.9	-10.0	0.57	0.05	503	6.5	1.7
2016	-113.8	218.4	-14.6	0.63	0.05	703	7.5	2.2
Average	-190.8	197.5	-12.3	0.67	0.01	602	8.0	
fernleaf biscuitroot '38'								
Year	intercept	linear	quadratic	R^2	P	Maximum yield lb/acre	Water applied plus spring precipitation for maximum yield inches/season	Spring precipitation inch
2014	281.9	44.1	-6.4	0.11	NS			1.7
2015	865.4	-11.3		0.01	NS			3.2
2016	474.8	61.7	-5.4	0.32	NS			2.2
Average	390.4	65.2	-5.0	0.07	NS			2.8
fernleaf biscuitroot '41'								
Year	intercept	linear	quadratic	R^2	P	Maximum yield lb/acre	Water applied plus spring precipitation for maximum yield inches/season	Spring precipitation inch
2014	222.2	29.1	-4.8	0.13	NS			1.7
2015	-587.4	286.5	-17.6	0.67	0.01	576	8.1	3.2
2016	181.3	29.4	-1.7	0.18	NS			2.2
Average	-88.8	122.4	-8.0	0.39	NS			2.8

Table 8. Amount of irrigation water plus precipitation for maximum *Lomatium* seed yield, years to seed set, and life span. A summary of multi-year research findings, Malheur Experiment Station, OSU, Ontario, OR.

Species	Optimum amount of irrigation plus precipitation	Critical precipitation period	Years to first seed set	Life span
	inches		from fall planting	years
fernleaf biscuitroot	9.5	spring	4	9+
Gray's biscuitroot	14	spring, winter, and fall	2	9+
barestem biscuitroot	no response		3	4+
nineleaf biscuitroot	10.6	spring	2	9+
Suksdorf's desertparsley	no response in 2014 and 2016, 20.3 cm irrigation in 2015	undetermined	5	5+

3. Irrigation Requirements for Seed Production of Five Native *Penstemon* species in a Semi-arid Environment

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Summary

Penstemon is an important wildflower genus in the Great Basin of the United States. Seed of *Penstemon* species are desired for rangeland restoration activities, but little cultural practice information is known for seed production of native penstemons. The seed yield response of five *Penstemon* species to four biweekly irrigations applying either 0, 1, or 2 inches of water (a total of 0, 4, or 8 inches of water/season) was evaluated over multiple years. Sharpleaf penstemon (*P. acuminatus*), seed yields were maximized by 4 – 8 inches of water applied per season in warmer, drier years and did not respond to irrigation in cooler, wetter years. In 6 years of testing, thickleaf beardtongue (*P. pachyphyllus*) seed yields only responded to irrigation in 2013 with 8 inches of applied water maximizing yields. In 6 years of testing, seed yields of scabland penstemon (*P. deustus*) only responded to irrigation in 2015, with highest yields resulting from 5.4 inches of water applied. In 6 years of testing, blue penstemon (*P. cyaneus*) only responded to irrigation in 2013, a dry year and in 2012, a year with average spring precipitation. Royal penstemon (*P. speciosus*) seed yields were maximized by 4 – 9 inches of water applied plus spring precipitation.

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 variation in spring rainfall and soil moisture results 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 do not compete with crop weeds in cultivated fields, and this could 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 designed experiments 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 five species of *Penstemon* native to the Intermountain West (Table 1).

Table 1. *Penstemon* species planted in the drip irrigation trials at the Malheur Experiment Station, Oregon State University (OSU), Ontario, OR.

Species	Common names
<i>Penstemon acuminatus</i>	sharpleaf penstemon, sand-dune penstemon
<i>Penstemon cyaneus</i>	blue penstemon
<i>Penstemon deustus</i>	scabland penstemon, hotrock penstemon
<i>Penstemon pachyphyllus</i>	thickleaf beardtongue
<i>Penstemon speciosus</i>	royal penstemon, sagebrush penstemon

Materials and Methods

Plant Establishment: Sharpleaf Penstemon, Scabland Penstemon, and Royal Penstemon

Seed of sharpleaf penstemon, scabland penstemon, and royal penstemon was received in late November 2004 from the RMRS (Boise, ID). The plan was to plant the seed in fall 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% by volume solution of 13% 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 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% 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/100 ft at 8 psi with emitters spaced 16 inches apart, resulting in a water application rate of 0.066 inch/hour.

On March 3, the seed 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 seed was planted at 0.25 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. Seed 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 were uneven. None of the species flowered in 2005. In early October 2005 more seed was received from the RMRS for replanting. The empty lengths of row were replanted by hand on October 26, 2005 and fall and winter moisture was allowed to germinate the seed. In the spring of 2006, the plant stands of the replanted species were excellent, except for scabland penstemon. On November 11, 2006, the scabland penstemon plots were replanted again at 30 seeds/ft of row.

Cultural Practices in 2006

On October 27, 2006, 50 lbs phosphorus (P)/acre and 2 lbs zinc (Zn)/acre were injected through the drip tape to all plots of each species. On November 17, all plots had Prowl® at 1 lb ai/acre broadcast on the soil surface for weed control. Irrigations for all species were initiated on May 19 and terminated on June 30.

Cultural Practices in 2007

Sharpleaf penstemon and royal penstemon 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).

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 1 lb ai/acre was sprayed on all plots of sharpleaf penstemon and royal penstemon on May 20 for lygus bug control. Irrigations for each species were initiated and terminated on different dates (Table 2). Due to substantial stand loss, all plots of scabland penstemon were disked out.

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 December 4, 2009, Prowl at 1 lb ai/acre was broadcast for weed control on all plots.

Cultural Practices in 2010

On November 17, Prowl at 1 lb ai/acre was broadcast on all plots for weed control. Due to substantial stand loss, all plots of sharpleaf penstemon were disked out.

Cultural practices in 2011

On November 9, Prowl at 1 lb ai/acre was broadcast on all plots for weed control.

Cultural Practices in 2013

On April 3, Select Max® at 32 oz/acre was broadcast for grass weed control on all plots of royal penstemon.

Cultural Practices in 2014

On April 18, Orthene[®] at 8 oz/acre was broadcast to all plots of royal penstemon for lygus bug control. On April 29, 5 lbs iron (Fe)/acre was applied through the drip tape to all plots of royal penstemon.

Cultural Practices in 2015

On April 20, Orthene at 8 oz/acre was broadcast to all plots of royal penstemon for lygus bug control.

Stand of royal penstemon was poor in 2015 due to die-off, especially in the plots with the highest irrigation rate. On November 2, seed of royal penstemon was planted on the soil surface at 30 seeds/ft of row. Following planting, 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.

Weeds were controlled in the first year after fall planting by hand-weeding. In subsequent years, weeds were controlled by yearly applications of Prowl (soil active herbicide) and hand-weeding. Stands of royal penstemon have regenerated by natural reseeding. Prowl was not applied after 2011 to encourage natural reseeding. While natural reseeding might be advantageous for maintaining stands for irrigation research, natural reseeding might be disadvantageous for seed production, because of changes in the genetic composition of the stand over time.

Plant establishment: Blue Penstemon, Scabland Penstemon, and Thickleaf Beardtongue

On November 25, 2009 seed of blue penstemon, scabland penstemon, and thickleaf beardtongue was planted in 30 inch rows using a custom-made plot grain drill with disc 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 blue penstemon and thickleaf beardtongue 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% sawdust and 50% hydroseeding mulch (Hydrostraw LLC, Manteno, IL) by volume. The mulch mixture was sprayed with water using a backpack sprayer.

Cultural Practices in 2011

Seed from the middle 2 rows in each plot of scabland penstemon was harvested with a small plot combine. Seed from the middle 2 rows in each plot of the other species was harvested manually.

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, 50 lbs nitrogen (N)/acre, 10 lbs P/acre, and 0.3 lb Fe/acre was

applied to all plots as liquid fertilizer injected through the drip tape. On April 23, 0.3 lb Fe/acre was applied to all plots as liquid fertilizer injected through the drip tape.

A substantial amount of plant death occurred in the scabland penstemon plots during the winter and spring of 2011/2012. For scabland penstemon, only the undamaged parts in each plot were harvested. Seed of all species was harvested and cleaned manually. On October 26, dead scabland penstemon 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.

Cultural Practices in 2013

Seed of blue penstemon and thickleaf beardtongue was harvested manually. The replanted scabland penstemon did not flower in 2013. Weeds were controlled by handweeding as necessary.

Cultural Practices in 2014

On April 29, 0.3 lb Fe/acre was applied through the drip tape to all plots. Seed of scabland penstemon was harvested with a small plot combine. Seed of the other species was harvested manually.

Cultural Practices in 2015

Seed of scabland penstemon was harvested with a small plot combine. Seed of the other species was harvested manually.

Stand of scabland penstemon was poor in 2015 due to die-off. On November 5, seed of scabland penstemon was planted on the soil surface at 30 seeds/ft of row. Following planting, 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.

Stands of blue penstemon and thickleaf beardtongue are currently poor, but might regenerate from natural reseeding. While natural reseeding might be advantageous for maintaining stands for irrigation research, natural reseeding might be disadvantageous for seed production, because of changes in the genetic composition of the stand over time. Weeds were controlled each year by handweeding.

Irrigation for Seed Production

In April 2006 each planted strip of sharpleaf penstemon, scabland penstemon, and royal penstemon 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 nonirrigated check, 1 inch of water applied per irrigation, and 2 inches of water applied per irrigation. Each treatment received four irrigations that were applied approximately every 2 weeks starting with bud formation and flowering. 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. Scabland penstemon and royal penstemon were irrigated together, but separately from sharpleaf penstemon.

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.

Blue penstemon, scabland penstemon (second planting), and thickleaf beardtongue were irrigated together starting in 2011 using the same procedures as previously described.

Flowering, Harvesting, and Seed Cleaning

Flowering dates for each species were recorded (Table 2). Each year, the middle two rows of each plot were harvested when seed of each species was mature (Table 2). The plant stand for the first planting of scabland penstemon was too poor to result in reliable seed yield estimates. Replanting of scabland penstemon in the fall of 2006 did not result in adequate plant stand in the spring of 2007.

All species were harvested with a Wintersteiger small plot combine. Scabland penstemon 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. The other species were threshed in the combine and the seed was further cleaned using a small clipper seed cleaner. Seed of blue penstemon, thickleaf beardtongue, and royal penstemon were harvested by hand when stands became too poor for combining.

Statistical analysis

Seed yield means were compared by analysis of variance and by linear and quadratic regression. Seed yield (y) in response to irrigation or irrigation plus precipitation (x , inches/season) was estimated by the equation $y = a + b \cdot x + c \cdot x^2$. For the quadratic equations, the amount of irrigation (x') that resulted in maximum yield (y') was calculated using the formula $x' = -b/2c$, where a is the intercept, b is the linear parameter, and c is the quadratic parameter. For the linear regressions, the seed yield responses to irrigation were based on the actual highest amount of water applied plus precipitation and the measured average seed yield.

For royal penstemon, seed yields for each year were regressed separately against 1) applied water; 2) applied water plus spring precipitation; 3) applied water plus spring and winter precipitation; and 4) applied water plus spring, winter, and fall precipitation. Winter and spring precipitation occurred in the same year that yield was determined; fall precipitation occurred the prior year.

Adding the seasonal precipitation to the irrigation response equation would have the potential to provide a closer estimate of the amount of water required for maximum seed yields for royal penstemon. Regressions of seed yield each year were calculated on all the sequential seasonal amounts of precipitation and irrigation, but only some of the regressions are reported below. The period of precipitation plus applied water that had the lowest standard deviation for irrigation plus precipitation over the years was chosen as the most reliable independent variable for predicting seed yield. For the other species, there were few years where a yield response to irrigation existed, so yield responses to only water applied are reported.

Results and Discussion

Precipitation from January through June in 2009, 2012, and 2014 was close to the average of 5.8 inches (Table 3). Precipitation from January through June in 2006, 2010, and 2011 was higher than the average, and precipitation from January through June in 2007, 2008, 2013, 2015, and 2016 was lower than the average of 5.8 inches. The accumulated growing degree-days (50-86°F) from January through June in 2006, 2007, 2013, 2014, 2015, and 2016 were higher than average (Table 3).

Flowering and Seed Set

Sharpleaf penstemon and royal penstemon 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. Sharpleaf penstemon and royal penstemon start flowering in early May (Table 2). 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 sharpleaf penstemon and royal penstemon in 2007 also was related to poor vegetative growth compared to 2006 and 2008. In 2009, all plots of sharpleaf penstemon and royal penstemon again showed poor vegetative growth and seed set. Root rot affected all plots of sharpleaf penstemon 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 royal penstemon in 2009, but the stand partially recovered due to natural reseeding.

The replanting of royal penstemon in the fall of 2015 resulted in a good stand in 2016. The new stand of royal penstemon did not flower in 2016.

Seed Yields

Sharpleaf Penstemon

There was no significant difference in seed yield between irrigation treatments for sharpleaf penstemon in 2006 (Tables 4 and 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 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. 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% 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. Sharpleaf penstemon performed as a short-lived perennial.

Blue Penstemon

In 2012, seed yields increased with increasing irrigation up to the highest tested of 8 inches (Tables 4 and 5). In 2013, seed yields showed a quadratic response to irrigation with a maximum seed yield at 4 inches of water applied. In 2015, seed yields were highest with the highest

amount of water applied, 8 inches (Table 4). Seed yields did not respond to irrigation in 2011, 2014, and 2016.

Scabland Penstemon

Seed yields did not respond to irrigation in any year except 2011 and 2015. In 2011, seed yields were highest with no irrigation (Tables 4 and 5). In 2015, seed yield showed a quadratic response to irrigation with a maximum seed yield at 5.4 inches of water applied.

Thickleaf Beardtongue

Seed yields did not respond to irrigation in 2011, 2012, 2014, 2015, and 2016 (Tables 4 and 5). In 2013, seed yields increased with increasing irrigation up to the highest level of 8 inches.

Royal Penstemon

In 2006-2009 and 2014 and 2015, seed yield of royal penstemon showed a quadratic response to irrigation rate plus spring precipitation (Tables 4 and 5). Seed yields were maximized by 7.7, 6.1, 6.4, 8.3, 6.9, and 8.2 inches of water applied plus spring precipitation in 2006, 2007, 2008, 2009, 2014, and 2015, respectively. In 2011 and 2012 there was no difference in seed yield between treatments. In 2010, seed yields were highest with no irrigation and 4.3 inches of spring precipitation. In 2013, seed yield increased with increasing water application, up to 8.9 inches, the highest amount tested (includes 0.9 inches of spring precipitation). 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.

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 semi-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 semi-arid-land species were low and varied by species (Table 6). Sharpleaf penstemon did not respond to irrigation in these trials. In 6 years of testing, seed yields of scabland penstemon responded to irrigation only in 2015. Natural rainfall was sufficient to maximize seed production in the absence of weed competition.

Acknowledgements

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Table 2. *Penstemon* flowering, irrigation, and seed harvest dates by species in 2006-2016, Malheur Experiment Station, OSU, Ontario, OR.

Species	Year	Flowering dates			Irrigation dates		Harvest
		Start	Peak	End	Start	End	
sharpleaf penstemon	2006	2-May	10-May	19-May	19-May	30-Jun	7-Jul
	2007	19-Apr		25-May	19-Apr	24-Jun	9-Jul
	2008	29-Apr		5-Jun	29-Apr	11-Jun	11-Jul
	2009	2-May		10-Jun	8-May	12-Jun	10-Jul
blue penstemon	2011	23-May	15-Jun	8-Jul	13-May	23-Jun	18-Jul
	2012	16-May	30-May	10-Jun	27-Apr	7-Jun	27-Jun
	2013	3-May	21-May	5-Jun	24-Apr	5-Jun	11-Jul
	2014	5-May	13-May	8-Jun	29-Apr	10-Jun	14-Jul
	2015	5-May		12-Jun	21-Apr	3-Jun	13-Jul
	2016	29-Apr		15-Jun	18-Apr	31-May	8-Jul
scabland penstemon ^a	2006	10-May	19-May	30-May	19-May	30-Jun	4-Aug
	2007	5-May	25-May	25-Jun	19-Apr	24-Jun	
	2008	5-May		20-Jun	18-Apr	31-May	
	2011	23-May	20-Jun	14-Jul	13-May	23-Jun	16-Aug
	2012	16-May	30-May	4-Jul	27-Apr	7-Jun	7-Aug
	2013	3-May	18-May	15-Jun	24-Apr	5-Jun	
	2014	10-May	20-May	19-Jun	29-Apr	10-Jun	21-Jul
	2015	1-May		10-Jun	21-Apr	3-Jun	23-Jul
	2016	no flowering			18-Apr	31-May	
thickleaf beardtongue	2011	10-May	30-May	20-Jun	13-May	23-Jun	15-Jul
	2012	23-Apr	2-May	10-Jun	27-Apr	7-Jun	26-Jun
	2013	26-Apr		21-May	24-Apr	5-Jun	8-Jul
	2014	22-Apr	5-May	4-Jun	29-Apr	10-Jun	13-Jul
	2015	24-Apr	5-May	26-May	21-Apr	3-Jun	10-Jul
	2016	18-Apr		13-May	18-Apr	31-May	22-Jun
royal penstemon	2006	10-May	19-May	30-May	19-May	30-Jun	13-Jul
	2007	5-May	25-May	25-Jun	19-Apr	24-Jun	23-Jul
	2008	5-May		20-Jun	29-Apr	11-Jun	17-Jul
	2009	14-May		20-Jun	19-May	24-Jun	10-Jul
	2010	14-May		20-Jun	12-May	22-Jun	22-Jul
	2011	25-May	30-May	30-Jun	20-May	5-Jul	29-Jul
	2012	2-May	20-May	25-Jun	2-May	13-Jun	13-Jul
	2013	2-May	10-May	20-Jun	2-May	12-Jun	11-Jul
	2014	29-Apr	13-May	9-Jun	29-Apr	10-Jun	11-Jul
	2015	28-Apr	5-May	5-Jun	21-Apr	3-Jun	30-Jun
	2016	no flowering					

Table 3. Early season precipitation and growing degree-days at the Malheur Experiment Station, OSU, Ontario, OR, 2006-2016.

Year	Precipitation (inches)		Growing degree-days (50-86°F)
	Jan-Jun	Apr-Jun	Jan-Jun
2006	9	3.1	1,273
2007	3.1	1.9	1,406
2008	2.9	1.2	1,087
2009	5.8	3.9	1,207
2010	8.3	4.3	971
2011	8.3	3.9	856
2012	5.8	2.3	1,228
2013	2.6	1.4	1,319
2014	5.1	1.6	1,333
2015	4.8	2.7	1,610
2016	4.4	2.1	1,458
73-year average	5.8	2.6	1,196 ^a

^a23-year average.

PLANT MATERIALS AND CULTURAL PRACTICES

Table 4. Native wildflower seed yield in response to irrigation rate (inches/season) in 2006 through 2016. Malheur Experiment Station, OSU, Ontario, OR.

Species	Year	0 inches	4 inches	8 inches	LSD (0.05)	Species	Year	0 inches	4 inches	8 inches	LSD (0.05)
		lb/acre						lb/acre			
sharpleaf penstemon ^a	2006	538.4	611.1	544	NS	thickleaf beardtounge	2011	569.9	337.6	482.2	NS
	2007	19.3	50.1	19.1	25.5 ^b		2012	280.5	215	253.7	NS
	2008	56.2	150.7	187.1	79		2013	159.4	196.8	249.7	83.6
	2009	20.7	12.5	11.6	NS		2014	291.7	238.6	282.1	NS
	2010	-- Stand disked out --					2015	89.5	73.5	93.3	NS
							2016	142.7	186.3	169.7	NS
							Average	255.6	208.0	255.1	NS
blue penstemon	2011	857.2	821.4	909.4	NS	royal penstemon ^a	2006	163.5	346.2	213.6	134.3
	2012	343.3	474.6	581.2	202.6 ^b		2007	2.5	9.3	5.3	4.7 ^b
	2013	221.7	399.4	229.2	74.4		2008	94	367	276.5	179.6
	2014	213.9	215.4	215.1	NS		2009	6.8	16.1	9	6.0 ^b
	2015	130.5	144.7	262.9	80.8		2010	147.2	74.3	69.7	NS
	2016	36.0	51.1	79.6	NS		2011	371.1	328.2	348.6	NS
	Average	303.4	345.8	371.9	NS		2012	103.8	141.1	99.1	NS
scabland penstemon ^c	2006	1246.4	1200.8	1068.6	NS		2013	8.7	80.7	138.6	63.7
	2007	120.3	187.7	148.3	NS		2014	76.9	265.6	215.1	76.7
	2008	-- Stand disked out --					2015	105.4	207.3	173.7	50.3
	2011	637.6	477.8	452.6	NS		2016	--- no flowering ---			
	2012	308.7	291.8	299.7	NS		Average	108.3	177.8	151.1	40.2
	2013	--- no flowering ---									
	2014	356.4	504.8	463.2	NS						
	2015	20.0	76.9	67.0	43.7 ^b						
	Average	333.0	339.9	321.4	NS						

^a Planted March, 2005, areas of low stand replanted by hand in October 2005.

^bLSD (0.10)

^c Planted 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.

Table 5. Regression analysis for native wildflower seed yield (y) in response to irrigation (x) (inches/season) using the equation $y = a + b \cdot x + c \cdot x^2$ in 2006-2016, and 4- to 10-year averages. For the quadratic equations, the amount of irrigation that resulted in maximum yield was calculated using the formula: $x = -b/2c$, where a is the intercept, b is the linear parameter and c is the quadratic parameter. Malheur Experiment Station, Oregon State University (OSU), Ontario, OR. (Continued on next page.)

sharpleaf penstemon							
Year	Intercept	linear	quadratic	R^2	P	Maximum yield	Water applied for maximum yield
2006	538.4	35.6	-4.4	0.03	NS ^a		
2007	19.3	15.4	-1.9	0.44	0.1	50.5	4.1
2008	56.2	30.9	-1.8	0.63	0.05	188.8	8.6
2009	19.5	-1.1		0.23	NS		
Average	165.6	17.1	-1.8	0.1	NS		
blue penstemon							
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		
2012	855.8	29.7		0.84	0.001	1093.4	8.0
2013	221.7	87.9	-10.9	0.63	0.05	398.9	4.0
2014	214.2	0.1		0.01	NS		
2015	113.2	16.6		0.32	NS		
2016	33.8	5.4		0.18	NS		
Average	360.6	9.2		0.24	NS		
scabland penstemon							
Year	intercept	linear	quadratic	R^2	P	Maximum yield	Water applied for maximum yield
						lb/acre	inches/season
2006	1260.9	-22.2		0.05	NS		
2007	120.3	30.2	-3.3	0.19	NS		
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		
2015	20.0	22.6	-2.1	0.42	0.10	81.0	5.4
Average	333.0	4.9	-0.79	0.03	NS		

^aNot significant. There was no statistically significant trend in seed yield in response to the amount of irrigation.

Table 5. (Continued) Regression analysis for native wildflower seed yield in response to irrigation rate (inches/season) in 2006-2016, and 4- to 10-year averages. Malheur Experiment Station, OSU, Ontario, OR.

thickleaf beardtongue							Water applied for maximum yield
Year	intercept	linear	quadratic	R^2	P	Maximum yield lb/acre	inches/season
2011	507.1	-11		0.04	NS ^a		
2012	263.1	-3.3		0.01	NS		
2013	156.8	11.3		0.33	0.1	247.2	8.0
2014	275.6	-1.2		0.01	NS		
2015	89.5	-8.5	1.1	0.06	NS		
2016	142.7	18.4	-1.9	0.07	NS		
Average	239.81	-0.06		0	NS		

royal penstemon							Water applied plus spring precipitation for maximum yield	Spring precipitation
Year	intercept	linear	quadratic	R^2	P	Maximum yield lb/acre	inches/season	inch
2006	-238.2	151.9	-9.9	0.66	0.05	347.2	7.7	3.4
2007	-5.1	4.7	-0.4	0.48	0.10	9.3	6.1	1.9
2008	-91.7	146.1	-11.4	0.56	0.05	378.4	6.4	1.4
2009	-19.5	8.6	-0.5	0.54	0.05	16.2	8.3	4.1
2010	177.8	-9.7		0.28	0.10	135.8	4.3	4.3
2011	374.0	-2.8		0.01	NS			4.8
2012	6.5	46.7	-3.6	0.54	0.05	158.8	6.5	2.6
2013	-2.8	16.2		0.77	0.001	141.0	8.9	0.9
2014	-78.8	102.9	-7.5	0.62	0.05	275.5	6.9	1.7
2015	-75.1	69.7	-4.2	0.64	0.05	211.6	8.2	3.2

^aNot significant. There was no statistically significant trend in seed yield in response to the amount of irrigation.

Table 6. Amount of irrigation water for maximum *Penstemon* seed yield, years to seed set, and life span. A summary of multi-year research findings, Malheur Experiment Station, OSU, Ontario, OR.

Species	Optimum amount of irrigation for seed production	Year of first seed set	Approximate life span
	inches/season	from fall planting	years
sharpleaf penstemon	0 in wetter years, 4 in warm, dry years	1	3
blue penstemon	0 in wetter years, 4-8 in drier years	1	3
scabland penstemon	response to irrigation in 1 out of 6 years	2	3
thickleaf beardtongue	no response in 2011, 2012, 2014, 2015, 20.3 cm in 2013 (drier year)	1-2	3
royal penstemon	0 in cool, wet years, 4-8 in warm, dry years	1-2	3

4. Prairie Clover and Basalt Milkvetch Seed Production in Response to Irrigation

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Summary

Legumes are important components of rangeland vegetation in the Intermountain West due to their supply of protein to wildlife and livestock and contribution of nitrogen to rangeland productivity. Seed of selected native legumes is needed for rangeland restoration, but cultural practices for native legume production are largely unknown. The seed yield response of three native legume species to irrigation was evaluated starting in 2011. Four biweekly irrigations applying either 0, 1, or 2 inches of water (a total of 0, 4, or 8 inches/season) were tested. Over the 6-year period of study, Searls' prairie clover (*Dalea searlsiae*) seed yield was maximized by 13-17 inches of water applied plus spring, winter, and fall precipitation per season. Blue Mountain or western prairie clover (*D. ornata*) seed yield was maximized by 13-16 inches of water applied plus spring, winter, and fall precipitation per season. Seed yield of basalt milkvetch (*Astragalus filipes*) did not respond to irrigation.

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 natural rangelands, 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 are often not competitive with crop weeds in cultivated fields, and this could limit wildflower seed production. Both sprinkler and furrow irrigation can 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 designed experiments 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 three native wildflower legume species (Table 1) planted in 2009.

Table 1. Wildflower species in the legume family planted in the fall of 2009 at the Malheur Experiment Station, OSU, Ontario, OR.

Species	Common names	Growth habit
<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

Materials and Methods

Plant Establishment

Each of three species was planted in four rows 30 inches apart in a 10 ft wide strip about 450 ft long on Nyssa silt loam at the Malheur Experiment Station, Ontario, Oregon. The soil had a pH of 8.3 and 1.1% organic matter. In October 2009, two drip tapes 5 ft 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/100 ft 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 three species (Table 1) was planted in 30 inch rows using a custom-made plot grain drill with disc 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 lbs/acre). Following planting and sawdust application, the beds were covered with row cover (N-sulate, DeWitt Co., Inc., Sikeston, MO), which 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.

After the newly planted wildflowers emerged, the row cover was removed in April 2010. The variable irrigation treatments were not applied to these legumes until 2011.

Each year, plots were hand-weeded as necessary. Seed from the middle two rows in each plot was harvested manually (Table 2).

Irrigation for Seed Production

In April 2011 each strip of each wildflower species was divided into 12 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 applied approximately every 2 weeks starting at bud formation and flowering. 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 the species due to different timings of flowering and seed formation. The irrigation treatments of the two *Dalea* spp. were applied together. The basalt milkvetch was irrigated separately to correspond to its flowering and seed set. Flowering, irrigation, and harvest dates were recorded (Table 2).

Seed Beetle Control

Harvested seed pods of western prairie clover, Searls' prairie clover, and basalt milkvetch were extensively damaged from feeding by seed beetles in 2013 and 2014, indicating that control measures during and after flowering would be necessary to maintain seed yields. On May 21,

2015, Capture[®] 2EC at 6.4 oz/acre (0.1 lb ai/acre) and Rimon[®] at 12 oz/acre (0.08 lb ai/acre) were broadcast in the evening to minimize harm to pollinators. On May 28, 2015, Rimon at 12 oz/acre was broadcast in the evening to minimize harm to pollinators. Seed beetles were not observed during flowering in 2016.

Statistical analysis

Seed yield means were compared by analysis of variance and by linear and quadratic regression. Seed yield (y) in response to irrigation or irrigation plus precipitation (x, inches/season) was estimated by the equation $y = a + b \cdot x + c \cdot x^2$. For the quadratic equations, the amount of irrigation (x') that resulted in maximum yield (y') was calculated using the formula $x' = -b/2c$, where a is the intercept, b is the linear parameter, and c is the quadratic parameter. For the linear regressions, the seed yield responses to irrigation were based on the actual highest amount of water applied plus precipitation and the measured average seed yield.

Seed yields for each year were regressed separately against 1) applied water; 2) applied water plus spring precipitation; 3) applied water plus spring and winter precipitation; and 4) applied water plus spring, winter, and fall precipitation. Winter and spring precipitation occurred in the same year that yield was determined; fall precipitation occurred the prior year.

Adding the seasonal precipitation to the irrigation response equation would have the potential to provide a closer estimate of the amount of water required for maximum seed yields. Regressions of seed yield each year were calculated on all the sequential seasonal amounts of precipitation and irrigation, but only some of the regressions are reported below. The period of precipitation plus applied water that had the lowest standard deviation for irrigation plus precipitation over the years was chosen as the most reliable independent variable for predicting seed yield. For basalt milkvetch, seed yield was not responsive to irrigation, so yield responses to only water applied are reported.

Results and Discussion

Precipitation from January through June was close to average in 2012, 2014, 2015, and 2016, higher than average in 2011, and lower than average in 2013 (Table 3). The accumulation of growing degree-days (50-86°F) was increasingly higher than average from 2012 to 2016, and was below average in 2011 (Table 3). Flowering and seed harvest were early in 2015 and 2016, probably due to warmer weather and greater accumulation of growing degree-days.

Searls' Prairie Clover

In 2012, 2014, 2015, and 2016 seed yields showed a quadratic response to irrigation plus spring, winter, and fall precipitation (Table 5). Maximum seed yields were achieved with 15, 17, 17, and 45 inches of water applied plus spring, winter, and fall precipitation in 2012, 2014, 2015, and 2016, respectively. In 2013, seed yields increased with increasing irrigation rate up to the highest tested of 8 inches plus 13.5 inches of spring, winter, and fall precipitation. In 2011, seed yields were highest with no irrigation plus 14.5 inches of spring, winter, and fall precipitation.

Blue Mountain or Western Prairie Clover

Seed yields showed a quadratic response to irrigation in 2012 - 2016 with a maximum seed yield at 16, 13, 15, 15, and 14.5 inches of water applied plus spring, winter, and fall precipitation, respectively (Tables 4 and 5). Seed yields in 2011 were highest with no irrigation plus 36.83 cm of spring, winter, and fall precipitation.

Basalt Milkvetch

Seed yields responded to irrigation only in 2013, when 4 inches of applied water was among the irrigation rates resulting in the highest yield (Tables 4 and 5). Low seed yields of basalt milkvetch are related to low plant stand and high seed pod shatter that makes seed recovery problematic.

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Table 2. Early season precipitation and growing degree-days at the Malheur Experiment Station, Ontario, OR, 2006-2016.

Year	Precipitation (inches)		Growing degree-days (50-86°F)
	Jan-Jun	Apr-Jun	Jan-Jun
2006	9	3.1	1,273
2007	3.1	1.9	1,406
2008	2.9	1.2	1,087
2009	5.8	3.9	1,207
2010	8.3	4.3	971
2011	8.3	3.9	856
2012	5.8	2.3	1,228
2013	2.6	1.4	1,319
2014	5.1	1.6	1,333
2015	4.8	2.7	1,610
2016	4.4	2.1	1,458
72-year average	5.8	2.7	1,196 ^a

^a23-year average.

Table 3. Native wildflower flowering, irrigation, and seed harvest dates by species. Malheur Experiment Station, OSU, Ontario, OR.

Species	Year	Flowering			Irrigation		Harvest
		Start	Peak	End	Start	End	
Searls' prairie clover							
	2011	8-Jun	20-Jun	20-Jul	27-May	6-Jul	21-Jul
	2012	23-May	10-Jun	30-Jun	11-May	21-Jun	10-Jul
	2013	13-May		15-Jun	8-May	19-Jun	29-Jun
	2014	15-May	4-Jun	24-Jun	6-May	17-Jun	1-Jul
	2015	13-May	26-May	16-Jun	5-May	17-Jun	22-Jun
	2016	11-May	28-May	10-Jun	3-May	14-Jun	16-Jun
Western prairie clover							
	2011	8-Jun	20-Jun	20-Jul	27-May	6-Jul	22-Jul
	2012	23-May	10-Jun	30-Jun	11-May	21-Jun	11-Jul
	2013	13-May	21-May	15-Jun	8-May	19-Jun	28-Jun
	2014	15-May	4-Jun	24-Jun	6-May	17-Jun	1-Jul
	2015	5-May	26-May	22-Jun	5-May	17-Jun	25-Jun
	2016	3-May	26-May	10-Jun	3-May	14-Jun	13-Jun
Basalt milkvetch							
	2011	20-May	26-May	30-Jun	13-May	23-Jun	18-Jul
	2012	28-Apr	23-May	19-Jun	11-May	21-Jun	5-Jul
	2013	3-May	10-May	25-May	8-May	19-Jun	28-Jun
	2014	5-May	13-May	28-May	29-Apr	10-Jun	24-Jun
	2015	17-Apr	13-May	1-Jun	21-Apr	3-Jun	16-Jun

Table 4. Native wildflower seed yield in response to irrigation rate (inches/season). Malheur Experiment Station, OSU, Ontario, OR.

Species	Year	0 inches	4 inches	8 inches	LSD (0.05)
----- lb/acre -----					
Searls' prairie clover					
	2011	262.7	231.2	196.3	50.1
	2012	175.5	288.8	303.0	93.6
	2013	14.8	31.7	44.4	6.1
	2014	60.0	181.4	232.2	72.9
	2015	221.2	330.7	344.2	68.3
	2016	148.7	238.8	222.3	56.0
	Average	147.2	217.1	223.7	30.5
Western prairie clover					
	2011	451.9	410.8	351.7	NS ^a
	2012	145.1	365.1	431.4	189.3
	2013	28.6	104.6	130.4	38.8
	2014	119.4	422.9	476.3	144.1
	2015	212.9	396.7	267.2	109.6
	2016	246.3	307.9	312.4	NS
	Average	201.5	326.1	332.0	72.6
Basalt milkvetch					
	2011	87	98.4	74	NS
	2012	22.7	12.6	16.1	NS
	2013	8.5	9.8	6.1	2.7 ^b
	2014	56.6	79.3	71.9	NS
	2015	17.8	12.5	11.6	NS
	Average	38.5	35.2	36.0	NS

^a NS = not significant, ^b LSD (0.10)

Table 5. Regression analysis for native wildflower seed yield (y) in response to irrigation (x) (inches/season) using the equation $y = a + b \cdot x + c \cdot x^2$. For the quadratic equations, the amount of irrigation that resulted in maximum yield was calculated using the formula: $x = -b/2c$, where a is the intercept, b is the linear parameter and c is the quadratic parameter. Malheur Experiment Station, Oregon State University (OSU), Ontario, OR.

Searls' prairie clover

Year	intercept	linear	quadratic	R^2	P	Maximum yield (lb•acre ⁻¹)	Water applied plus precipitation for max.yield (inches/season)	Precipitation, spring, winter, fall (inches)
2011	383.3	-8.3		0.49	0.05	263.3	14.5	14.5
2012	-384.4	92.7	-3.1	0.62	0.05	309.3	15.0	8.4
2013	-4.1	3.7		0.54	0.01	45.1	13.3	5.3
2014	-400.8	74.8	-2.2	0.79	0.001	234.0	17.0	8.1
2015	-515.3	101.9	-3.0	0.56	0.05	350.4	17.0	10.4
2016	-548.3	102.8	-3.3	0.56	0.05	245.2	15.4	10.1

Western prairie clover

Year	intercept	linear	quadratic	R^2	P	Maximum yield (lb•acre ⁻¹)	Water applied plus precipitation for max.yield (inches/season)	Precipitation, spring, winter, fall (inches)
2011	635.9	-12.5		0.11	NS	454.9	14.5	14.5
2012	-815.6	154.8	-4.8	0.65	0.01	431.8	16.1	8.4
2013	-149.4	41.9	-1.6	0.88	0.001	407.8	13.3	5.3
2014	-1258.9	233.6	-7.8	0.87	0.001	486.6	14.9	8.1
2015	-1597.0	267.3	-8.9	0.64	0.05	399.0	14.9	10.4
2016	-1096.9	203.5	-6.9	0.55	0.10	393.0	14.6	10.1

Basalt milkvetch

Year	intercept	linear	quadratic	R^2	P
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
2015	17.1	-0.8		0.16	NS
Average	43.3	-0.2		0.01	NS

^aNot significant. There was no statistically significant trend in seed yield in response to the amount of irrigation.

5. Native Beeplant Seed Production in Response to Irrigation in a Semi-arid Environment

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Summary

Beeplants (*Cleome* spp.) are annual species that favor pollinators in the Intermountain West. Beeplant seed is desired for rangeland restoration activities, but little cultural practice information is known for its seed production. The seed yield response of Rocky Mountain beeplant (*C. serrulata*) and yellow spiderflower (also known as yellow beeplant; *C. lutea*) to four biweekly irrigations applying either 0, 1, or 2 inches of water (total of 0, 4 cm, or 8 inches/season) was evaluated over multiple years. Rocky Mountain beeplant seed yield was maximized by 8 inches of water applied per season in 2011, but did not respond to irrigation in 2012, 2014, or 2015. Beeplant stands were lost to flea beetles in 2013.

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 natural rangelands, the annual variation in spring rainfall and soil moisture results 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 do not compete well with crop weeds in cultivated fields, which could also limit their 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 designed experiments 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 Rocky Mountain beeplant and yellow spiderflower.

Materials and Methods

Plant Establishment

Each species was planted in separate strips containing four rows 30 inches apart (a 10 ft wide strip) and about 450 ft long on Nyssa silt loam at the Malheur Experiment 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.

Starting in 2010, seed of Rocky Mountain beeplant was planted each year in 30 inch rows using a custom-made plot grain drill with disc openers in mid-November. All seed was planted on the soil surface at 20-30 seeds/ft of row in the same location each year. After planting, sawdust was

applied in a narrow band over the seed row at 0.26 oz/ft of row (558 lbs/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. Starting in 2011, seed of yellow spiderflower was also planted each year. After the newly planted wildflowers had emerged, the row cover was removed in April each year.

Starting in 2013, each spring after the row cover was removed, bird netting was placed over the Rocky Mountain beeplant and yellow spiderflower plots to protect seedlings from bird feeding. The bird netting was placed over No. 9 galvanized wire hoops.

Flea Beetle Control

Flea beetles were observed feeding on leaves of Rocky Mountain beeplant and yellow spiderflower in April of 2012. On April 29, 2012, all plots of Rocky Mountain beeplant and yellow spiderflower were sprayed with Capture[®] at 5 oz/acre to control the flea beetles. On June 11, 2012, Rocky Mountain beeplant was again sprayed with Capture at 5 oz/acre to control a reinfestation of flea beetles.

Flea beetle feeding occurred earlier in 2013 than in 2012. Upon removal of the row cover in March of 2013, the flea beetle damage for both species at seedling emergence was extensive and resulted in full stand loss. Flea beetles were not observed on either *Cleome* species in 2014.

On March 20, 2015, after removal of the row cover, all plots of Rocky Mountain beeplant and yellow spiderflower were sprayed with Capture at 5 oz/acre to control flea beetles. On April 3, 2015, all plots of Rocky Mountain beeplant and yellow spiderflower were sprayed with Entrust[®] at 2 oz/acre (0.03 lb ai/acre) to control flea beetles.

On March 18, 2016, after removal of the row cover, all plots of Rocky Mountain beeplant and yellow beeplant were sprayed with Radiant at 7 oz/acre to control flea beetles. On April 6, all plots of Rocky Mountain beeplant and yellow spiderflower were sprayed with Capture at 5 oz/acre to control flea beetles. On June 30, all plots of Rocky Mountain beeplant were sprayed with Sivanto[®] at 14 oz/acre to control flea beetles.

Weeds were controlled by hand weeding as necessary.

Irrigation for Seed Production

In April, 2011, each strip of each wildflower species was divided into 12 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 four irrigations that were applied approximately every 2 weeks starting with bud formation and flowering. 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. Flowering, irrigation, and harvest dates were recorded (Table 1). In 2014, after the four bi-weekly irrigations ended, Rocky Mountain beeplant and yellow spiderflower received three additional bi-weekly irrigations starting on August 12 in an attempt to extend the flowering and seed production period. On August 12, 50 lbs

nitrogen/acre, 30 lbs phosphorus/acre, and 0.2 lb iron/acre were applied through the drip tape to all plots of Rocky Mountain beeplant and yellow spiderflower.

Flowering and Harvest

The two species have a long flowering and seed set period (Table 1), making mechanical harvesting difficult. Mature seed pods were harvested manually 2 to 4 times each year.

Table 1. Rocky Mountain beeplant and yellow spiderflower flowering, irrigation, and seed harvest dates by species. Malheur Experiment Station, OSU, Ontario, OR.

Species	Year	Flowering dates			Irrigation dates		Harvest
		Start	Peak	End	Start	End	
<i>Rocky Mountain beeplant</i>	2011	25-Jun	30-Jul	15-Aug	21-Jun	2-Aug	26-Sep
	2012	12-Jun	30-Jun	30-Jul	13-Jun	25-Jul	24-Jul to 30-Aug
	2013	stand loss to fleabeetles					
	2014	4-Jun	24-Jun	22-Jul	20-May	1-Jul	11-Jul to 30-Jul
	2015	20-May	24-Jun	15-Sep	20-May	30-Jun	1-Jul to 15-Aug
	2016	23-May		20-Sep	16-May	29-Jun	28 Jun to
<i>yellow spiderflower</i>	2012	16-May	15-Jun	30-Jul	2-May	13-Jun	12-Jul to 30-Aug
	2013	stand loss to fleabeetles					
	2014	29-Apr	4-Jun	22-Jul	23-Apr	3-Jun	23-Jun to 30-Jul
	2015	8-Apr	13-May	6-Jul	17-Apr	27-May	4-Jun to 30-Jul
	2016	13-Apr	13-May	25-Jul	18-Apr	31-May	14 Jun to 22 Jul

Results and Discussion

Precipitation from January through June in 2012 and 2014 was close to the average of 5.8 inches (Table 2). Precipitation from January through June in 2013, 2015, and 2016 was lower than the average of 5.8 inches. Precipitation from January through June in 2011 was higher than the average of 5.8 inches. The accumulated growing degree-days (50-86°F) from January through June in 2013-2016 were higher than average (Table 2) and were associated with early flowering and seed harvest.

Rocky Mountain Beeplant

In 2011, seed yields increased with increasing irrigation up to the highest tested of 8 inches (Tables 3 and 4). Seed yields did not respond to irrigation in 2012, 2014, 2015, or 2016. There was no plant stand in 2013 due to early, severe flea beetle damage. The additional irrigations starting on August 12, 2014 did result in an extension/resumption of flowering, but seed harvested in mid-October was not mature. Flowering in 2015 and 2016 continued through the end of September, but as in 2014, seed set in September did not mature. Seed set and seed production were extremely poor in 2016. Continued flea beetle infestations could have caused

the poor seed set. A more intensive control program than the three insecticide applications in 2016 might be necessary. Birds were also observed feeding on seed pods and might also have been responsible for the low seed yields.

The winter and spring of 2011 were wetter and this annual plant developed much better in 2011, responded to irrigation, and had higher seed yield. Our results over years suggest that *Cleome* spp. may need early irrigation in drier years in addition to irrigation during flowering and seed set.

Yellow Spiderflower

Seed yields did not respond to irrigation in 2012, 2014, or 2015 (Tables 3 and 4). In 2016 seed yields were highest with no irrigation. There was no plant stand in 2013. Early attention to flea beetle control is essential for yellow spiderflower seed production. The additional irrigations starting on August 12, 2014 did not result in an extension or resumption of flowering.

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Table 2. Early season precipitation and growing degree-days at the Malheur Experiment Station, OSU, Ontario, OR, 2011-2016.

Year	Precipitation (inches)		Growing degree-days (50-86°F)
	Jan-Jun	Apr-Jun	Jan-Jun
2011	8.3	3.9	856
2012	5.8	2.3	1,228
2013	2.6	1.4	1,319
2014	5.1	1.6	1,333
2015	4.8	2.7	1,610
2016	4.4	2.1	1,458
73-year average	5.8	2.6	1,196 ^a

^a23-year average.

Table 3. Rocky Mountain beeplant and yellow spiderflower seed yield in response to irrigation rate (inches/season). Malheur Experiment Station, OSU, Ontario, OR.

Species	Year	Irrigation rate			LSD (0.05)
		0 inches	4 inches	8 inches	
Rocky Mountain beeplant	2011	446.5	499.3	593.6	100.9 ^b
	2012	184.3	162.9	194.7	NS ^a
	2013	No stand			
	2014	66.3	80	91.3	NS
	2015	54.0	41.0	37.9	NS
	2016	0.8	2.1	1.6	NS
	Average	125.8	131.2	153.4	NS
yellow spiderflower	2012	111.7	83.7	111.4	NS
	2013	No stand			
	2014	207.1	221.7	181.7	NS
	2015	136.9	80.5	113.0	NS
	2016	65.6	48.9	35.0	18.7
	Average	130.3	108.7	110.3	NS

^aLSD (0.10).^bNot significant: There was no statistically significant trend in seed yield in response to the amount of irrigation.**Table 4.** Regression analysis for Rocky Mountain beeplant and yellow spiderflower seed yield (y) in response to irrigation (x) (inches/season) using the equation $y = a + bx + cx^2$. Malheur Experiment Station, OSU, Ontario, OR.

Rocky Mountain beeplant							
Year	intercept	linear	quadratic	R ²	P	Maximum yield	Water applied for maximum 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 ^a		
2014	66.7	3.1		0.16	NS		
2015	52.4	-2.0		0.08	NS		
2016	0.8	0.6	-0.1	0.19	NS		
Average	123.0	3.4		0.36	0.05	263	8
Yellow spiderflower							
Year	intercept	linear	quadratic	R ²	P	Maximum yield	Water applied for maximum yield
						lb/acre	inches/season
2012	102.4	-0.031		0.01	NS		
2014	207.1	10.4	-1.7	0.2	NS		
2015	122.0	-3.0		0.08	NS		
2016	65.2	-3.8		0.45	0.05	65.2	0.0
Average	126.5	-2.5		0.04	NS		

^aNot significant.

6. Irrigation Requirements for Seed Production of Several Native Wildflower Species Planted in the Fall of 2012

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Introduction

Commercial seed production of native wildflowers is necessary to provide the quantity of seed needed for restoration of Intermountain West rangelands. Native wildflower plants may not be well adapted to croplands. Native plants are often not competitive with crop weeds in cultivated fields, and this poor competitiveness with weeds could 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 tape at a 12 inch depth and avoiding wetting the soil surface, we designed experiments to assure flowering and seed set without undue encouragement of weeds or opportunistic diseases. The trials reported here tested effects of three low rates of irrigation on seed yield of 13 native wildflower species (Table 1).

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

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

^aPlanted in the fall of 2011.

^bRecently classified as *Cymopterus nivalis* S. Watson "snowline springparsley". Planted in the fall of 2009.

Materials and Methods

Plant establishment

Each wildflower species was planted on 5 ft beds in rows 450 ft long on Nyssa silt loam at the Malheur Experiment Station, Ontario, Oregon. The soil had a pH of 8.3 and 1.1% organic matter. In October 2012, drip tape (T-Tape TSX 515-16-340) was 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 or 30 inch rows using a custom-made plot grain drill with disc 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 lbs/acre). Following planting and sawdust application, the beds were covered with row cover (N-sulate, DeWitt Co., Inc., Sikeston, MO), which covered four rows (two beds) and was applied with a mechanical plastic mulch layer. Hayden's cymopterus (*Cymopterus bipinnatus*) was planted on November 25, 2009, and limestone hawksbeard (*Crepis intermedia*) was planted on November 28, 2011 as previously described using similar methods.

Weeds were controlled by hand-weeding as necessary.

Starting in March following fall planting, the row cover was removed. Immediately following the removal of the row cover, bird netting was placed over the seedlings on No. 9 galvanized wire hoops to prevent bird feeding on young seedlings and new shoots. During seedling emergence, wild bird seed was placed several hundred meters from the trial to attract quail away from the trials. Bird netting was removed in early May. Bird netting was applied and removed each spring.

Cultural Practices in 2012

On April 13, 2012, 22.7 kg nitrogen/acre, 4.5 kg phosphorus/acre, and 0.1 kg iron/acre was applied to all plots of Hayden's cymopterus as liquid fertilizer injected through the drip tape.

Cultural Practices in 2013

On July 26, all plots of hoary tansyaster (*Machaeranthera canescens*) were sprayed with Capture[®] at 19 oz/acre (0.3 lb ai/acre) for aphid control. On October 31, seed of threadleaf phacelia (*Phacelia linearis*) was planted as previously described. Due to poor stand, seed of Douglas' dustymaiden (*Chaenactis douglasii*) was replanted on November 1, as previously described. Stand of coyote tobacco (*Nicotiana attenuate*) was extremely poor and seed was unavailable for replanting.

Cultural Practices in 2014

On November 11, threadleaf phacelia, coyote tobacco, and manyflower thelypody (*Thelypodium milleflorum*) were replanted as previously described. Stand of Douglas' dustymaiden, which was replanted in the fall of 2013, was poor and did not allow evaluation of irrigation responses. Lengths of row with missing stand in plots of Douglas' dustymaiden were replanted by hand. Row cover was not applied to replanting of Douglas' dustymaiden.

Cultural Practices in 2015

On November 2, coyote tobacco and nakedstem sunray (*Enceliopsis nudicaulis*) were replanted as previously described. Before planting, the ground was not tilled, only cultipacked. On November 5, threadleaf phacelia, Douglas' dustymaiden, and scarlet gilia (*Ipomopsis aggregate*) were replanted as previously described.

Irrigation for Seed Production

In March of 2010 for Hayden's cymopterus, and March of 2013 for the other species, the planted strip of each wildflower species was divided into 12 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 nonirrigated 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 at bud formation and flowering. 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 coyote tobacco, which did not germinate in 2014 and the *Ligusticum* spp., which did not flower.

Harvest

All species were harvested manually in 2013. Due to a long flowering duration, seed of nakedstem sunray, Douglas' dustymaiden and limestone hawksbeard required multiple harvests. Seed of nakedstem sunray was harvested manually once a week. Seed of Douglas' dustymaiden and limestone hawksbeard was harvested weekly with a leaf blower in vacuum mode. In 2016, the duration of flowering for limestone hawksbeard was much shorter and uniform in timing between irrigation treatments. In 2016, seed of limestone hawksbeard was harvested by mowing and bagging just prior to the seed heads opening. A seed sample from each plot of limestone hawksbeard was cleaned manually to determine the proportion of pure seed. A sample of light yellow (immature) seed and dark brown (mature) seed of limestone hawksbeard was analyzed for viability (tetrazolium). In 2016, seed of Douglas' dustymaiden was harvested manually once a week.

Hoary tansyaster seed was harvested by cutting and windrowing the plants. After drying for 2 days the hoary tansyaster plants were beaten on plastic tubs to separate the seed heads from the stalks. Silverleaf phacelia was harvested with a small plot combine in 2014 and 2015. Showy goldeneye (*Heliomeris multiflora*) was harvested with a small plot combine in 2015 and 2016. The duration of flowering for showy goldeneye tends to increase with increasing irrigation. In 2013 and 2014, the duration of flowering in the wetter plots of showy goldeneye was much longer than in the drier plots, making a single mechanical harvest unfeasible. In 2015, the duration of flowering in the wetter plots of showy goldeneye was shorter enabling mechanical harvest. In 2016, plots of the driest treatment were harvested manually before the other plots, which were harvested mechanically on July 8.

Seed of all species was cleaned manually.

Results and Discussion

Precipitation from January through June in 2013 (2.6 inches) was lower and in 2011 (8.3 inches) was higher than the 73-year average of 5.8 inches (Table 3). Precipitation for the other years was close to the average. The accumulation of growing degree-days (50-86°F) was higher than average in 2013-2016 (Table 3).

Stands of Porter's licorice-root (*Ligusticum porteri*) and Canby's's licorice-root (*L. canbyi*) were poor and uneven and did not permit evaluation of irrigation responses. Stands of Douglas' dustymaiden were poor in 2013 and 2014, and did not permit evaluation of irrigation responses. After replanting in the fall of 2013 and 2014, adequate stand of Douglas' dustymaiden was established, allowing evaluations of irrigation responses in 2015 and 2016.

Stand of coyote tobacco was uneven and did not permit evaluation of irrigation responses in 2015.

Scarlet gilia had very little flowering in 2013, then flowered and set seed in 2014. The stand of scarlet gilia died over the winter of 2014-2015, which indicated a biennial growth habit. Hayden's cymopterus did not flower in either 2010 or 2011, and had very little flowering in 2012.

Stand of replanted threadleaf phacelia was very poor in 2015, but was replaced by an excellent volunteer stand of silverleaf phacelia (*Phacelia hastate*), originating from unharvested seed of the adjacent silverleaf phacelia stand. Irrigation responses for silverleaf phacelia were evaluated for the new stand and for the 3-year-old stand. Threadleaf phacelia was replanted in the fall of 2016 in a different location in the field, but the stand in the spring of 2016 was extremely poor.

Limestone hawksbeard flowered and produced seed for the first time in 2015, the third year after fall planting in 2011. The uniform and short flowering of limestone hawksbeard in 2016 allowed the seed from all plots to be harvested once. A single mechanical harvest is more efficient, but some of the seed could be immature since harvest needed to occur just before seed heads opened. 77% of the seed harvested in 2016 was mature and had a viability of 57%. The other 23% percent of the harvested seed was immature and had a viability of 5%. This suggests that the single harvest as conducted in this trial resulted in adequate seed quality.

Extensive die-off of nakedstem sunray occurred over the winter of 2014-2015, and was more severe in the plots receiving the highest amount of irrigation.

Partial die-off of hoary tansyaster over the winter of 2015/2016 resulted in stand too uneven for an irrigation trial in 2016.

Seed Yield Responses (Tables 4 and 5)

Douglas' dustymaiden seed yields did not respond to irrigation in 2015 and 2016.

Limestone hawksbeard seed yields increased with increasing irrigation rate up to the highest rate of 20.3 cm in 2015. In 2016, seed yields of limestone hawksbeard did not respond to irrigation.

Hayden's cymopterus seed yields did not respond to irrigation in 2013 and 2016. In 2014, seed yields increased with increasing irrigation rate up to the highest rate of 8 inches. In 2015, seed yields showed a quadratic response to irrigation with a maximum seed yield at 4 inches of water applied.

Nakedstem sunray seed yield was very low and did not respond to irrigation in 2013. In 2014, seed yield showed a quadratic response to irrigation with a maximum seed yield at 5.4 inches of water applied. Significant stand loss occurred over the winter of 2014-2015, especially in the irrigated plots. Seed yields of nakedstem sunray were substantially reduced in 2015 and were highest without irrigation. In 2016, seed yield showed a quadratic response to irrigation with a maximum seed yield at 5.8 inches of water applied. Seed yields have been very low each year due at least in part to very low plant stands.

Showy goldeneye seed yield increased with increasing irrigation rate up to the highest rate of 20.3 cm in 2013-2015. Showy goldeneye seed yield did not respond to irrigation in 2016.

Scarlet gilia seed yields were highest with 4 inches of water applied in 2014.

Hoary tansyaster seed yields showed a quadratic response to irrigation with a maximum seed yield at 2.4 inches of water applied in 2013. In 2014, 2015, and averaged over the 3 years, seed yields of hoary tansyaster did not respond to irrigation.

Silverleaf phacelia (planted in the fall of 2012) seed yields showed a quadratic response to irrigation with a maximum seed yield at 2.1 and 7.5 inches of water applied in 2013 and 2014, respectively. In 2015, seed yield of silverleaf phacelia did not respond to irrigation, possibly due to loss of stand in this weak perennial.

Seed yields of silverleaf phacelia (planted in the fall of 2014) increased with increasing irrigation rate up to the highest rate of 8 inches in 2015.

Seed yields of threadleaf phacelia showed a quadratic response to irrigation in 2013 with a maximum seed yield at 6.2 inches of water applied. In 2014, seed yields of threadleaf phacelia did not respond to irrigation.

The establishment of manyflower thelypody has been difficult and plant stands have been poor. Seed yield of manyflower thelypody did not respond to irrigation in 2014.

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Table 2. Native wildflower flowering, irrigation, and seed harvest dates by species. Malheur Experiment Station, OSU, Ontario, OR. Continued on next page.

Station, CSC, Ontario, UK. Continued on next page.						
Year	Flowering dates			Irrigation dates		Harvest
	Start	Peak	End	Start	End	
Douglas' dustymaiden						
2013	23-May	30-Jun	15-Jul	22-May	3-Jul	2-Jul, 22-Jul
2014	20-May		15-Jul	13-May	24-Jun	poor stand
2015	5-May		10-Jul	5-May	17-Jun	weekly, 6-8 to 7-15
2016	23-May			23-May	8-Jul	weekly, 6-17 to
hoary tansyaster						
2013	13-Aug		1-Oct	17-Jul	28-Aug	2-Oct
2014	20-Aug	17-Sep	5-Oct	22-Jul	2-Sep	6-Oct
2015	10-Aug	17-Sep	1-Oct	11-Aug	22-Sep	6-Oct, 15-Oct
2016	17-Aug	20-Sep	10-Oct			partial winter die-off
silverleaf phacelia						
2013	17-May		30-Jul	22-May	3-Jul	30-Jul (0 in), 7-Aug, 19-Aug (8 in)
2014	5-May		10-Jul	29-Apr	10-Jun	14-Jul
2015 (1st year)	28-Apr	26-May	7-Aug	20-May	30-Jun	6-Aug
2015 (3rd year)	28-Apr	26-May	7-Aug	29-Apr	10-Jun	7-Jul (0 in), 21-Jul (4, 8 in)
2016	28-Apr		17-Jun	27-Apr	7-Jun	
threadleaf phacelia						
2013	3-May	16-May	15-Jun	2-May	12-Jun	2-Jul
2014	5-May	4-Jun	1-Jul	1-May	10-Jun	7-Jul
2015	winter die-off					
nakedstem sunray						
2013	30-Jun		15-Sep	3-Jul	14-Aug	weekly, 8-Aug to 30-Aug
2014	5-May	1-Jul	30-Jul	6-May	17-Jun	weekly, 14-Jul to 30-Aug
2015	28-Apr	13-May	5-Aug	29-Apr	10-Jun	weekly, 2-Jun to 15-Aug
2016	20-Apr		30-Jul	3-May	14-Jun	weekly, 27-Apr to 29-Jul
showy goldeneye						
2013	15-Jul		30-Aug	5-Jun	17-Jun	8-Aug, 15-Aug, 28-Aug
2014	20-May	20-Jun	30-Aug	13-May	24-Jun	weekly, 15-Jul to 15-Aug
2015	5-May	26-May	10-Jul	5-May	17-Jun	13-Jul
2016	5-May	15-Jun	30-Sep	9-May	22-Jun	8-Jul
2013	5-Apr		15-May	12-Apr	22-May	10-Jun
2014	7-Apr		29-Apr	7-Apr	20-May	16-Jun
2015	25-Mar		24-Apr	1-Apr	13-May	8-Jun
2016	15-Mar		25-Apr	31-Mar	9-May	7-Jun
Hayden's cymopterus						
2013	5-Apr		15-May	12-Apr	22-May	10-Jun
2014	7-Apr		29-Apr	7-Apr	20-May	16-Jun
2015	25-Mar		24-Apr	1-Apr	13-May	8-Jun
2016	15-Mar		25-Apr	31-Mar	9-May	7-Jun
scarlet gilia						
2013	31-Jul	very little flowering		31-Jul	11-Sep	
2014	22-Apr	13-May	30-Jul	23-Apr	3-Jun	20-Jun
2015	winter die-off					
2016	no flowering			7-Jun	22-Jul	
manyflower thelypody						
2013	No flowering					
2014	22-Apr	5-May	10-Jun	23-Apr	3-Jun	2-Jul
2015	No flowering					
2016	11-Apr	6-May	8-Jun	11-Apr	23-May	21-Jun
limestone hawksbeard						
2015	28-Apr	5-May	1-Jun	21-Apr	3-Jun	weekly, 6-1 to 7-2
2016	29-Apr		25-May	27-Apr	7-Jun	26-May
coyote tobacco						
2016	16-May		31-Jul	16-May	22-Jun	weekly, 21-Jun to 29-Jul

Table 3. Early season precipitation and growing degree-days at the Malheur Experiment Station, Ontario, OR, 2013-2016.

Year	Precipitation (inches)		Growing degree-days (50-86°F)
	Jan-Jun	Apr-Jun	Jan-Jun
2013	2.6	1.4	1,319
2014	5.1	1.6	1,333
2015	4.8	2.7	1,610
2016	4.4	2.1	1,458
73-year average	5.8	2.6	1,196 ^a

^a23-year average.**Table 4.** Native wildflower seed yield in response to season-long irrigation rate (inches). Malheur Experiment Station, OSU, Ontario, OR.

Species	Year	Irrigation rate			
		0 inches	4 inches	8 inches	LSD (0.05)
Douglas' dustymaiden	2015	132.1	137.6	183.3	NS ^a
	2016	29.1	16.0	27.2	NS
	Average	80.6	76.8	105.2	NS
limestone hawksbeard	2015	75.5	75.8	153.7	58.1
	2016	91.9	113.1	85.6	NS
	Average	83.7	94.5	118.9	NS
Hayden's cymopterus	2013	194.2	274.5	350.6	NS
	2014	1236.2	1934	2768.5	844.7
	2015	312.3	749.0	374.9	240.7
	2016	1501.4	2120.6	1799.0	546.6 ^b
	Average	811.0	1339.0	1216.1	282.2
nakedstem sunray	2013	2.3	6.8	5.9	NS
	2014	1.5	34.6	29.1	20.7
	2015	15.7	3.2	4.4	7.3
	2016	10.5	47.6	45.9	34.9
	Average	7.5	25.3	21.3	16.8
showy goldeneye	2013	28.7	57.6	96.9	NS
	2014	154.6	200.9	271.7	107.3 ^b
	2015	81.7	115.6	188.2	58.2
	2016	92.3	89.2	98.0	NS
	Average	89.3	114.1	163.7	33.0
scarlet gilia	2014	47.1	60.9	63.6	9
hoary tansyaster	2013	206.1	215	124.3	73.6
	2014	946.1	1210.2	1026.3	NS
	2015	304.1	402.6	459.1	NS
	Average	163.0	240.3	233.3	NS
coyote tobacco	2016	49.4	151.0	95.8	81.4
showy goldeneye (planted fall 2012)	2013	35.3	102.7	91.2	35.7
	2014	87.7	305.7	366.4	130.3
	2015	78.8	79.3	65.0	NS
	Average	67.3	162.6	174.2	34.5
silverleaf phacelia (planted fall 2014)	2015	0.0	21.4	50.4	13.7
threadleaf phacelia	2013	121.4	306.2	314.2	96
	2014	131.9	172.9	127.2	NS
	Average	126.7	239.5	220.7	87.2
manyflower thelypody	2014	200.5	246.2	205.6	NS

^aNot significant. ^bLSD (0.10).

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Table 5. Regression analysis for native wildflower seed yield (y) in response to irrigation (x) (inches/season) using the equation $y = a + bx + cx^2$. For the quadratic equations, the amount of irrigation that resulted in maximum yield was calculated using the formula: $x = -b/2c$, where a is the intercept, b is the linear parameter and c is the quadratic parameter. Malheur Exp. Station, OSU, Ontario, OR.

Species	Year	intercept	linear	quadratic	R ²	P	Maximum yield lb/acre	Water applied for maximum yield inches/season
Douglas' dustymaiden	2015	125.4	6.4		0.08	NS ^a		
	2016	25.1	-0.2		0.01	NS		
	Average	75.2	3.1		0.07	NS		
limestone hawksbeard	2015	58.6	12.7		0.32	0.10	160	8.0
	2016	91.9	11.4	-1.5	0.25	NS		
	Average	81.4	4.4		0.13	NS		
Hayden's cymopterus	2013	194.9	19.6		0.07	NS		
	2014	1214.6	190.6		0.41	0.05	2740	8
	2015	312.3	210.5	-25.3	0.46	0.10	750	4.2
	2016	1501.4	272.4	-29.4	0.34	NS		
	Average	811.0	213.4	-20.3	0.51	0.05	1371	5.2
nakedstem sunray	2013	3.1	0.4		0.16	NS		
	2014	1.5	13.1	-1.2	0.6	0.05	37	5.4
	2015	13.4	-1.4		0.29	0.10	13	0.0
	2016	10.5	14.1	-1.2	0.57	0.05	51.6	5.8
	Average	7.5	7.2	-0.7	0.46	0.10	26.4	5.3
showy goldeneye	2013	27	8.5		0.38	0.05	95	8
	2014	150.5	14.6		0.27	0.10	268	8
	2015	75.2	13.3		0.48	0.05	182	8
	2016	90.7	0.7		0.01	NS		
	Average	85.2	9.3		0.50	0.01	160	9
scarlet gilia	2014	48.5	2.1		0.23	NS		
hoary tansyaster	2013	206.1	14.7	-3.1	0.54	0.05	223	2.4
	2014	946.1	122	-14	0.13	NS		
	2015	311.1	19.4		0.02	NS		
	Average	163.0	29.9	-2.6	0.03	NS		
coyote tobacco	2016	49.4	45.0	-4.9	0.50	0.05	153	4.6
silverleaf phacelia	2013	35.3	26.7	-2.5	0.66	0.01	108	5.4
(planted fall 2012)	2014	87.7	74.2	-4.9	0.76	0.01	367	7.5
	2015	78.8	2.0	-0.5	0.04	NS		
	Average	67.3	34.3	-2.6	0.9	1	180	6.6
silverleaf phacelia						0.00		
(planted fall 2014)	2015	-1.3	6.3		0.88	1	49	8
threadleaf phacelia	2013	121.4	68.3	-5.5	0.69	0.01	333	6.2
	2014	131.9	21.1	-2.7	0.11	NS		
	Average	126.7	44.7	-4.1	0.48	0.1	248	5.4
manyflower thelypody	2014	200.5	22.2	-2.7	0.12	NS		

^aNot significant. There was no statistically significant trend in seed yield in response to amount of irrigation.

7. Direct Surface Seeding Systems for the Establishment of Native Plants in 2016

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Introduction

Seed of native plants is needed to restore rangelands of the Intermountain West. Reliable commercial seed production is needed to make seed readily available. Direct seeding of native range plants has been problematic for many species evaluated at the Malheur Experiment Station. Fall planting is important for many species to overcome physiological dormancy through cold stratification, yet this technique still has resulted in poor stands some years at the Malheur Experiment Station. Inadequate soil moisture, crusting, and seed predation by birds are identified hindrances to adequate stand establishment for fall-planted seed. Previous trials to address these issues examined seed pelleting, planting depth, and soil anticrustant with four species planted in the fall (Shock et al. 2010). Planting at depth with soil anticrustant improved emergence compared to surface planting whereas seed pelleting did not improve emergence. Planting at $\frac{1}{8}$ inch depth resulted in higher emergence than either surface planting or planting at $\frac{1}{4}$ inch depth for three of the four species. Emergence for one species was too poor for any conclusions to be made. Despite these positive results, emergence was extremely poor for all species tested. Soil crusting, loss of soil moisture, and bird damage could have contributed to the poor emergence.

In established native perennial fields at the Malheur Experiment Station and in rangelands we observed prolific emergence from seed naturally falling on the soil surface and subsequently covered by thin layers of normally occurring organic debris. Building on this observation, we developed and tested planting systems, focusing on surface-planted seed (Table 1, Shock et al. 2012-2014). Treatments include row cover, sawdust, sand, and seed treatments. Row cover acts as a protective barrier against soil desiccation and bird damage. Sawdust was intended to 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. Trials did not test all possible combinations of treatments, but focused on combinations likely to result in adequate stand establishment based on previous observations.

Materials and Methods

In 2016, 14 species for which stand establishment has been problematic were included and an additional species (royal penstemon; *Penstemon speciosus*) was chosen as a check, because it has reliably produced good stands at Ontario. Seed weights for all species were determined. In November, 2016, a portion of the seed was treated with a liquid mix of the fungicides Thiram and Captan (10 g Thiram and 10 g Captan in 0.5 L 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 23, 2015. The experimental design was a randomized complete block with six replicates. Plots were one 30 inch-wide by 5 ft-long bed. The seed was placed on the soil surface in two rows on each bed.

The four factors (row cover, sawdust, sand, and mulch) were applied after planting. Sawdust was applied in a narrow band over the seeded row at 0.26 oz/ft of row (558 lbs/acre). For the treatments receiving both sawdust and sand, sand was applied at 0.65 oz/ft of row (1,414 lbs/acre) as a narrow band over the sawdust. Following planting and sawdust and sand applications, some 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. Mouse bait packs were scattered under the row cover. For the hydro seeding mulch treatments, 10 lbs of hydro seeding paper mulch (Premium Hydro seeding Mulch, Applegate Mulch) 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 thin 1 inch band over the seed row. On April 6, 2016, the row cover was removed and the trial was sprayed with Poast at 24 oz/acre for control of grass weeds. The trial was then hand weeded. Emergence counts were recorded in all plots on May 2.

Tetrazolium tests were conducted to determine seed viability of each species (Table 2) and the results were used to correct the emergence data to emergence as a percentage of planted viable seed. 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% probability level, LSD (0.05). To evaluate factors, the following treatment comparisons were used: row cover, treatments 1 and 5; seed treatment, treatments 1 and 3; sawdust, treatments 1 and 2; sand, treatments 1 and 4; mulch, treatments 2 and 6.

Results and Discussion

2016 Results

Stand of threadleaf phacelia, Western prairie clover, Searls' prairie clover, and Rocky Mountain beeplant across all treatments was 10% or less (Table 3). There was no significant difference in stand between planting systems for threadleaf phacelia, western prairie clover, Searls' prairie clover, and Rocky Mountain beeplant. There were statistically significant differences in stand between planting systems for eleven species.

The row cover with sawdust plus seed treatment resulted in higher stands than no row cover (bare ground) with sawdust and seed treatment for Douglas' dustymaiden, hoary tansyaster, silverleaf phacelia, cleftleaf wildheliotrope (*Phacelia crenulata*), showy goldeneye, royal penstemon, and common yarrow (*Achillea millefolium*) (Table 3). Sawdust added to the row cover plus seed treatment only improved stand of royal penstemon and reduced stand of coyote tobacco and common yarrow.

Adding seed treatment to sawdust plus row cover did not improve stand of any species, and reduced stands of cleftleaf wildheliotrope, showy goldeneye, coyote tobacco, and scarlet gilia. Adding sand to sawdust, seed treatment, plus row cover combination improved stand for hoary tansyaster, silverleaf phacelia, showy goldeneye, and yellow spiderflower, but reduced stand for common yarrow. Hydroseed mulch with seed treatment resulted in lower stand than row cover with seed treatment for hoary tansyaster, silverleaf phacelia, cleftleaf wildheliotrope, showy goldeneye, coyote tobacco, manyflower thelypody, royal penstemon, common yarrow, and yellow spiderflower. For scarlet gilia, there was no difference in stand between Hydroseed mulch with seed treatment and row cover with seed treatment. However, for scarlet gilia, seed treatment was detrimental and all systems that had seed treatment had low stand negating an evaluation of hydroseed mulch for this species.

Averaged over species, row cover with sawdust plus seed treatment resulted in higher stands than no row cover (bare ground) with sawdust and seed treatment. Averaged over species, adding sawdust to row cover and seed treatment did not improve stand. Averaged over species, when seed treatment was added to the row cover and sawdust combination, stands were reduced. Adding sand to sawdust, seed treatment, plus row cover combination increased stand. Applying hydroseed mulch over the seed row resulted in lower stand than row cover with seed treatment.

2013, 2015, 2016 Results

A subset of 8 of the 15 species in the 2016 trial were included in emergence trials in 2013 and 2015 (Shock et al. 2013, 2015) testing the same establishment systems. These results are presented in Tables 4 and 5. The three year results show that planting systems that include row cover have most consistently improved stand establishment. Sawdust and sand are factors that for some species in some years have shown value in improving stand, but their performance has not been consistent. Averaged over the 3 years, sawdust had a negative effect on stand for silverleaf phacelia, coyote tobacco, and manyflower thelypody and a positive effect for hoary tansyaster. Averaged over the 3 years, sand had a positive effect on stand for Douglas' dustymaiden and showy goldeneye.

Seed treatments with the fungicides Thiram and Captan have generally had no effect or a negative effect on stand establishment. In the three years of testing, seed treatment only improved stand of royal penstemon and hoary tansyaster in 2013. Seed treatment reduced stands of Scarlet gilia in 2013 and 2016, showy goldeneye in 2015 and 2016, coyote tobacco in 2016, and silverleaf phacelia in 2015.

References

Shock, C. C.; Feibert, E. B. G.; Saunders, L. D.; Shaw, N. 2010. Emergence of native plant seeds in response to seed pelleting, planting depth, scarification, and soil anti-crusting treatment. Annual Report. 2009. Corvallis, OR: Oregon State University, Malheur Experiment Station: 218-222.

Shock, C. C.; Feibert, E. B. G.; Saunders, L. D.; Shaw, N. 2012. Direct surface seeding strategies for establishment of Intermountain West native plants for seed production. Annual Report. 2011. Corvallis, OR: Oregon State University, Malheur Experiment Station: 130-135.

Shock, C. C.; Feibert, E. B. G.; Saunders, L. D.; Johnson, D.; Bushman, S. 2013. Direct surface seeding strategies for establishment of two native legumes of the Intermountain West. Annual Report. 2012. Corvallis, OR: Oregon State University, Malheur Experiment Station: 132-137.

Shock, C. C.; Feibert, E. B. G.; Saunders, L. D.; Shaw, N. 2014. Direct surface seeding systems for successful establishment of native wildflowers. Annual Report. 2013. Corvallis, OR: Oregon State University, Malheur Experiment Station: 159-165.

Shock, C. C.; Feibert, E. B. G.; Rivera, A.; Saunders, L. D.; Kilkenny, F.; Shaw, N. 2015. Direct surface seeding strategies for emergence of native plants in 2014. Annual Report. 2014. Corvallis, OR: Oregon State University, Malheur Experiment Station: 275-279.

Shock, C. C.; Feibert, E. B. G.; Rivera, A.; Saunders, L. D.; Kilkenny, F.; Shaw, N. 2015. Direct surface seeding strategies for emergence of native plants in 2015. Annual Report. 2015. Corvallis, OR: Oregon State University, Malheur Experiment Station: 175-180.

Table 1. Planting systems evaluated for emergence of 15 native plant species. Malheur Experiment Station, OSU, Ontario, OR, 2016.

#	Row Cover	Seed Treatment ^a	Sawdust	Sand	Mulch
1	yes	yes	yes	no	no
2	yes	yes	no	no	no
3	yes	no	yes	no	no
4	yes	yes	yes	yes	no
5	no	yes	yes	no	no
6	no	yes	no	no	yes
7	no	no	no	no	no

^aMixture of Captan and Thiram fungicides for prevention of seed decomposition and seedling damping off.

Table 2. Seed weights and tetrazolium test (seed viability) results for seed used for the planting system treatments in the fall of 2015 and evaluated in the spring of 2016, Malheur Experiment Station, OSU, Ontario, OR.

Species	Common name	Preplant untreated seed weight	Tetrazolium test
		seeds/g	%
<i>Chaenactis douglasii</i>	Douglas' dustymaiden	682	72
<i>Machaeranthera canescens</i>	hoary tansyaster	1,590	70
<i>Silverleaf phacelia</i>	silverleaf phacelia	1,098	98
<i>Cleftleaf wildheliotrope</i>	cleftleaf wildheliotrope	918	87
<i>Phacelia linearis</i>	threadleaf phacelia	4,091	98
<i>Heliomeris multiflora</i>	showy goldeneye	1,800	76
<i>Nicotiana attenuata</i>	coyote tobacco	8,333	90
<i>Thelypodium milleflorum</i>	manyflower thelypody	3,629	97
<i>Ipomopsis aggregata</i>	scarlet gilia	616	81
<i>Penstemon speciosus</i>	showy penstemon	662	85
<i>Dalea ornata</i>	western prairie clover	341	84
<i>Dalea searlsiae</i>	Searls' prairie clover	274	81
<i>Achillea millefolium</i>	yarrow	12,162	37
<i>Cleome lutea</i>	Yellow spiderflower	214	87
<i>Cleome serrulata</i>	Rocky Mountain beeplant	134	90

Table 3. Plant stands of 15 native plant species on May 2, 2016 in response to 7 planting systems used in November 2015. Stand for each species was corrected to the percent of viable seed based on the tetrazolium test. To evaluate factors, the following treatment comparisons were used: Row cover, treatments 1 and 5; Seed treatment, treatments 1 and 3; Sawdust, treatments 1 and 2; Sand, treatments 1 and 4. OSU, Malheur Experiment Station, Ontario, OR.

Species	Row cover, seed treatment, sawdust	Row cover, seed treatment	Row cover, sawdust	Row cover, seed treatment, sawdust, sand	Seed treatment, sawdust	Mulch, seed treatment	Untreated check	Average
	----- % Stand -----							
<i>Douglas' dustymaiden</i>	22.3	16.3	24.2	23.2	10.7	14.2	5.3	16.6
<i>hoary tansyaster</i>	28.9	26.0	25.2	38.7	14.8	16.2	16.0	23.7
<i>silverleaf phacelia</i>	23.2	28.3	21.8	31.7	11.1	3.6	8.5	18.3
<i>cleftleaf wildheliotrope</i>	15.5	13.9	30.5	17.1	2.3	1.9	0.8	11.7
<i>threadleaf phacelia</i>	6.2	1.8	2.3	11.7	4.5	2.7	1.8	4.4
<i>showy goldeneye</i>	33.1	31.0	44.9	41.2	6.7	1.2	2.3	22.9
<i>coyote tobacco</i>	6.5	21.7	15.2	10.1	0.1	0.1	0.4	7.7
<i>manyflower thelypody</i>	10.9	15.3	9.8	14.4	9.3	6.1	5.2	10.1
<i>scarlet gilia</i>	2.6	1.8	22.9	4.1	0.6	0.2	2.7	5.0
<i>royal penstemon</i>	23.4	11.4	15.9	26.3	3.7	0.5	0.5	11.7
<i>western prairie clover</i>	4.0	6.4	4.8	4.0	0.4	0.1	0.0	2.8
<i>Searls' prairie clover</i>	2.8	2.3	1.0	3.0	0.3	0.1	0.1	1.4
<i>common yarrow</i>	27.9	51.1	25.7	18.2	10.5	8.0	9.3	21.5
<i>yellow spiderflower</i>	19.0	14.4	18.2	28.9	11.9	6.3	6.1	15.0
<i>Rocky Mountain beeplant</i>	7.2	2.6	7.0	7.7	4.6	1.4	1.5	4.6
Average	15.6	16.3	18.0	18.7	6.1	4.2	4.0	
LSD (0.05)								
Treatment	1.6							
Species	2.8							
Treatment X species	7.3							

PLANT MATERIALS AND CULTURAL PRACTICES

Table 4. Plant stands of nine native plant species in response to seven planting systems used in 2013, 2015, and 2016. Stand for each species was corrected to the percent of viable seed based on the tetrazolium test. To evaluate factors, the following treatment comparisons were used: Row cover, treatments 1 and 5; Seed treatment, treatments 1 and 3; Sawdust, treatments 1 and 2; Sand, treatments 1 and 4. OSU, Malheur Experiment Station, Ontario, OR.

Year	Species	Row cover, seed treatment, sawdust	Row cover, seed treatment	Row cover, sawdust	Seed treatment, sawdust	Row cover, seed treatment, sawdust, sand	Mulch, seed treatment	Untreated check	Average
----- % Stand -----									
2013	<i>Douglas' dustymaiden</i>	18.8	26.5	17.5	4.2	39.1	12.2	5.4	17.7
	<i>hoary tansyaster</i>	67.3	47.4	48.8	18.7	57.7	19.1	22.1	40.2
	<i>silverleaf phacelia</i>	10.6	23.6	19.9	1	14.2	0.7	2	10.3
	<i>threadleaf phacelia</i>	2.6	0.1	0.1	0	2.7	0	0.1	0.8
	<i>showy goldeneye</i>	8	14.3	11.2	0.3	17.4	0.1	0.3	7.4
	<i>coyote tobacco</i>	4.4	11.8	1.8	0	4.2	12.2	0	4.9
	<i>manyflower thelypody</i>	23.2	37	28.5	1.7	19.7	2.4	2	16.4
	<i>scarlet gilia</i>	0.3	1.1	14.3	0	1	0	0.7	2.5
	<i>royal penstemon</i>	27	27	7.6	0	33.1	0.7	0.1	13.6
	Average	18	21	16.6	2.9	21	5.3	3.6	12.6
2015	<i>Douglas' dustymaiden</i>	3.9	2.9	14.8	2.6	4.3	1.1	7.3	5.3
	<i>hoary tansyaster</i>	35.4	30.7	30.5	17.7	27.4	8.3	17.4	23.9
	<i>silverleaf phacelia</i>	0.9	2.5	1.8	2.2	2.4	2.3	1.3	1.9
	<i>threadleaf phacelia</i>	9	4	3.1	5	11.6	4.4	1.8	5.6
	<i>showy goldeneye</i>	27.5	27.1	44.4	9.1	31.6	6	9.9	22.2
	<i>coyote tobacco</i>	1.2	0.8	1.8	0.2	1.3	0	0.3	0.8
	<i>manyflower thelypody</i>	1.4	2.1	2.1	1.2	2.2	1.6	1.6	1.7
	<i>scarlet gilia</i>	0.3	1.7	2.5	0.7	2.2	0.6	0.3	1.2
	<i>royal penstemon</i>	4.7	1.6	2.1	1.3	10.2	0.6	1.6	3.2
	Average	9.4	8.2	11.5	4.4	10.4	2.8	4.6	7.3
2016	<i>Douglas' dustymaiden</i>	22.3	16.3	24.2	10.7	23.2	14.2	5.3	16.6
	<i>hoary tansyaster</i>	28.9	26	25.2	14.8	38.7	16.2	16	23.7
	<i>silverleaf phacelia</i>	23.2	28.3	21.8	11.1	31.7	3.6	8.5	18.3
	<i>threadleaf phacelia</i>	6.2	1.8	2.3	4.5	11.7	2.7	1.8	4.4
	<i>showy goldeneye</i>	33.1	31	44.9	6.7	41.2	1.2	2.3	22.9
	<i>coyote tobacco</i>	6.5	21.7	15.2	0.1	10.1	0.1	0.4	7.7
	<i>manyflower thelypody</i>	10.9	15.3	9.8	9.3	14.4	6.1	5.2	10.1
	<i>scarlet gilia</i>	2.6	1.8	22.9	0.6	4.1	0.2	2.7	5.0
	<i>royal penstemon</i>	23.4	11.4	15.9	3.7	26.3	0.5	0.5	11.7
	Average	17.5	17.1	20.2	6.8	22.4	5	4.8	13.4

PLANT MATERIALS AND CULTURAL PRACTICES

Table 4 (cont.). Plant stands of nine native plant species in response to seven planting systems used in 2013, 2015, and 2016. Stand for each species was corrected to the percent of viable seed based on the tetrazolium test. To evaluate factors, the following treatment comparisons were used: Row cover, treatments 1 and 5; Seed treatment, treatments 1 and 3; Sawdust, treatments 1 and 2; Sand, treatments 1 and 4. OSU, Malheur Experiment Station, Ontario, OR.

Year	Species	Row cover, seed treatment, sawdust	Row cover, seed treatment	Row cover, sawdust	Seed treatment, sawdust	Row cover, seed treatment, sawdust, sand	Mulch, seed treatment	Untreated check	Average
.Average	<i>Douglas' dustymaiden</i>	15.7	15.2	18.6	5.8	22.2	9.2	6	13.2
	<i>hoary tansyaster</i>	44.3	34.7	34.8	17.1	41.3	14.5	18.5	29.3
	<i>silverleaf phacelia</i>	11.6	18.2	14.5	4.9	16.1	2.2	3.8	10.2
	<i>threadleaf phacelia</i>	5.9	1.9	1.8	3.2	8.7	2.4	1.3	3.6
	<i>showy goldeneye</i>	22.9	24.1	33.5	5.4	30	2.4	4.2	17.5
	<i>coyote tobacco</i>	4.1	11.4	6.3	0.1	5.2	4.1	0.2	4.5
	<i>manyflower thelypody</i>	11.8	18.1	13.5	4.1	12.1	3.4	2.9	9.4
	<i>scarlet gilia</i>	1.1	1.5	13.2	0.4	2.4	0.3	1.3	2.9
	<i>royal penstemon</i>	19.2	14	8.5	1.7	23.2	0.6	0.7	9.7
	Average	15.2	15.5	16.1	4.7	17.9	4.3	4.3	11.1
	LSD (0.05)								
	Treatment	1.6							
	Species	2.3							
	Year	1.1							
	Treatment*species	6.2							
	Treatment*species*year	8.9							

Publications

Refereed Journal Articles

Shock, C.C.; Feibert, E.B.G.; Shaw, N.; Shock, M.; Saunders, L.D. 2015. Irrigation to Enhance Native Seed Production for Great Basin Restoration. *Natural Areas Journal* 35(1):74-82.

Shock, C.C.; Feibert, E.B.G.; Rivera, A.; Saunders, L.D.; Shaw, N.; Kilkenny, F.F. 2016. Irrigation Requirements for Seed Production of Five *Lomatium* Species in a Semiarid Environment. *HortScience* 51: 1270-1277.

Annual Reports

Shock, C.C.; Feibert, E.B.G.; Rivera, A.; Saunders, L.D.; Kilkenny, F.F.; Shaw, N. 2016. Direct surface seeding systems for the establishment of native plants in 2015. p 175-180 In Shock C.C. (Ed.) Oregon State University Agricultural Experiment Station, Malheur Experiment Station Annual Report 2015, Department of Crop and Soil Science Ext/CrS 156.

Shock, C.C.; Feibert, E.B.G.; Rivera, A.; Saunders, L.D.; Shaw, N.; Kilkenny, F.F. 2016. Native beeplant seed production in response to irrigation in a semi-arid environment. p 181-185 In Shock C.C. (Ed.) Oregon State University Agricultural Experiment Station, Malheur Experiment Station Annual Report 2015, Department of Crop and Soil Science Ext/CrS 156.

Shock, C.C.; Feibert, E.B.G.; Rivera, A.; Saunders, L.D.; Shaw, N.; Kilkenny, F.F. 2016. Irrigation requirements for native buckwheat seed production in a semi-arid environment. p 186-192 In Shock C.C. (Ed.) Oregon State University Agricultural Experiment Station, Malheur Experiment Station Annual Report 2015, Department of Crop and Soil Science Ext/CrS 156.

Shock, C.C., Feibert, E.B.G.; Rivera, A.; Saunders, L.D.; Johnson, D.; Bushman, S.; Shaw, N.; Kilkenny, F. 2016. Prairie clover and basalt milkvetch seed production in response to irrigation. p 193-198 In Shock C.C. (Ed.) Oregon State University Agricultural Experiment Station, Malheur Experiment Station Annual Report 2015, Department of Crop and Soil Science Ext/CrS 156.

Shock, C.C.; Feibert, E.B.G.; Rivera, A.; Saunders, L.D.; Shaw, N.; Kilkenny, F.F. 2016. Irrigation requirements for seed production of five *Lomatium* species in a semi-arid environment. p 199-210 In Shock C.C. (Ed.) Oregon State University Agricultural Experiment Station, Malheur Experiment Station Annual Report 2015, Department of Crop and Soil Science Ext/CrS 156.

Shock, C.C.; Feibert, E.B.G.; Rivera, A.; Saunders, L.D.; Shaw, N.; Kilkenny, F.F. 2016. Irrigation requirements for seed production of five native *Penstemon* species in a semi-arid environment. p 211-222 In Shock C.C. (Ed.) Oregon State University Agricultural Experiment Station, Malheur Experiment Station Annual Report 2015, Department of Crop and Soil Science Ext/CrS 156.

Shock, C.C.; Feibert, E.B.G.; Rivera, A.; Saunders, L.D.; Shaw, N.; Kilkenny, F.F. 2016. Irrigation requirements for seed production of several native wildflower species planted in the fall of 2012. p 223-229 In Shock C.C. (Ed.) Oregon State University Agricultural Experiment

Station, Malheur Experiment Station Annual Report 2015, Department of Crop and Soil Science Ext/CrS 156.

Shock, C.C.; Feibert, E.B.G.; Rivera, A.; Saunders, L.D.; Shaw, N.; Kilkenny, F.F.; Prendeville, H.; St. Clair, B.; Halford, A. 2016. Seed increases of great basin native forbs and grasses for restoration research projects. p 230-233 In Shock C.C. (Ed.) Oregon State University Agricultural Experiment Station, Malheur Experiment Station Annual Report 2015, Department of Crop and Soil Science Ext/CrS 156.

Field days

Native Wildflower Seed Production Field Day, Malheur Experiment Station, Oregon State University (OSU), Ontario, Oregon, 12 May 2016

Presentations

Shock, C.C. 2016. Irrigation requirements for seed production of five native *Lomatium* species in a semi-arid environment. American Society of Horticultural Sciences; 2016 August 10; Atlanta, GA. <https://ashs.confex.com/ashs/2016/meetingapp.cgi/Paper/25077>

Shock, C.C.; Feibert, E.B.G.; Rivera, A.; Saunders, L.D.; Shaw, N.; Kilkenny, F.F.. 2016. Forb establishment and seed production in drier, hotter years. Great Basin Native Plant Project and the Society for Ecological Restoration, Great Basin meeting; 2016 April 11; Boise, Idaho.

Shock, C.C., Feibert, E.B.G.; Saunders, L.D.; Parris, C.; Shaw, N. 2016. Planting systems for improved stands of Great Basin native perennials medicinal herb growing and marketing conference; 2016 April 17; Port Townsend, WA.

Management Applications and/or Seed Production Guidelines

Irrigation water requirements for native wildflower seed production

Clint Shock and Erik Feibert, 24 January 2017

Wildflower species irrigated with drip systems at the Malheur Experiment Station, OSU, Ontario, OR.

Species	Common names	Flowering dates*	Irrigation water needs		Years to first harvest	Stand life	Seed yield
			range	average			
			inches/year			years	lb/ac per harvest
<i>Eriogonum umbellatum</i>	sulphur-flower buckwheat	L. May to July	0-8	5	1	11+	100-350
<i>Eriogonum heracleoides</i>	parsnip-flowered buckwheat	May to June	0-4	5	2	6+	50-400
<i>Penstemon acuminatus</i>	sharp-leaf penstemon	L. April to E. June	0-4	0	2	3	100-600
<i>Penstemon deustus</i>	scabland penstemon	May to E. July	0-4	0	1	2	200-600
<i>Penstemon speciosus</i>	royal penstemon	May to June	0-5	4	2	3	25-350
<i>Penstemon cyaneus</i>	blue penstemon	May to June	0-8	0	1	3	200-800
<i>Penstemon pachyphyllus</i>	thick-leaf beardtongue	L. April to E. June	0-8	0	2	3	200-500
<i>Lomatium dissectum</i>	fern-leaf biscuitroot	April to E. May	0-12	7	4	9+	300-1200
<i>Lomatium triternatum</i>	nine-leaf biscuitroot	April to E. June	4-10	8	2	10+	700-2000
<i>Lomatium grayi</i>	Gray's biscuitroot	L. March to E. May	0-8	5	2	10+	300-1200
<i>Lomatium nudicaule</i>	barestem biscuitroot	April to May	0	0	3	5+	500-600
<i>Cymopterus bipinnatus</i>	Hayden's cymopterus	April to May	0-8	5	3	5+	300-2500
<i>Sphaeralcea parvifolia</i>	smallflower globemallow	May to June	0	0	1	4-5	100-500
<i>Sphaeralcea grossulariifolia</i>	gooseberry-leaf globemallow	May to June	0	0	1	4-5	150-400
<i>Sphaeralcea coccinea</i>	scarlet globemallow	May to June	0	0	1	4-5	100-300
<i>Dalea searlsiae</i>	Searls' prairie clover	May to June	0-9	6	2	6+	150-300
<i>Dalea ornata</i>	western prairie clover	May to June	0-8	5	2	6+	150-450
<i>Astragalus filipes</i>	basalt milkvetch	L. April to June	0	0	2	4+	10-100
<i>Cleome serrulata</i>	Rocky mountain beeplant	June to August	0-8	8	1	1	100-500
<i>Cleome lutea</i>	yellow spiderflower	May to July	0-4	0	1	1	100-200
<i>Machaeranthera canescens</i>	hoary tansyaster	Mid-Aug to L. Sept.	0-2	0	1	3+	200-400
<i>Phacelia hastata</i>	silver-leaf phacelia	May to July	0-8	7	1	3+	100-300
<i>Phacelia linearis</i>	thread-leaf phacelia	E. May to L. June	0-6	5	1	1	150-300
<i>Enceliopsis nudicaulis</i>	nakedstem sunray	May to August	0-6	5	1	2	10-35
<i>Helionis multiflora</i>	showy goldeneye	L. May to August	0-8	8	1	4+	50-250

*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 12 May 2016.
- Continued improvement of native plant database on the internet at <http://www.malag.aes.oregonstate.edu/wildflowers/>
- Many of our forb production reports are available on line at www.cropinfo.net

Acknowledgements

This project was funded by the U.S. Forest Service (USFS) Great Basin Native Plant Project (GBNPP), U.S. Bureau of Land Management (BLM), Oregon State University (OSU), Malheur County Education Service District, and supported by Formula Grant nos. 2016-31100-06041 and 2016-31200-06041 from the USDA National Institute of Food and Agriculture (NIFA).



RESTORATION STRATEGIES



Project Title Restoring Sagebrush After Large Wildfires: An Evaluation of Different Restoration Methods across a Large Elevation Gradient

Project Agreement No. 15-IA-11221632-205

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Project Description

We are evaluating natural recovery and four different restoration techniques to reestablish sagebrush after large wildfires.

Introduction

We are evaluating sagebrush restoration success with five methods across an elevation gradient using a randomized block design. Treatments were randomly assigned within block (site) and include: 1) natural recovery (control), 2) broadcast seeding sagebrush, 3) broadcast seeding sagebrush followed by roller-packing, 4) broadcast seeding sagebrush seed pillows, and 5) planting sagebrush seedlings. All sagebrush used in the study were big sagebrush. However, subspecies (Wyoming or mountain) of big sagebrush varied based on the potential natural community type. Wyoming big sagebrush (*Artemisia tridentata ssp. wyomingensis*) and mountain big sagebrush (*Artemisia tridentata ssp. vaseyana*) were seeded and planted on sites where Wyoming or mountain big sagebrush was dominant prior to burning.

Objectives

The objectives of this study are to 1) determine where different post-fire sagebrush restoration methods should be applied based on environmental characteristics to efficiently and effectively restore sagebrush, and 2) evaluate newly developed technologies to restore sagebrush steppe habitat. We hypothesize that 1) natural recovery and seeding sagebrush will be more successful as elevation increases, 2) improving soil-seed contact by using a roller-packer after seeding sagebrush will improve seeding success, and 3) at lower elevations, seed pillows and planting seedlings will be more successful than other methods at establishing sagebrush.

Methods

Treatments were applied along five transects that span an elevation gradient from 1219 to 2134 m (4000 to 7000 ft). Along each elevation gradient, treatments were applied at approximately 1219, 1372, 1524, 1676, 1829, 1981, and 2134 m (4000, 4500, 5000, 5500, 6000, 6500, and 7000 ft) elevation. At each elevation on each transect, treatments were randomly assigned to five 5 X 10 m plots with a 2 m buffer between treatment plots in each year. Total number of blocks was

35 (five elevation transects X seven elevations per transect = 35 blocks) and total number of treatment plots was 350 (five treatments X 2 years X 35 blocks = 350 plots). All sagebrush seeding treatments were applied at a rate of 1.1 kg pure live seed per hectare in the fall. Roller-packing was applied by pulling a small roller-packer by hand across the plot after seeding. Seed pillows were a mixture that promotes survival, growth, and establishment of sagebrush (exact formulation is not reported because of proprietary rights). Seeds and seed pillows were broadcasted using a non-automated centrifugal flinger fertilizer spreader. Sagebrush seedlings were hand planted at a density of one seedling per m². Sagebrush seedlings were grown to a pre-planting height of approximately 15 cm by planting five sagebrush seeds in seedling cone containers in a greenhouse. Cone containers were 3.8 cm diameter at the top and 21 cm tall. Sagebrush seedlings were thinned to one individual per cone container. Sagebrush seedlings were planted in the spring by digging a hole approximately 21 cm deep, placing the seedling in the hole, and pressing the soil around the roots of the seedlings.

Vegetation measurements will be conducted for four years after treatments are applied. Sagebrush and other shrub cover will be measured using the line-intercept method on three, 10 m transects within each plot. The 10 m transects will be placed at 1.5, 2.5, and 3.5 m points along the 5 m side of the treatment plot. Density of sagebrush and other shrubs will be measured by counting all plants rooted inside the 5 X 10 m plot. Average height of sagebrush will be determined by measuring the height of 10 randomly selected sagebrush plants per plot. Sagebrush biomass production per plot will be estimated using height and two perpendicular diameter measurements of the sagebrush canopy from 10 randomly selected sagebrush plants to determine average sagebrush production and then multiplying average production by the density of sagebrush.

Herbaceous vegetation cover and density will be measured in 30, 0.2 m² quadrats in each treatment plot. The quadrats will be spaced at 1 m intervals along each 10 m transect. Herbaceous cover will be visually estimated by species in the 0.2 m² quadrats. Density will be measured by species by counting all plants rooted inside the 0.2 m² quadrats.

Site characteristics will be measured at each block. Elevation, longitude, and latitude will be determined using topographical maps. Aspect will be determined using a compass. Slope will be measured with a clinometer. Soil depth will be determined by digging to a restrictive layer. Soil texture will be determined using the hydrometer method for the 0-20 cm depth and 20-40 cm depth. Precipitation will be determined from PRISM precipitation maps. Average, minimum, and maximum temperatures, Ecological Site, and frost free days will be determined for each block from Natural Resources Conservation Service (NRCS) Soil Surveys. Post-fire weather characteristics will be determined from nearby weather stations.

Expected Results and Discussion

We expect to determine which methods are most successful at different elevations to restore sagebrush after wildfire. We expect to determine how natural sagebrush recovery varies by elevation and other site characteristics.

Management Applications

Preliminary data analyses suggest that at higher elevations natural recovery after fire is sufficient. Natural recovery of sagebrush in lower elevation Wyoming big sagebrush communities is not occurring. Preliminary results suggest that seeding Wyoming big sagebrush after wildfire can successfully establish sagebrush in some years; however, success may depend on spring precipitation. Success of different restoration treatments appears to vary by elevation and year.

Presentations

Hulet, A.; K.W. Davies. 2016. Restoring Sagebrush after Mega-Fires: Success of Different Restoration Methods across an Elevation Gradient. Society for Range Management Annual Meetings; January 2016; Corpus Christi, TX.

Hulet, A. 2016. Sagebrush and Fire: The Good, the Bad, and Why We Should Care. University of Idaho Forest, Rangeland, and Fire Sciences Seminar Series; March 2016; Moscow, ID.

Project Title Forb Islands: Possible Techniques to Improve Forb Seedling Establishment for Diversifying Sagebrush-Steppe Communities

Project Agreement No. 15-IA-11221632-211 (USDA-ARS)
151141-0001 (Utah State University)

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Project Description

Introduction

Public land management agencies (BLM, Forest Service) are interested in expanding the biodiversity of rangeland plantings. Diverse native Great Basin forbs are essential for feeding both native pollinator communities (Cane 2008; Watrous and Cane 2011; Cane 2011; Cane et al. 2012, 2013) and wildlife, especially sage-grouse (Wisdom et al. 2002; Rowland et al. 2006). The seeding of native grasses and shrubs on Great Basin sage-steppe sites has been increasingly

successful in recent years. Although many native forb species are becoming more commercially available because of Great Basin Native Plant Project (GBNPP) collaborations, establishment of native forbs remains sporadic and challenging. The period of favorable soil water and temperature conditions is often not long enough for successful forb establishment. A possible alternative to conventional seeding of forb species is to establish forb islands (distinct focal areas where forbs are established), which employ techniques to extend the favorable period for germination and establishment of Great Basin forbs. These forb islands could be sources of seed for the colonization of adjacent rangeland areas in subsequent years.

Objectives

Determine if the HFFS or N-sulate fabric in combination with seed coating can improve the establishment of Great Basin forbs at three sites in Utah and Idaho.

Methods

The HFFS incorporates two parallel, specially designed snow fences that trap snow in uniform, dense drifts that slowly melt and extend soil water availability by 30-45 days (David 2013). The N-sulate fabric is a medium-weight, permeable, UV-treated, and re-usable fabric designed to protect nursery ground beds, annual flowers, and vegetable gardens from freezing temperatures and rapid drying of the soil surface (Jensen 2009). Highly variable weather patterns in the Great Basin means that conditions needed to break dormancy and provide conditions conducive to forb establishment may not be present in most years. While seed dormancy may aid in preventing seed germination during unfavorable conditions, dormancy can limit the establishment of forbs in the face of invasive weed competition immediately after wildfires and allow weeds to preempt rangeland sites before forbs establish. New seed enhancement technology is being developed for breaking seed dormancy and enhancing seed germination and early seedling growth (Madsen and Hulet 2015). With this approach seeds can be coated with various treatments that can overcome seed dormancy impediments (Madsen and Svejcar 2011).

Field studies were established during November 2015 with three primary treatments (HFFS, N-sulate fabric, and Control) in a randomized complete block design with four replications at two sites in Utah (Spanish Fork, Clarkston) and one site in Idaho (Virginia). The two Utah sites are located on cultivated land, and the Virginia site was recently placed into the Conservation Reserve Program (CRP) to control erosion and enhance pollinator and sage-grouse habitat. During November 2015, 33 rows of two forb species (basalt milkvetch, western prairie clover) treated with 14 specific seed coatings (Table 1) seeded into 1.5 m long rows at a rate of 82 PLS/m² in each of the three main site treatments (HFFS, N-sulate, and Control) with a four-row Hege cone seeder (Figure 1). The remaining 1.5 m portion in each of the 33 rows in each treatment combination was seeded to 10 forb species native to the Intermountain West with three seed treatments provided for each species compared to two check species, small burnet (*Sanguisorba minor*) and sainfoin (*Onobrychis viciifolia*) (Table 2).

RESTORATION STRATEGIES

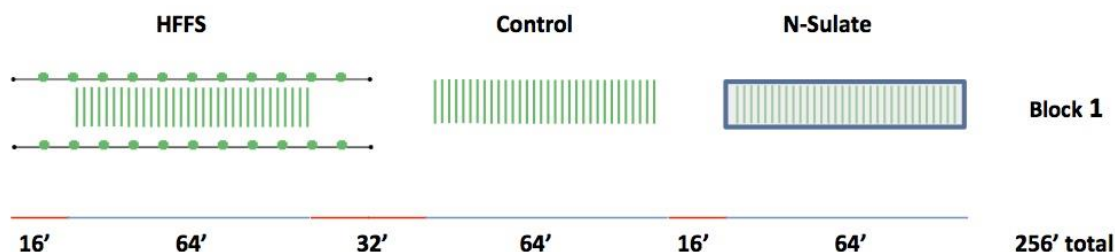


Figure 1. Plot layout for one block indicating the seeded rows in each main site treatment.

Organza mesh bags containing 25 seeds of each of the species with specific seed treatments were placed alongside the three main site treatments and covered with soil at each site for retrieval in March, April, and June of 2016 to determine seed treatment effects on germination. Seedling emergence and phenological development were determined for seedlings in the seeded rows at each site on a monthly basis beginning in March 2016 and ending July 2016. Soil water content and soil temperatures were monitored continuously at the three study sites to provide a mechanistic understanding of seedling responses and for hydrothermal model analysis (Hardegree et al. 2013).

Results

Germination Bags:

1. Two Legume Study: Results showed significant differences in germination between HFFS, N-sulate, and Control treatments at individual sites for the two Great Basin native legumes, with the HFFS treatment generally having the lowest proportion of germinated seeds. At both Spanish Fork and Clarkston, germination rates were highest in the N-sulate treatment, followed by the Control treatment, and then the HFFS treatment. At Virginia, the Control treatment had the highest germination rate, followed by the N-sulate treatment, and then the HFFS treatment. Mean germination rates at all three sites differed, with seeds at Spanish Fork exhibiting significantly higher mean germination rates than those at Clarkston and Virginia, which did not differ.

Seed coatings generally increased germination at all three sites. Scarified seeds had significantly higher germination rates than non-scarified seeds. Seeds with a fungicide and/or hydrophobic coating had higher germination rates than non-coated seeds. Scarified seeds with a fungicide coating did not have significantly different germination rates than seeds that were only scarified. Additionally, seeds that were scarified and had a hydrophobic coating did not differ from seeds that were only scarified. Moreover, seeds that had combinations of fungicide and hydrophobic coatings were not significantly different from those with fungicide-only, hydrophobic-only, or scarification-only treatments.

2. Diverse Species Study: Results for the 10 native forb species did not differ between the HFFS, N-sulate, and Control treatments within individual sites. However, germination proportions were highest for Spanish Fork compared to Clarkston and Virginia, which were not significantly different. Within each species across all sites, seed treatments did not significantly increase germination compared to non-treated seeds, except for two species. Seeds of silvery lupine (*Lupinus argenteus*) that were mechanically scarified had significantly higher germination rates

than non-scarified seeds. Seeds of thicket beardtongue (*Penstemon pachyphyllus*) that were treated with gibberellic acid had significantly higher germination than non-treated seeds. Species that had the highest germination rates at all three sites were: bigflower agoseris (*Agoseris grandiflora*), parsnipflower buckwheat (*Eriogonum heracleoides*), scarlet gilia (*Ipomopsis aggregata*), silvery lupine, hairy bigleaf lupine (*Lupinus prunophilus*), thicket beardtongue, and royal penstemon (*P. speciosus*).

Seedling Establishment:

1. Two Legume Study: Results for basalt milkvetch and western prairie clover showed that Spanish Fork and Virginia had the highest seedling emergence in March and April 2016. Clarkston had significantly lower seedling emergence than both Spanish Fork and Virginia, which remained consistent in May and June 2016. At Spanish Fork, mean seedling emergence was significantly higher in the HFFS treatment, followed by Control and then N-sulate treatments. At Clarkston, mean seedling emergence was highest in the N-sulate treatment with no significant difference between HFFS and Control treatments. At Virginia, the Control treatment had the highest mean seedling emergence, followed by the N-sulate and HFFS treatments. Scarified seeds did not have significantly higher rates of seedling emergence than non-scarified seeds. However, seeds that were scarified and treated with fungicide or scarified and had a hydrophobic coating exhibited higher germination rates than both scarified and non-scarified seeds. Generally, seedling emergence rates were highest for seeds that received a combination of scarification, fungicide, and hydrophobic coatings at all three sites in all treatments. Mean seedling emergence differed among the three sites with Virginia having the highest seedling emergence, followed by Spanish Fork and then Clarkston, which were not significantly different.

2. Diverse Species Study: Seedling emergence of the 10 native forb species was significantly highest at Spanish Fork in the HFFS treatment, followed by the Control and N-sulate treatments. At both Clarkston and Virginia, Control treatments had the highest seedling emergence, followed by HFFS and N-sulate treatments. Seed treatments generally increased seedling emergence at all three sites, with the highest seedling emergence observed for parsnipflower buckwheat and scarlet gilia coated with Obvious fungicide and royal penstemon treated with gibberellic acid. Seedling emergence was significantly highest at Clarkston, followed by Spanish Fork and Virginia. Species that had the highest seedling emergence across all three sites were: parsnipflower buckwheat, scarlet gilia, silvery lupine, hairy bigleaf lupine, thicket beardtongue, and royal penstemon.

Management Applications

This project will provide land managers with information to diversify their rangeland revegetation projects.

Presentations

Fund, Adam; Hulvey, Kristin; Jensen, Scott; Madsen, Matt; Tilley, Derek; Monaco, Tom; Cane, Jim; Johnson, Douglas. 2016. Forb Islands: Novel Techniques to Improve Native Forb Establishment. April 11, 2016. Great Basin Native Plant Project Meeting; 2016 April 11-12; Boise, ID.

References

- Cane, J. H. 2008. Pollinating bees crucial to farming wildflower seed for U.S. habitat restoration. In: R.R. James and T.L. Pitts-Singer (eds.), *Bees in Agricultural Ecosystems*. New York: Oxford Univ. Press: 48-64.
- Cane, J. H. 2011. Meeting wild bees' needs on western US rangelands. *Rangelands* 33: 27-32.
- Cane, J. H.; Love, B; Swoboda, K. A. 2013. Breeding biology and bee guild of Douglas' dustymaiden, *Chaenactis douglasii* (Asteraceae, Helenieae). *Western North American Naturalist* 72: 563-568.
- Cane, J. H.; Weber, M.; Miller, S. 2012. Breeding biologies, pollinators, and seed beetles of two prairie-clovers, *Dalea ornata* and *Dalea searlsiae* (Fabaceae: Amorphaeae), from the Intermountain West, USA. *Western North American Naturalist* 72: 16-20.
- David, E. 2013. Innovative snow harvesting technology increases vegetation establishment success in native sagebrush ecosystem restoration. *Plant and Soil* 373: 843-856.
- Hardegree S. P.; Moffet, C. A.; Flerchinger, G. N.; Cho, J; Roundy, B. A.; Jones, T. A.; James, J. J.; Clark, P. E.; Pierson, F. B. 2013. Hydrothermal assessment of temporal variability in seedbed microclimate. *Rangeland Ecology and Management* 66: 127-135.
- Jensen, S. 2009. The quest for natives: cultural practices, species screening and private growers. Ogden, UT; Department of Agriculture, Forest Service, Intermountain Research Station. Great Basin Native Plant Selection and Increase Project Annual Report: 12-18.
- Madsen, M. D.; Hulet, A. 2015. Primed seed matrix composition and method of making extruded seed pellets. U.S. Patent Application No. 62/111,451.
- Madsen, M. D.; Svejcar, T. J. 2013. Development and application of "seed pillow" technology for overcoming the limiting factors controlling rangeland reseeding success. U.S. Patent Application No. 14/039,873.
- Rowland, M. M.; Wisdom, M. J.; Suring, L. H.; Meinke, C. W. 2006. Greater sage-grouse as an umbrella species for sagebrush-associated vertebrates. *Biological Conservation* 129: 323-335.
- Watrous, K. W.; Cane, J. H. 2011. Breeding biology of the threadstalk milkvetch, *Astragalus filipes* (Fabaceae), with a review of the genus. *American Midland Naturalist* 165: 225-240.
- Wisdom, M. J.; Rowland, M. M.; Wales, B. C.; Hemstrom, M. A.; Hann, W. J.; Raphael, M. G.; Holthausen, R. S.; Gravenmier, R. A.; Rich, T. D. 2002. Modeled effects of sagebrush-steppe restoration on greater sage-grouse in the interior Columbia Basin, USA. *Conservation Biology* 16: 1223-1231.

RESTORATION STRATEGIES

Table 1. List of seed coating treatments for two native legume species study (*Astragalus filipes* and *Dalea ornata*).

Scientific name	Common name	Untreated	Scarification	Coated	Obvious ¹ fungicide	Farmore fungicide	Captan fungicide
<i>Astragalus filipes</i>	Basalt milkvetch	x	x	x	x	x	x
<i>Dalea ornata</i>	Western prairie clover	x	x	x	x	x	x

		Hydrophobic rate 1	Hydrophobic rate 2
<i>Astragalus filipes</i>	Basalt milkvetch	x	x
<i>Dalea ornata</i>	Western prairie clover	x	x

		Obvious + Hydrophobic 1	Obvious + Hydrophobic 2
<i>Astragalus filipes</i>	Basalt milkvetch	x	x
<i>Dalea ornata</i>	Western prairie clover	x	x

		Farmore + Hydrophobic 1	Farmore + Hydrophobic 2
<i>Astragalus filipes</i>	Basalt milkvetch	x	x
<i>Dalea ornata</i>	Western prairie clover	x	x

		Captan + Hydrophobic 1	Captan + Hydrophobic 2
<i>Astragalus filipes</i>	Basalt milkvetch	x	x
<i>Dalea ornata</i>	Western prairie clover	x	x

RESTORATION STRATEGIES

Table 2. List of seed coating treatments for the diverse species study.

Scientific name	Common name	Untreated	Scarification	Obvious fungicide	Farmore fungicide	Heat	Leach	Gibberellic acid
<i>Agoseris grandiflora</i>	Bigflower agoseris	x		x	x			
<i>Eriogonum heracleoides</i>	Parsnipflower buckwheat	x		x			X	
<i>Heliomeris multiflora</i> var. <i>nevadensis</i>	Nevada goldeneye	x		x	x			
<i>Ipomopsis aggregata</i>	Scarlet gilia	x		x		X		
<i>Lupinus argenteus</i>	Silvery lupine	x	x	x				
<i>Lupinus prunophilus</i>	Hairy bigleaf lupine	x	x	x				
<i>Onobrychis viciifolia</i>	Sainfoin	x						
<i>Penstemon pachyphyllus</i>	Thickleaf beardtongue	x		x				X
<i>Penstemon speciosus</i>	Royal penstemon	x		x				X
<i>Sanguisorba minor</i>	Small burnet	x						
<i>Sphaeralcea coccinea</i>	Scarlet globemallow	x		x	x			

Project Title Placing Fall-harvested Wyoming Big Sagebrush Plants to Catch Snow and Provide Seed for Creating Sagebrush Islands

Project Agreement No. 17-JV-11221632-016

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Project Description

Introduction

Within the sagebrush steppe ecosystem, sagebrush plants influence a number of ecosystem properties, including nutrient distribution, plant species diversity, and soil moisture and temperature (McAdoo et al. 2013a). Sagebrush is also a critical habitat component for a number of sagebrush-associated wildlife species (McAdoo et al. 1989; Crawford et al. 2004; Shipley et al. 2006; Davies et al. 2011). Recent increases in frequency and size of wildfires and associated annual grass expansion within Wyoming big sagebrush (*Artemisia tridentata* spp. *wyomingensis*) communities have increased the need for effective sagebrush restoration tools and protocols.

Some areas have burned with such frequency that sagebrush seed is absent. Even where remnant sagebrush is present, recruitment from existing seedbanks is unreliable and apparently episodic under natural conditions (Perryman et al. 2001). Active vegetation management for restoration of sagebrush-perennial grass communities is necessary and some areas require seeding or planting of desirable vegetation (McAdoo et al. 2013b). But successfully planting sagebrush from seed is challenging because of low and erratic precipitation on drier sites, difficulty in obtaining adequate seed supplies of required subspecies from adapted sites when needed, limited shelf life of seeds, and inadequate cold storage space (Shaw et al. 2005). Unfortunately, restoration of Wyoming big sagebrush on areas where it is critical, but absent, has also been limited by inadequate restoration techniques and technologies. Recent research shows that planting sagebrush seedlings can be successful (Davies et al. 2103; McAdoo et al. 2103a). While limited

in spatial extent, such plantings can provide a mechanism for establishing sagebrush islands to introduce a sagebrush seed source for long-term sagebrush expansion. In turn, shrub islands can potentially accelerate vegetation recovery of disturbed areas, serving to enhance the local biodiversity of plants and animals (Longland and Bateman 2002).

Obviously, the economics of planting individual sagebrush limits the size of areas planted; and soil moisture, a huge variable in the successful establishment of sagebrush either from seed or by direct planting can be quite variable from year to year. The investigators propose to use a modified “pile seeding” (Boyd and Obradovich 2014) approach to enhance sagebrush establishment from seed in islands. Sagebrush seeds naturally disperse in late fall or early winter, and artificial seeding on snow has been successful in some areas (Jacobs et al. 2011). Because sagebrush seeds tend to germinate where snow accumulates, soon after snowmelt (Jacobs et al. 2011), we plan to use cut sagebrush plants both as the source of sagebrush seed and as a means of trapping snow for enhanced germination.

Objectives

Our primary objective is to evaluate the fall placement of Wyoming big sagebrush plants, harvested at near seed-ripe, in recently burned areas. The harvested sagebrush plants will serve both as snow catchments and seed source as the seeds dehisce.

Methods

During each of two years and at each of three replicated study areas within the 20-25 cm (8-10 inch) precipitation zone (Nevada), and 25-30 cm (10-12 Inch) precipitation zone (Oregon) we will establish treatments within recently burned sites. We will employ a randomized block design, with five blocks at each site. Within each block, six 15-m² circular plots per treatment will be established; plots within a block will be installed at 20 m intervals. Plots will be randomly assigned to treatment in 2016 or 2017 and as either treated with a shrub placement, seeded, or untreated (control). At each plot randomly selected for sagebrush placement, a Wyoming big sagebrush plant (harvested just before seed-ripe) will be placed and secured (if necessary) with wire and rebar. Seeded plots will be hand-broadcast with commercially purchased Wyoming big sagebrush seed to simulate standard agency seeding practice.

Establishment of sagebrush plants will be determined by counting seedlings during the first growing season after shrub placements and seeding; survival for each year of treatment will be determined by counting the number of sagebrush plants remaining during the second growing season. Size differences will allow differentiation between seedling cohorts of the two planting years (Boyd and Obradovich 2014). Data will be analyzed using mixed-model ANOVA (PROC MIXED, Littell et al. 1996) with repeated years.

Expected Results and Discussion

We anticipate that sagebrush seed that drops from the fall-harvested plants will have higher survival and establishment rates than broadcast-seeded sagebrush. If indeed this is the case, land managers will have yet another tool for establishing islands of sagebrush in burned areas. These islands would presumably become seed sources for gradual colonization of sagebrush into larger areas for postfire rehabilitation.

References

- Boyd, C. S.; Obradovich, M. 2014. Is pile seeding Wyoming big sagebrush (*Artemisia tridentata* subsp. *wyomingensis*) an effective alternative to broadcast seeding? *Rangeland Ecology & Management* 67:292–297.
- Crawford, J. A.; Olson, R. A.; West, N. E.; Mosley, J. C.; Schroeder, M. A.; Whitson, T. D.; Miller, R. F.; Gregg, M. A.; Boyd, C.S.. 2004. Ecology and management of sage-grouse and sage-grouse habitat. *Journal of Range Management* 57:2–19.
- Davies, K. W.; Boyd, C. S.; Beck, J. L.; Bates, J. D.; Svejcar, T. J.; Gregg, M.A . 2011. Saving the sagebrush sea: An ecosystem conservation plan for big sagebrush plant communities. *Biological Conservation* 144:2573-2584.
- Davies, K. W.; Boyd, C. S.; Nafus, A. M. 2013. Restoring the sagebrush component in crested wheatgrass-dominated communities. *Rangeland Ecology & Management* 66:472–478.
- Jacobs, S.; Scianna, J. D.; Winslow, S. R. 2011. Big sagebrush establishment. USDA, Natural Resources Conservation Service Plant Materials Technical Note No. MT-68. 9 p.
- Littell, R. C.; Milliken, G. A.; Stroup, W. W.; Wolfinger, R. D. 1996. SAS system for mixed models. Cary, NC: SAS Institute.
- Longland, W. S.; Bateman, R. D. 2002. Viewpoint: the ecological value of shrub islands on disturbed sagebrush rangelands. *Journal of Range Management* 55(6):571-575.
- McAdoo, J. K.; Boyd, C. S.; Sheley, R. L. 2013a. Site, competition, and plant stock influence transplant success of Wyoming big sagebrush. *Rangeland Ecology & Management* 66:305–312.
- McAdoo, J. K.; Longland, W. S.; Evans, R. A. 1989. Nongame bird community responses to sagebrush invasion of crested wheatgrass seedings. *Journal of Wildlife Management* 53:494-502.
- McAdoo, J. K.; Schultz, B. W.; Swanson, S. R. 2013b. Aboriginal precedent for active management of sagebrush-perennial grass communities in the Great Basin. *Rangeland Ecology & Management* 66:241-253.
- Perryman, B. L.; Maier, A. M.; Hild, A. L.; Olson, R. A. 2001. Demographic characteristics of big sagebrush in Wyoming. *Journal of Range Management* 54:166-170.
- Shaw, N. L.; DeBolt, A. M.; Rosentreter, R. 2005. Reseeding big sagebrush: Techniques and issues. U.S. Department of Agriculture, Forest Service, RMRS-P-38.
- Shipley, L. A.; Davila, T. B.; Thines, N. J.; and Elias, B. A. 2006. Nutritional requirements and diet choices of the pygmy rabbit (*Brachylagus idahoensis*): a sagebrush specialist. *Journal of Chemical Ecology* 32:2455-2474.

Project Title Long-term Effects of Post-fire Seeding Treatments

Project Agreement No. 15.IA.11221632.066

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Project Description

Introduction

Post-fire seeding has been widely applied on public lands throughout the Great Basin for the purpose of reducing soil erosion, suppressing invasion of exotic annual plants such as cheatgrass (*Bromus tectorum*) and establishing desirable perennial plants during a window of opportunity following fire (Ott et al. 2003; Thompson et al. 2006; Pyke et al. 2013). The effectiveness of post-fire seeding has been commonly evaluated on the short term, especially 1-3 years (Pyke et al. 2013), but less is known about long-term effectiveness, and few studies have evaluated long-term effects of seed mix composition. Non-native forage grasses such as crested wheatgrass (*Agoropyron cristatum*) have often been utilized for post-fire rehabilitation in areas where soil protection and invasive plant suppression are the primary concerns (Ott et al. 2003; Pyke et al. 2013). However, seed mixes composed of native grasses, forbs and shrub are preferable for areas where ecological restoration is the ultimate objective (Richards et al. 1998; USDI BLM 2007). Native shrubs have often been included in post-fire seed mixes because of their value for wildlife, including the greater sage-grouse (*Centrocercus urophasianus*), a candidate for listing under the Endangered Species Act (Arkle et al. 2014).

Objectives

We sought to determine the long-term (15+ years) effects of post-fire seeding in sagebrush and pinyon-juniper ecosystems of the Great Basin using a seeding experiment in Tintic Valley, Utah (Thompson et al. 2006) as our case study. The experiment had been implemented following a wildfire that burned across the valley 1999. The objective of the experiment was to test different seed mixes, some of which contained commonly seeded non-native species (of Eurasian origin) whereas others were comprised entirely of native species (of western North American origin). Our objective was to examine effects of these seed-mix treatments on vegetation composition beyond the three-year evaluation period reported by Thompson et al. (2006). In this report we focus on perennial grass cover and shrub cover as positive indicators of vegetation recovery and exotic annual cover as a negative indicator.

Methods

Study sites are located in Tintic Valley, Utah, on public lands that burned during the July 1999 Railroad wildfire. Thompson et al. (2006) selected areas in the vicinity of Jericho (39°42'–45'N, 112°11'–17'W) where pre-burn vegetation consisted of Wyoming big sagebrush (*Artemisia tridentata* ssp. *Wyomingensis*), and in the vicinity of Mud Springs (39°51'–54'N, 112°11'–15'W) where pinyon-juniper stands had burned. Five experimental blocks were established within each of these areas. Seeding treatments were applied in November 1999 using rangeland drills at the Jericho site and aerial seeding followed by chaining at the Mud Springs site. Four treatments differing by seed mix, plus an untreated control, were applied to randomly-assigned rectangular

strips, 213 m long and 46 m (Jericho site) or 73 m (Mud Springs site) wide, within each block. Seed mixes were comprised of 7-8 predominately introduced species supplied by the Bureau of Land Management (BLM) (BLM mix), a combination of 4-6 native and 5 introduced species supplied by the Agricultural Research Service (ARS) (ARS mix), 7-8 native species accessions (Native Low mix, NL) and 11 native species accessions at high seeding rates (Native High mix, NH) (Thompson et al. 2006; Table 1).

Vegetation measurements taken during the first three years following the 1999 Railroad Fire (Thompson et al. 2006) were re-measured in 2015 and 2016. Quadrats and belts previously sampled were relocated from permanent markers. Within each quadrat, percent cover of litter, bare ground, and plant canopy cover by species were estimated on a modified Daubenmire cover class scale, and nested frequency scores were assigned based on presence in sub-quadrats of different sizes. Density counts were taken within quadrats for grass and forb species and within belts for shrubs. Data collection was carried out in August 2015 by a field crew from the Utah Division of Wildlife Resources, and in August-September 2016 by a crew from Brigham Young University.

Results and Discussion

Our site visits in 2015 and 2016 revealed differences in vegetation composition among treatments that had received different seed mixes in 1999. To illustrate these differences, we present condensed results from the Jericho drill-seeding site in 2015 (Figure 1). At this site, the BLM and ARS seed mix treatments were dominated by non-native perennial grasses, primarily crested wheatgrass, intermediate wheatgrass (*Thinopyrum intermedium*) and Siberian wheatgrass (*Agropyron fragile*). We group these two treatments under the name “rehabilitation mixes” and compare them with “restoration mixes” (Native Low and Native High) which had been seeded with all native species and were dominated by western wheatgrass (*Pascopyrum smithii*) and needle-and-thread (*Hesperostipa comata*) in 2015.

Table 1. Seed mix composition and seeding rates at aerial-seeded and drill-seeded sites in Tintic Valley, Utah (after Thompson et al. 2006, Table 1).

Species	Variety/Cultivar	PLS ¹	Mud Springs Aerial Seeding				Jericho Drill Seeding			
			ARS ²	BLM	NH	NL	ARS	BLM	NH	NL
<u>Non-native Perennial Grasses</u>										
Crested wheatgrass	Hycrest	0.85	—	4.5 ³	—	—	—	2.2	—	—
Crested wheatgrass hybrid	CD II	0.93	3.6	—	—	—	1.8	—	—	—
Intermediate wheatgrass	Luna	0.92	—	3	—	—	—	2.2	—	—
Tall wheatgrass	Alkar	0.83	—	3	—	—	—	2.2	—	—
Russian wildrye	Bozoisky	0.86	3	3	—	—	1.5	2.2	—	—
Siberian wheatgrass	Vavilov	0.89	3.8	—	—	—	1.9	—	—	—
Smooth brome	Lincoln	0.81	—	3	—	—	—	—	—	—
<u>Native Perennial Grasses</u>										
Basin wildrye	Magnar	0.86	—	—	3	—	—	—	2.2	—
Bluebunch wheatgrass	Whitmar	0.85 E	—	—	4.5	4.5	—	—	2.2	2.2
Bluebunch wheatgrass	Goldar	0.86	—	3	4.5	4.5	—	—	2.2	2.2
Bluebunch wheatgrass	Secar	0.89	2.5	—	—	—	1.3	—	—	—
Indian ricegrass	Rimrock	0.92	1.2	—	—	—	0.6	—	—	—
Indian ricegrass	Nezpar	0.85 E	—	—	3	3	—	—	2.2	2.2
Needle and thread	VNS	0.88	—	—	3	—	—	—	2.2	—
Sandberg bluegrass	—	0.85	—	—	3	1.5	—	—	2.2	—
Squirreltail	VNS	0.77	—	—	3	—	—	—	2.2	—
Thickspike wheatgrass	Critana	0.93	1.2	—	—	—	0.6	—	—	—
Western wheatgrass	Rosanna	0.85 E	2.4	—	3	3	1.2	—	2.2	1.1

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Western wheatgrass	Aribba	0.88	—	—	—	—	—	1.1	—	—
Shrubs										
Antelope bitterbrush	—	0.8 E	+	+	+	+	—	—	1.1	1.1
Forage kochia	Immigrant	0.71	0.8	—	—	—	0.4	—	—	—
Fourwing saltbush	—	0.32	+	+	+	+	—	0.6	1.1	1.1
Wyoming big sagebrush	—	0.14	—	—	3	1.5	—	—	2.2	1.1
Forbs										
Alfalfa	Rangelander	0.56	3	—	—	—	1.5	—	—	—
Alfalfa (inoculated)	Ladak	0.92	—	—	—	—	—	0.6	—	—

¹PLS indicates pure live seed; E, percentage unknown but expected to be at least what is listed.

²Seed-mix treatments: ARS indicates Agricultural Research Service mix; BLM, Bureau of Land Management mix; NH, Native high-diversity mix; NL, Native low-diversity mix.

³Seeding rates shown are in kg ha⁻¹; + indicates seeds dribbled onto tractor treads at total rate of 2.2 kg ha⁻¹.

In 2015, 16 years after drill seeding, mean cover of perennial grasses was highest in the rehabilitation mixes (23%), somewhat lower in restoration mixes (19%), and lowest in the unseeded control treatment (4%) (Figure 1). Nearly all perennial grasses were of species that had been included in the seed mixes (Table 1), with <0.1% cover of miscellaneous species. The presence of perennial grasses in the unseeded control indicates that residual populations of these grasses were present prior to seeding, and/or that seeded populations spread into unseeded areas over time. Seeding perennial grasses clearly resulted in higher perennial cover than the alternative of not seeding at the Jericho site where residual populations were sparse and slow to recover. Non-native perennial grasses of the rehabilitation mixes performed especially well, but native perennial grasses of the restoration mixes also became well-established (Figure 1).

Cover of exotic annual grasses (predominately cheatgrass) was inversely related to perennial grass cover at the Jericho site in 2015, being highest in the unseeded control (15%), lower in the restoration mixes (6%) and lowest in the rehabilitation mixes (2%) (Figure 1). This pattern was also evident for exotic annual forbs (Figure 1) which included desert alyssum (*Alyssum desertorum*), Russian thistle (*Salsola tragus*), tumbled mustard (*Sisymbrium altissimum*) and redstem storksbill (*Erodium cicutarium*). These results highlight the importance of perennial grasses for exotic annual suppression (Leffler et al. 2014). The rehabilitation mixes appear to have been especially effective at suppressing exotic annuals, possibly because of greater competitiveness of the non-native seed-mix perennials compared to natives of the restoration mixes, although the restoration mixes might have exhibited greater cheatgrass suppression had they become better established.

RESTORATION STRATEGIES

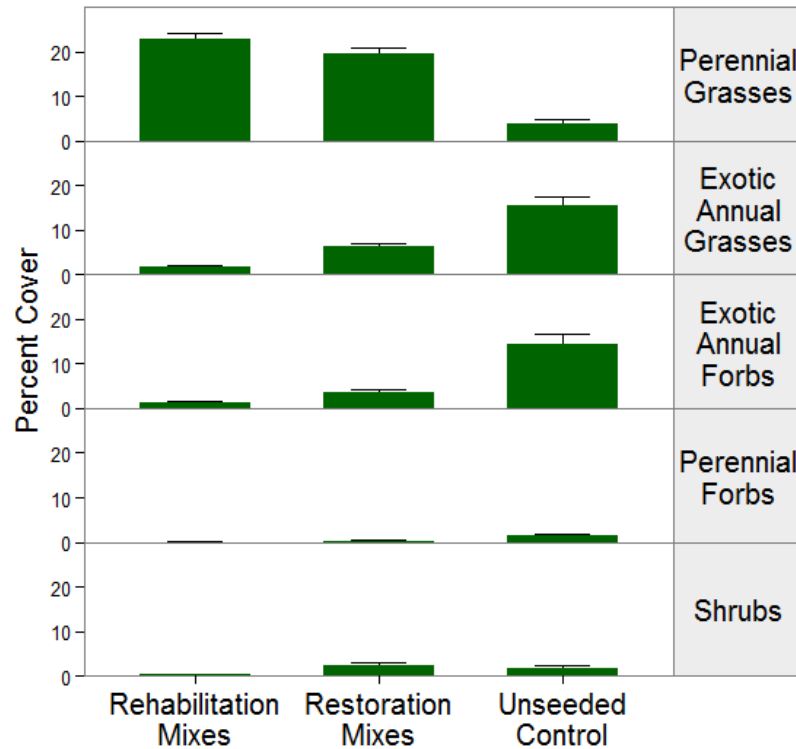


Figure 1. Cover of plant functional groups at the Jericho site in 2015, 16 years after drill-seeding treatments were applied. Bars indicate means and error bars are standard errors. Seed mixes with predominantly non-native species (ARS and BLM, see Table 1) are combined in the treatment category “Rehabilitation Mixes” while seed mixes containing all native species (NL and NH; see Table 1) are combined as “Restoration Mixes”.

Perennial forb cover was relatively low and consisted almost entirely on non-seeded species, because alfalfa was the only forb that had been seeded (Table 1) and it was detected in only trace amounts at the Jericho site in 2015. Forb species such as milkvetch (*Astragalus* spp.), globemallow (*Sphaeralcea* spp.), and hoary tansyaster (*Machaeranthera canescens*) were most abundant in the unseeded control where total perennial forb cover was 1.4% (Figure 1).

Shrub cover was negligible in the rehabilitation mixes (<0.5%), but higher in the restoration mixes (2.5%) and unseeded control (1.6%). This pattern appears to be due in part to the greater quantity and diversity of shrubs included in the restoration mixes compared to the rehabilitation mixes (Table 1), resulting in higher shrub establishment in the former (Figure 1). However, non-seeded shrubs such as rubber rabbitbrush (*Ericameria nauseosa*) and broom snakeweed (*Gutierrezia sarothrae*) also recruited naturally into the restoration mix treatment area as well as the unseeded control. The comparative lack of shrubs in the rehabilitation mix area suggests that rehabilitation mix species competitively inhibited shrub recruitment.

Management Applications

Seeding treatments may be beneficial following fire on Wyoming big sagebrush sites if residual native perennials are sparse and invasive annuals are present. Once established, seeded perennials can persist for more than a decade. Our results indicate that rehabilitation objectives

of perennial establishment and invasive annual suppression can be achieved using native seed mixes as an alternative to conventional mixes containing non-native species. Non-native seed mixes can be more effective at suppressing invasive annuals, but native seed mixes are preferable for restoring vegetation composition and structure including shrubs that are important to wildlife.

References

Arkle, Robert S.; Pilliod, David S.; Hanser, Steven E.; Brooks, Matthew L.; Chambers, Jeanne C.; Grace, James B.; Knutson, Kevin C.; Pyke, David A.; Welty, Justin L.; Wirth, Troy A. 2014. Quantifying restoration effectiveness using multi-scale habitat models: implications for sage-grouse in the Great Basin. *Ecosphere* 5:art31.

Leffler, A. Joshua; Leonard, Eamonn D.; James, Jeremy J.; Monaco, Thomas A. 2014. Invasion is contingent on species assemblage and invasive species identity in experimental rehabilitation plots. *Rangeland Ecology & Management* 67:657-666.

Ott, Jeffrey E.; McArthur, E. Durant; Roundy, Bruce A. 2003. Vegetation of chained and non-chained seedings after wildfire in Utah. *Journal of Range Management* 56:81-91.

Pyke, David A.; Wirth, Troy A.; Beyers, Jan L. 2013. Does seeding after wildfires in rangelands reduce erosion or invasive species? *Restoration Ecology* 21:415-421.

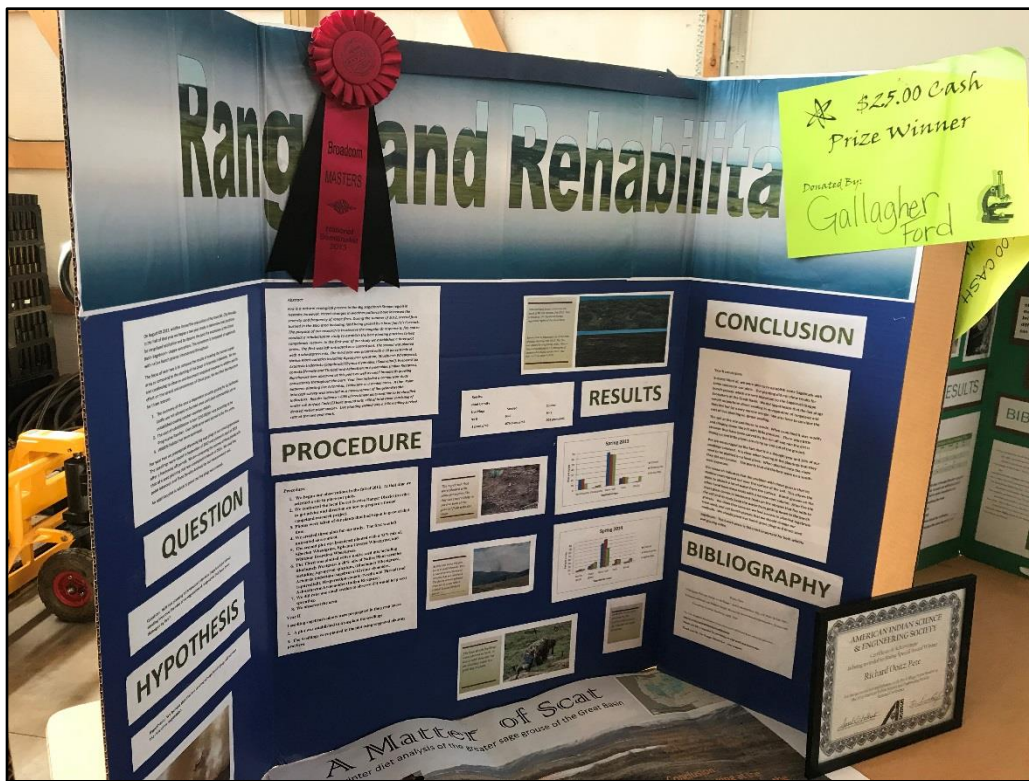
Richards, Rebecca T.; Chambers, Jeanne C.; Ross, Christopher. 1998. Use of native plants on federal lands: policy and practice. *Journal of Range Management* 51:625-632.

Thompson, Tyler W.; Roundy, Bruce A.; McArthur, E. Durant; Jessop, Brad D.; Waldron, Blair; Davis, James N. 2006. Fire rehabilitation using native and introduced species: A landscape trial. *Rangeland Ecology & Management* 59:237-248.

USDI BLM [U.S. Department of the Interior, Bureau of Land Management]. 2007. Burned area emergency stabilization and rehabilitation handbook. Washington, DC: U.S. Department of the Interior, Bureau of Land Management, Handbook H-1742-1. 80 p.



SCIENCE DELIVERY



Project Title SeedZone Mapper Mobile App Development

Project Agreement No. 13-IA-11221632-161

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Project Description

Introduction

Generalized provisional seed zones were developed by Bower et al. (2014) to guide seed movement for native species for which no information is available regarding genetic variation for traits important to adaptation. These provisional seed zones were based on climatic data and are increasingly being used when making collections of seed as foundation seed for farm field increase or for direct sowing in restoration plantings. The provisional seed zones are available as downloadable GIS shapefiles and are also contained in an interactive web map on the SeedZone mapper website (available at http://www.fs.fed.us/wwetac/threat_map/SeedZones_Intro.html), part of the Western Wildlands Environmental Threat Assessment Center's (WWETAC) Wildland Threat Mapper. Land managers, contractors, and restoration practitioners have indicated the usefulness of these web-based resources, but these platforms are usually not available for use in the field when an internet connection is not available.

Knowledge of the seed zone where native plant material is collected is critical information that needs to be passed on to restoration specialists using these materials. Field personnel need a reliable way of determining the seed zone at their current location and at adjacent collection sites, in both connected (WiFi, mobile phone carrier network) and disconnected environments.

Objectives

Develop a mobile device (iOS or Android) app that would allow anyone with a smartphone or tablet device to utilize their devices on-board GPS to determine the provisional seed zone at their location even if a cell signal is not available. The app would show the user the seed zone that they are currently located in, along with a scrollable and zoomable map that would allow the user

to determine the proximity of adjacent seed zones, and view other base map layers such as roads, contours, and land ownership, and collected pertinent data on materials being collected

Methods

To meet the needs of field operating seed collectors, we have developed several mobile applications that function on both Android, iOS (Apple), and PC devices.

ArcGIS Collector is an application framework where the end user loads the Collector app on their mobile device and then connects to a map created in ArcGIS On-Line. We configured maps in ArcGIS-On-Line, one for use in connected environments and the other had capabilities for the user to download maps for off-line use. Collector allows the user to record attributes for a recorded point; we built an editable feature layer with attributes such as collector name, date, species, and quantity that the user may enter values for using a form in the application.

The **Statewide PSZ Android Apps** were built using the Javascript/HTML/Leaflet code (see below) developed for the Provisional Seed Zone Mobile browser as a starting point. We then used Adobe PhoneGap software which is a wrapper for browser code that builds Android and iOS compatible applications. The base browser code and XML files used by Phonegap were further modified to support seamless switching between on-line and off-line environments. Because of file size limitations, we packaged these applications by state; they are stand-alone apps that contain all of the seed zone and map tile data for each state so they can function off-line.

The **Provisional Seed Zone Mobile** web map is a web browser map that was written in Javascript, HTML, and Leaflet. Leaflet is a light weight mobile mapping javascript library that is highly responsive (compatible with a wide variety of devices such as phones up to PC's). The map is hosted on the WWETAC's fs.fed.us site (https://www.fs.fed.us/wwetac/threat-map/seedZones/Prov_SZ_Map.html) and is CONUS-wide.

Expected Results and Discussion

The **ArcGIS Collector Seed Zone Maps** use the United States Forest Service (USFS) ArcGIS On-Line organization account to capture and store collection data as well as providing seed zone location information. This solution is available to USFS employees; contractors and cooperating agencies must check with their Forest Service point of contact to see if they can get an ArcGIS On-Line account. Collector must be set up in a connected environment before leaving for the field. Once the maps for the area of interest are downloaded to the device, all functionality is available in a disconnected environment (eg. in the field).

If you will be working in an unconnected environment, and just need to know where you are and what seed zone you are in but will not be collecting any data, the **Statewide PSZ Android Apps** are compatible with phones and tablets running the Android operating system. If you anticipate working in more than one state, you may install more than one statewide app. The apps contain seed zone and basic map data so they can function in a disconnected environment. When a mobile network is detected and the device connects, the app will switch to an on-line operating mode which enables a more detailed streets background map and imagery. This app is the best

choice for those that anticipate being in and out of connected environments, however, it is available for Android devices only.

If you will be working in a connected environment, and just need to know where you are and what seed zone you are in but will not be collecting any data, the **Provisional Seed Zone Mobile WebMap** opens in a web browser on your device and zooms to your location. Email or txt the html link above to your device. The icon in the upper right allows you to switch between street map and imagery. This solution is CONUS-wide. (Android, iOS, PC). A tap or click on the map will display a popup of the seed zone at that location.

References

Bower, A.D.; St. Clair, J.B.; Erickson, V.E. 2014. Generalized provisional seed zones for native plants. *Ecol. Apps.* 25:913-919

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 application is an integral function 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, and reports; presented through posters, brochures, and flyers; and 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 informational materials to GBNPP cooperators and collaborators to advance successful Great Basin restoration efforts.

Results and Discussion

Although I have worked less on this project in 2016 than in other years, progress continues in disseminating science information gathered by all cooperators of the GBNPP project.

I continue to:

- Communicate regularly with GBNPP cooperators about upcoming events, project reporting, and project due dates.
- Compile and edit the GBNPP annual report.
- Regularly update the GBNPP website.

Project Title Climate Smart Restoration Tool

Project Agreement No. 15-JV-11261953-071

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Project Description

Introduction

Work has begun on the Climate Smart Restoration Tool (CSRT), an interactive web-based application that allows users to match current seed sources with future climate conditions. Natural resource managers must match the climatic adaptability of their seed sources to the climatic conditions of their restoration sites in order to better ensure successful long-term restoration outcomes. There is an urgent need to adopt climate-smart approaches to ecosystem management, but progress has been slow because landowners and natural resource managers lack readily available, site-specific information on which to act. Existing scientific information

has been unavailable at the scale needed by natural resource managers and restoration practitioners.

In the past, managers may have used geographically and topographically defined ecoregions or seed zones to help inform selection of seed sources. Climate projections are now available at relevant spatial scales to define zones based on combinations of climate variables, rather than just geography and topography. These climate projections can also be used to calculate climate-based seed transfer distances and define focal point seed zones. Once acceptable climatic transfer limits have been defined (i.e., using seed zones or other approaches), managers will be able to explore how within-species assisted migration might be used to ensure the success of their restoration efforts given climate change challenges.

The CSRT will be designed to (1) easily incorporate new scientific information (e.g., climate projections, physiological thresholds) and (2) allow users to select parameters of interest (e.g., climate change scenarios, and time periods). Climates associated with existing ecoregions and seed zones will be displayed so that natural resource managers can choose the appropriate seed source for their restoration site, or decide where seed from a particular source can be planted in the future. Managers will also be able to view spatial maps of current and future climates, seed zones, ecoregions, and other contextual map layers. The CSRT will provide the ability to download outputs of the tool to PowerPoint slides, PDF documents, and GeoTIFF files in order to share those results with others and perform additional analysis within desktop data processing environments.

Because of the uncertainty in climate change projections, the CSRT is primarily intended as a planning and educational tool. It can be used to explore alternative future conditions, assess risk, and plan potential responses. The tool allows the user to control many input parameters so the results are appropriate for the management practices, climate change assumptions, and risk tolerance of the user.

Objectives

Provide a user-friendly, web-based tool for matching seed sources with current and future climates at restoration sites.

Methods

The CSRT will be implemented following the same method used to develop and publish the Seedlot Selection Tool (SST; <https://seedlotselectiontool.org/sst/>; Figure 1). We will develop a fully functional and widely available version of the CSRT using the latest open-source software and incorporating mechanisms for its long-term maintenance. We will work collaboratively with key stakeholders to ensure that the application is effective in meeting their needs, using a variety of mechanisms including webinars and targeted outreach.

Brad St.Clair will provide scientific and management expertise in collaboration with Francis Kilkenny, United States Forest Service (USFS) Rocky Mountain Research Station (RMRS), Boise, ID and Bryce Richardson, Research Geneticist, USFS RMRS, Provo, UT. ClimateNA climate data will be leveraged from the existing SST, and additional data as required will be provided by Tongli Wang, University of British Columbia.

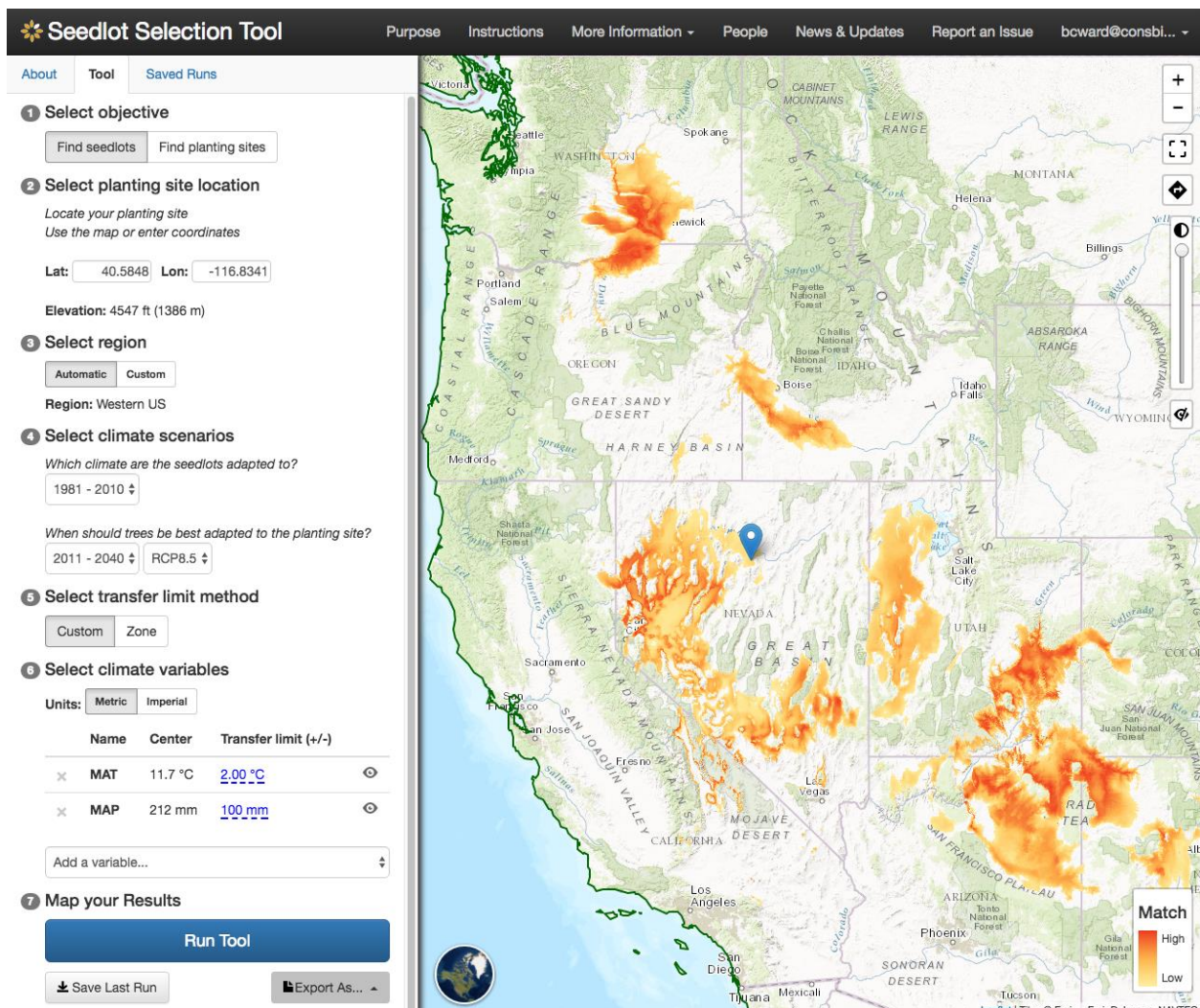


Figure 1: Screenshot of the Seedlot Selection Tool (SST), a forest-centric tool that helps natural resource managers match forest tree seed sources and climate conditions at planting sites. This example shows the amount of match between the selected site (1981-2010 observed climate) and climate conditions under the next 23 years based on Mean Annual Temperature (MAT) and Mean Annual Precipitation (MAP), within 2° MAT and 100mm MAP transfer limits.

Expected Results and Discussion

Natural resource managers and a wide range of other users will be able to use the CSRT to explore current and future climate information and match seed sources to future climate conditions. We will work with project cooperators to promote the CSRT using webinars and targeted outreach.



SPECIES INTERACTIONS



Project Title Impacts of Climate Change and Exotic Species on Native Plant-Microbial Interactions

Project Agreement No. 15-JV-11221632-190

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Project Description

Introduction

Restoration of Great Basin native plant communities and their associated communities of animals and microorganisms is complicated by the combined impacts of climate change and exotic species invasions. Local maladaptation from increasing aridity constrains the use of locally-sourced germplasm in restoration efforts (Breed et al. 2012). Subsequently, it has become increasingly evident that restoration efforts should include germplasm that is best-suited to a range of future environmental conditions, especially a more arid climate (Jones and Monaco 2009; Breed et al. 2012). Studies that test phenotypic responses to a range of environmental conditions using germplasm sourced from multiple provenances is an important first step towards testing the feasibility of assisted migration initiatives for restoration in current and future environments (Wang et al. 2010). Further, seed transfer guidelines that include delineation of eco-regions may also be important to determine as transferring plants outside of eco-regions may introduce them to a unique set of pests and pathogens to which they may not be defended. We are unaware of any studies that have examined eco-region fidelity to plant pests and pathogens.

In addition to assisted migration of key native plants as part of restoration, simultaneous transfer of potentially co-evolved community interactions may be important to maximize restoration success. For instance, there is growing evidence that facilitative interspecific plant interactions among foundation plant species are under selection (Martin and Harding 1981; Thorpe et al. 2007; Grady et al. 2017). Maintaining facilitative plant interactions may be especially important for restoring ecosystems during a time of climate change and exotic plant invasion (Suttle et al. 2007; Crutsinger et al. 2008). Recent research also indicates that intra-specific interactions may be facilitative via maternal effects or kinship recognition (Callaway and Mahall 2007; Dudley and File 2007). If intraspecific facilitation has evolved, then we would expect that plants growing closer together would have increased performance and this increased performance would be especially pronounced in competition with exotic species.

In addition, exotic species often modify soil properties, disrupt beneficial relationships between native plants and soil microbes, and even promote invasion of other exotics (Jordan et al. 2008;

Schaeffer et al. 2011). Revegetation efforts and natural regeneration of natives can be limited by the absence of these beneficial microorganisms (Meinhardt and Gehring 2012). While most current assisted migration programs focus on single species, restoration programs that include co-evolved interacting species across multiple trophic dimensions (e.g. from plants to microorganisms) may increase restoration effectiveness. Understanding this community genetic “interactome” is critical for advancing restoration practice and theory during rapid environmental change.

Objectives

We have created two common gardens (Flagstaff, Arizona; Moab, Utah) including a total of 4,000 planted sagebrush to test the following hypotheses: 1) Genetic variation across the thermal range of big sagebrush (*Artemisia tridentata*) and Indian ricegrass (*Achnatherum hymenoides*) is correlated to past climate such that plants are locally adapted; 2) Geographic distance among sagebrush provenances is correlated to community composition of herbivores, herbivory, and susceptibility to pathogens; 3) Competition with exotic species reduces plant fitness and exacerbates maladaptation due to climate change; 4) Sagebrush kinship facilitation increases growth of sagebrush in the presence of weeds, and 5) Soil microbial inoculation increases growth rate in both weed and non-weed areas. Taken together, this study will increase our knowledge of both abiotic and biotic adaptations and the importance of both to restoration.

Methods

Common garden establishment: Our study will focus on five common gardens, two developed with Great Basin Natural Plant Project (GBNPP) funding to test hypotheses related to local adaptation and plant intraspecific facilitation, and three developed with prior funding to examine microbial-plant interactions. The two provenance common gardens are located at the approximate warm and cold edges of the thermal distribution of sagebrush at Rio Mesa Center near Moab, Utah and managed by the University of Arizona (warm garden), and at the Museum of Northern Arizona in Flagstaff (cold garden). At these sites, we have installed fencing to reduce above and belowground browsing, irrigation systems for supplement watering during plant establishment (watered twice at time of planting with 0.5 L per plant), and weather stations. For gardens to test microbial inoculation, we used three common gardens (Mountain Home, Idaho; west Salt Lake, Nevada; Fredonia, Arizona). We added live and commercial soil microbial inoculum and no addition to approximately 9,000 plants of big sagebrush and squirreltail, with and without competition by cheatgrass (*Bromus tectorum*).

Experimental Design: For the provenance plantings, during winter, 2015, we collected seeds from 25 separate locations for big sagebrush from each of eight mother plants. In 2016, at both the warm and cold common gardens, we planted greenhouse-grown seedlings into four blocks that included plots of 25 populations in population plots of eight plants per population with each plant representing one genetic family (i.e. derived from one mother plant). Each block included the following four treatments: 1) weeds controlled, high sagebrush density; 2) weeds controlled, low sagebrush density; 3) weeds not controlled, high sagebrush density; 4) weeds not controlled, low sagebrush density. Both gardens are located in a weed-infested field. The no competition treatment will be created by hand removal of all weeds.

The microbial inoculation gardens were planted in spring 2015 and included five blocks. Each block contains 16 plots of nine big sagebrush or Indian ricegrass with each of four plots being exposed to the following treatments: 1) soil inoculation with live soil inoculum from a local source (within 1km from the garden) from the rhizosphere; 2) soil inoculation from the same source as 1 but sterilized in a microwave; 3) soil inoculum from a commercial source; 4) same as 3 but sterilized in a microwave.

Measurements: For each plant, we will measure growth (height, canopy diameter, diameter at root collar, aboveground biomass, canopy volume), survival, plant physiological traits (specific leaf area, leaf nitrogen content), herbivore communities, herbivory rate, and pathogen infections. We will also examine fungal infection rates for a subset of plants growing in the microbial inoculation experiment.

Statistical Procedures: For provenance data, we will compare among treatments using a combination of analysis of variance (ANOVA) and restricted maximum likelihood procedures at both the block level ($n=4$ for population variation among 25 populations) and at the individual plant level ($n = 36$ per population). For microbial inoculation data, we will use mixed model analyses to examine treatment effects with 20 plots per treatment group ($n = 20$), with block as a random effect.

Expected Results and Discussion

To reiterate our hypotheses (expected results), we expect that: 1) Genetic variation across the thermal range of big sagebrush and Indian ricegrass is correlated to past climate such that plants are locally adapted; 2) Geographic distance among sagebrush provenances is correlated to community composition of herbivores, herbivory, and susceptibility to pathogens; 3) Competition with exotic species reduces plant fitness and exacerbates maladaptation due to climate change; 4) Sagebrush kinship facilitation increases growth of sagebrush in the presence of weeds, and 5) Soil microbial inoculation increases growth rate in both weed and non-weed areas. Taken together, this study will increase our knowledge of both abiotic and biotic adaptations and the importance of both to restoration. Our primary data will be compiled at the end of the growing season in 2017. We will discuss our results in the next annual report.

Management Applications and/or Seed Production Guidelines

Our research is intended to improve the effectiveness of sagebrush restoration. We plan to provide recommendations on assisted migration, eco-region and seed zone suitability for revegetation efforts, appropriate density for plantings based on facilitation, and microbial inoculation guidelines. These recommendations will be based on our results that will be forthcoming at the end of 2017.

Presentations

We plan to present our preliminary findings at three conferences in 2017 and will include relevant citations in the next report.

Publications

We plan to publish one study in 2017 on our microbial inoculation findings. Further publications are expected from provenance tests in spring 2018.

Additional Products

- Plant materials development (seed zones) to be shared with GBNPP.
- We plan to apply for addition grants to expand this research related to scaling up sagebrush restoration where appropriate.
- Our research will be shared on websites and social media (Facebook: Adaptive Restoration Community).

References

- Breed, M. F.; Stead, M. G.; Ottewell, K. M.; Gardner, M. G; Lowe, A. J. 2012. Which provenance and where? Seed sourcing strategies for revegetation in a changing environment. *Conservation Genetics* 14: 1-10.
- Callaway, R. M.; Mahall, B. E. 2007. Family Roots. *Nature* 448: 145-147.
- Crutsinger, G. M.; Souza, L.; Sanders, N. J. 2008. Intraspecific diversity and dominant genotypes resist plant invasions. *Ecology Letters* 11: 16–23.
- Dudley, S. A.; File, A. L. 2007. Kin recognition in an annual plant. *Biology Letters* 3: 435-438.
- Grady, K. C.; Wood, T.; Kolb, T. E.; Shuster, S. M.; Gehring, C. A.; Whitham, T. G. 2015. Interactions among foundation tree species lead to local biotic adaptation. *Proceedings of the National Academy of Sciences*. (*In review*).
- Jones, T. A.; Monaco, T. A. 2009. A role for assisted evolution in designing native plant materials for domesticated landscapes. *Frontiers in Ecology and the Environment* 7: 541–547.
- Jordan, N. R.; Larson, D. L.; Huerdm S. C. 2008. Soil modification by invasive plants: effects on native and invasive species of mixed-grass prairies. *Biological Invasions* 10(2): 177-190.
- Martin, M. M.; Harding, J. 1981. Evidence for the evolution of competition between two species of annual plants. *Evolution* 35: 975–987.
- Meinhardt, K. A.; Gehring, C. A. 2012. Disrupting mycorrhizal mutualisms: a potential mechanism by which exotic tamarisk outcompetes native cottonwoods. *Ecological Applications* 22: 532-549.
- Schaeffer, S. M.; Ziegler, S. E.; Belnap, J.; Evans, R. D. 2011. Effects of *Bromus tectorum* invasion on microbial carbon and nitrogen cycling in two adjacent undisturbed arid grassland communities. *Biogeochemistry* 115: 427-441.
- Suttle, K. B.; Thomsen, M. A.; Power, M. E. 2007. Species interactions reverse grassland responses to changing climate. *Science* 315: 640-642.

Thorpe, A. S.; Aschehoug, E. T.; Atwater, D. Z.; Callaway, R. M. 2011. Interactions among plants and evolution. *Journal of Ecology* 99: 729-740.

Wang, T.; O'Neill, G. A.; Aitken, S. N. 2010. Integrating environmental and genetic effects to predict responses of tree populations to climate. *Ecological Applications* 20: 153–163.

Project Title Isolation and Identification of Root Fungal Endophytes Associated with Wyoming Big Sagebrush Seedlings

Project Agreement No. 14-JV-11221632-014

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Project Description

Introduction

Plant roots form symbioses with a variety of endophytic fungi. A well-known group of root endophytic fungi are the arbuscular mycorrhizae (AMF) (Smith et al. 2010). Previous work supported by this project showed that Wyoming big sagebrush seedlings are colonized by a variety of AMF and that increases in colonization can lead to increases in seedling survival (Carter et al. 2014; Davidson et al. 2016). In addition to AMF, another group of root-colonizing fungi is the dark septate endophytes (DSE) (Mandyam and Jumpponen 2005; Knapp et al. 2012). Compared to AMF, DSE have received little attention. However, DSE are common in many ecosystems including semiarid and arid environment, where they may be more abundant than AMF (Herrera et al. 2010; Porras-Alfaro et al. 2011). Furthermore, DSE can be found in many host plants, but their presence and abundance in Wyoming big sagebrush is unclear. To gain information in this area, we have begun to search for DSE in sagebrush roots. DSE are found in a few orders within the fungus phylum Ascomycota and taxonomic identification provides important clues to determine whether a fungus may be a DSE or not (Knapp et al. 2015). However, definitive identification of an isolate as a DSE requires analysis of morphological characteristics of the fungal-root association as well as tests for lack of pathogenicity (Mandyam 2008; Knapp et al. 2012). A combination of these approaches was used to establish the presence of DSE in Wyoming big sagebrush roots.

Objectives

- 1) Determine whether fungal endophytes other than AMF are present in Wyoming big sagebrush roots.
- 2) Implement procedures to isolate fungal endophytes from sagebrush roots.
- 3) Identify dark septate endophytic fungi that may be present in Wyoming big sagebrush roots.

Methods

Two year old seedlings of Wyoming big sagebrush were collected from the Morely Nelson Snake River Birds of Prey National Conservation Area (43°18'48.43"N, 116°21'48.57"W). The roots of these seedlings were extensively washed with water and subsequently surface-sterilized using 0.8% sodium hypochlorite, 70% ethanol, and sterile water. Surface-sterilized root segments were placed on potato dextrose agar and incubated in the dark at 23° C. Hyphae growing from the root segments were isolated and transferred to fresh medium.

Of the various isolates, one was selected to ascertain its taxonomic identity and endophytic nature. Taxonomic identification was based on sequences from the ITS and LSU regions of genes for ribosomal RNA, which were amplified using the primer pairs ITS1F-ITS4 and LR1-FLR2, respectively.

To test whether the fungal isolate was a DSE, sagebrush seedlings were grown under aseptic conditions in Murashige and Skoog medium. One month after germination, some of the cultures were inoculated with the fungal isolate and grown for another two months. During this period, non-inoculated and inoculated seedlings were visually examined to assess possible differences between them. Subsequently, the seedlings were removed from the medium and the roots used to determine morphological characteristics of the fungal-plant association. These observations were made on whole mounts of cleared roots, which were incubated with Alexa Fluor 488-wheat germ agglutinin to specifically stain fungal cell walls.

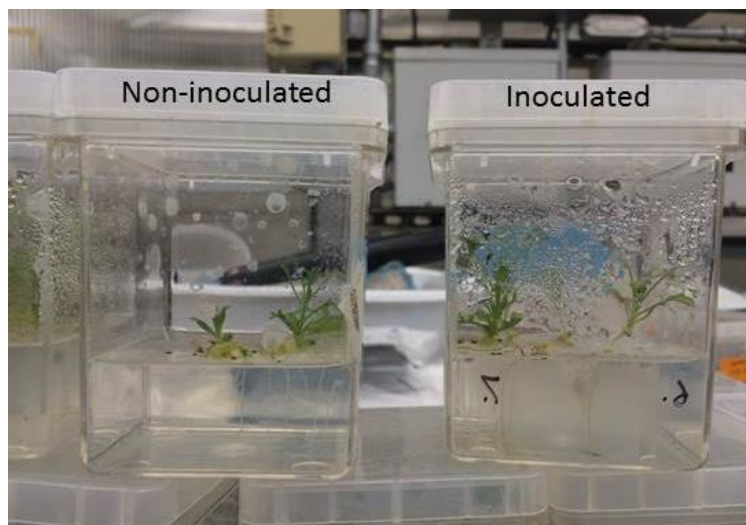
Results and Discussion

An isolate obtained from Wyoming big sagebrush showed in culture morphological characteristic typical of DSE including melazined and septate hyphae. DNA was extracted from this fungus and PCR amplification with the ITS1F-ITS4 primer pair yielded a single band of approximately 750 bp. Similarly, amplification with the LR1-FLR2 primer pair yielded a single band of about 700 bp. The sequences obtained from these PCR products were used to conduct a BLAST search. For the amplified ITS region, the closest matches had 98% percent identity with the isolate from Wyoming big sagebrush. These matches included various uncultured root-associated fungi and a known species, *Darksidea delta* (Knapp et al. 2012). For the amplified LSU region, the closest matches had 99% identity and included various species within the *Darksidea*: *D. alpha*, *D. delta*, *D. epsilon*, *D. gamma*, and *D. zeta*. Based on these results, the isolated fungus is within the *Darksidea* genus. This genus is within the family Lentitheciaceae in the order Pleosporales and the phylum Ascomycota (Knapp et al. 2015). Many DSE have been identified within the Pleosporales and some within *Darksidea* (Knapp et al. 2012). This genus is common in semiarid and arid environments and species with this genus appear to have a worldwide distribution (Herrera et al. 2010; Porras-Alfaro et al. 2011; Knapp et al. 2015).

To further analyze the association between the isolated *Darksidea* sp. and Wyoming big sagebrush, seedlings growing under sterile conditions were inoculated with this fungus. The fungus grew extensively in the medium and appeared to form extensive associations with the roots. Notwithstanding this fungal growth, inoculated seedlings did not show disease symptoms and their growth and morphology was similar to the non-inoculated seedlings (Fig. 1).

Figure 1. Non-inoculated and DSE-inoculated Wyoming sagebrush seedlings growing in half Murashige and Skoog medium without sugar. No clear differences in growth were apparent between non-inoculated and inoculated seedlings, indicating that the DSE was not acting as a parasite. Similar results were observed in three other replicate flasks.

After harvesting the inoculated seedlings, observation of their cleared roots revealed the presence of microsclerotia and a few dark-melanized hyphae (Fig. 2A). However, the majority of hyphae was in a hyaline-translucent state. After fluorescent staining, the hyaline hyphae was detectable.



Observations of the stained hyphae indicate that *Darksidea* formed numerous associations with the root epidermis (Fig. 2B and C). Furthermore, longitudinal sections of fragmented roots ascertained that the hyphae were also abundant inside the root (Fig. 2D).

Taken together, the results of the genetic analysis, the inoculation experiment, and the microscopic observations indicate that *Darksidea* sp. is a root endophyte of Wyoming big sagebrush. Further work is needed to ascertain the species of *Darksidea* and the effect of the association on Wyoming big sagebrush under natural conditions.

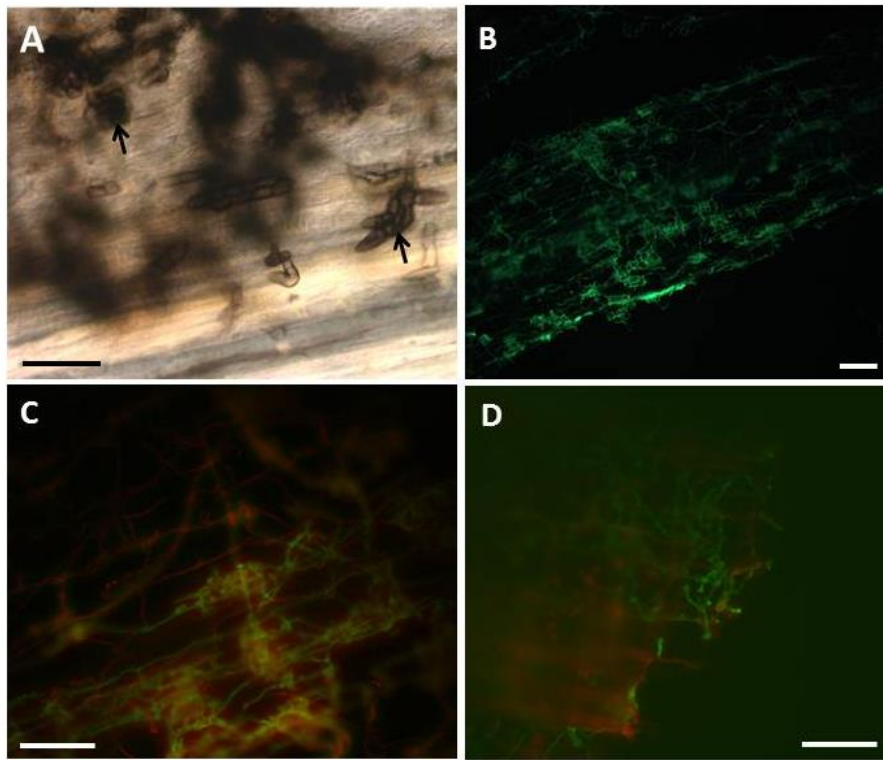


Figure 2. Microscopic observations of *Darksidea* sp. in Wyoming big sagebrush roots. A, Roots showing melinized hyphae and microsclerotia (indicated by arrows). B, Hyaline hyphae on sagebrush roots, the hyphae was labeled with Alexa Fluor 488-wheat germ agglutinin. C, Enlarged view of a root segment showing plant cell walls (red) and hyphae (yellow-green). D, Fractured root showing hyphae inside the roots (green) and plant cell walls (red). Bars in A, C, and D = 50 μ m and bar in B = 20 μ m

Management Applications

Growth and survival of sagebrush seedlings can be affected by fungi that form symbiotic associations with plant roots. A group of symbiotic fungi common in semiarid and arid environments is the DSE. In various plant species, experimental evidence indicates that DSE can improve mineral acquisition and increase plant drought and heat tolerance (Barrow and Osuna 2002; Barrow et al. 2008; Rodriguez et al. 2009; Yuan et al. 2010). These characteristics make DSE good candidates in the search for symbiotic organisms that may increase growth and survival of Wyoming big sagebrush seedlings. We have identified a DSE capable of forming extensive associations with Wyoming big sagebrush with no damaging symptoms to its host. These results represent a first step towards testing the notion that DSE could be used to increase survival of sagebrush seedlings under summer drought. The information obtained thus far is insufficient to provide management recommendations. However, recommendations will become more apparent after testing the effect of DSE on growth and stress tolerance of sagebrush seedlings.

Presentations

- Davidson, B.E.; Schoenwald, J.; Serpe, M.D. 2016. Assessing host preferences for arbuscular mycorrhizal fungi in Wyoming big sagebrush seedlings and Sudan grass. Presented at the Annual Meeting of the Great Basin Native Plant Project in Boise, ID
- Velasco, J.A.; Serpe, M.D. 2016. Drought effects on the symbiosis between Wyoming big sagebrush seedlings and arbuscular mycorrhizal fungi. Presented at the Annual Meeting of the Great Basin Native Plant Project in Boise, ID
- Carpenter, C.; Serpe, M.D. 2016. Multiplication of arbuscular mycorrhizal and dark septate endophyte fungi isolated from the Morely Nelson Snake River Birds of Prey, National Conservation Area. Presented at the Morely Nelson Snake River Birds of Prey NCA conference in Boise, ID

Publications

- Davidson, B.E.; Novak, S.J.; Serpe, M.D. 2016. Consequences of inoculation with native arbuscular mycorrhizal fungi for root colonization and survival of *Artemisia tridentata* ssp. *wyomingensis* seedlings after transplanting. *Mycorrhiza* 26:595–608

References

- Barrow, J.R.; Lucero, M.E.; Reyes-Vera, I.; Havstad, K.M. 2008. Do symbiotic microbes have a role in regulating plant performance and response to stress? *Communicative & Integrative Biology* 1:69–73. doi: 10.4161/cib.1.1.6238
- Barrow, J.R.; Osuna, P. 2002. Phosphorus solubilization and uptake by dark septate fungi in fourwing saltbush, *Atriplex canescens* (Pursh) Nutt. *Journal of Arid Environments* 51:449–459. doi: 10.1006/jare.2001.0925
- Carter, K.A.; Smith, J.F.; White, M.M.; Serpe, M.D. 2014. Assessing the diversity of arbuscular mycorrhizal fungi in semiarid shrublands dominated by *Artemisia tridentata* ssp. *wyomingensis*. *Mycorrhiza* 301–314.
- Davidson, B.E.; Novak, S.J.; Serpe, M.D. 2016. Consequences of inoculation with native arbuscular mycorrhizal fungi for root colonization and survival of *Artemisia tridentata* ssp. *wyomingensis* seedlings after transplanting. *Mycorrhiza*. doi: 10.1007/s00572-016-0696-1
- Herrera, J.; Khidir, H.H.; Eudy, D.M.; Porras-Alfaro, A.; Natvig, D.O.; Sinsabaugh, R.L. 2010. Shifting fungal endophyte communities colonize *Bouteloua gracilis*: effect of host tissue and geographical distribution. *Mycologia* 102:1012–1026. doi: 10.3852/09-264
- Knapp, D.G.; Kovács, G.M.; Zajta, E.; Groenewald, J.Z.; Crous, P.W. 2015. Dark septate endophytic pleosporalean genera from semiarid areas. *Persoonia - Molecular Phylogeny and Evolution of Fungi* 35:87–100. doi: 10.3767/003158515X687669

Knapp, D.G.; Pintye, A.; Kovács, G.M. 2012. The Dark Side Is Not Fastidious – Dark Septate Endophytic Fungi of Native and Invasive Plants of Semiarid Sandy Areas. PLoS ONE 7:e32570. doi: 10.1371/journal.pone.0032570

Mandyam, K. 2008. Dark septate fungal endophytes from a tallgrass prairie and their continuum of interactions with host plants. ProQuest

Mandyam, K.; Jumpponen, A. 2005. Seeking the elusive function of the root-colonising dark septate endophytic fungi. Stud Mycol 173–189.

Porras-Alfaro, A.; Herrera, J.; Natvig, D.O.; Lipinski, K.; Sinsabaugh, R.L. 2011. Diversity and distribution of soil fungal communities in a semiarid grassland. Mycologia 103:10–21. doi: 10.3852/09-297

Rodriguez, R.J.; White Jr, J.F.; Arnold, A.E.; Redman, R.S. 2009. Fungal endophytes: diversity and functional roles. New Phytologist 182:314–330. doi: 10.1111/j.1469-8137.2009.02773.x

Smith, S.E.; Facelli, E.; Pope, S.; Smith, F.A. 2010. Plant performance in stressful environments: interpreting new and established knowledge of the roles of arbuscular mycorrhizas. Plant Soil 326:3–20.

Yuan, Z.; Zhang, C.; Lin, F. 2010. Role of Diverse Non-Systemic Fungal Endophytes in Plant Performance and Response to Stress: Progress and Approaches. Journal of Plant Growth Regulation 29:116–126. doi: 10.1007/s00344-009-9112-9

Project Title Comprehensive Assessment of Restoration Seedings to Improve Restoration Success

Project Agreement No. 15-JV-11221632-197

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Project Description

Introduction

Restoration projects rely on seedling establishment and persistence to foster invasion resistance and improve resilience to environmental stress and disturbance (James et al. 2010; Chambers et al. 2014). However, few studies have comprehensively evaluated the landscape-level performance of seeded species or the factors that control their short-term establishment and long-term persistence (Hardegree et al. 2011; Knutson et al. 2014). Assessing the role of these factors across physiographic regions that experience high temporal and spatial variability in environmental conditions will reveal the effectiveness of various pre-seeding land treatments and enhance our capacity to select appropriate restoration species for specific ecological sites based on their seedling establishment and persistence.

The Utah Watershed Restoration Initiative (WRI) is a collaborative effort among landowners, and state and federal agencies with the goal of enhancing wildlife habitat, biological diversity, and water resources by manipulating vegetation at large scales (<http://wildlife.utah.gov/watersheds/>). From the WRI database, we identified 99 sagebrush and 68 conifer-encroached (i.e., pinyon-juniper) restoration sites along gradients in elevation (1250-2500 m) and annual precipitation (200-500 mm) in the Great Basin, Colorado Plateau, and Rocky Mountain physiographic provinces. Prior to seeding, sites were treated with prescribed fire and/or various

other treatments to reduce woody fuels and foster the growth of existing herbaceous vegetation and seeded species. Sites were seeded using broadcast, drill, or aerial techniques to restore a diverse array of grass, forb, and shrub species. Given this assortment of sites, restoration treatments, and seeded species, we propose to assess the relative success of seeded grass, forb, and shrub species as part of an ongoing effort to determine environmental and ecological factors controlling sagebrush ecosystem restoration.

Objectives

Specific project objectives are to 1) determine the separate and combined effects of soils, environmental parameters, restoration treatments, and seeding techniques on plant species establishment and persistence, 2) decipher the association between plant species traits and seedling establishment and persistence in the field, and 3) quantify the cost effectiveness and efficiency of these seeding efforts.

Methods

Detailed vegetation monitoring has been conducted at WRI sites before and at various intervals after applying restoration/seeding treatments. In the first year of this project we compiled cover and density data and assessed species establishment and persistence with respect to environmental parameters, restoration treatments, and seeding techniques. We used effect-size analysis (e.g., log response ratio of pre/post species cover and density) to analyze field data collected between 2003 and 2013. Effect sizes can either be positive or negative, depending on whether a species established or failed, respectively. This technique is ideal for analysis of disparate sites and treatment years.

We used this approach to assess responses of 14 perennial species including seven grasses, five forbs, and three shrubs to aerator, pipe harrow and fire treatments across 63 project sites (Table 1). We separately examined establishment (1-4 years after treatment) and persistence (5-10 years after treatment) of the focal plant species. Moderator analyses also were used to explore the effects of environmental factors such as soil type, sagebrush community type, ecoregion, native vs. introduced, and species*treatment effects.

SPECIES INTERACTIONS

Table 1. Scientific name, common name, species code used, and growth form (S, shrub; F, forb, and G, grass) of seeded species. Arrange by growth form and then in alphabetical order.

Species	Common Name	Species Code	Growth Form	Native/ Introduced
<i>Atriplex canescens</i> (Pursh) Nutt.	fourwing saltbrush	ATCA	S	Native
<i>Bassia prostrata</i> (L.) A.J. Scott	forage kochia	BAPR	S	Introduced
<i>Artemisia tridentata</i> Nutt.	Sagebrush	ARTR	S	Native
<i>Linum perenne</i>	Blue Flax	LIPE	F	Introduced
<i>Melilotus officinalis</i> (L.) Lam.	yellow sweetclover	MEOF	F	Introduced
<i>Medicago sativa</i> L.	Alfalfa	MESA	F	Introduced
<i>Onobrychis viciifolia</i> Scop.	Sainfoin	ONVI	F	Introduced
<i>Sanguisorba minor</i> Scop.	small burnet	SAMI3	F	Introduced
<i>Achnatherum hymenoides</i> (Roem. & Schult.) Barkworth	Indian Ricegrass	ACHY	G	Native
<i>Agropyron cristatum</i> (L.) Gaertn.	crested wheatgrass	AGCR	G	Introduced
<i>Elymus lanceolatus</i> (Scribn. & J.G. Sm.) Gould	thickspike wheatgrass	ELLA	G	Native
<i>Leymus cinereus</i> (Scribn. & Merr.) Á. Löve	Great Basin Wildrye	LECI4	G	Native
<i>Pascopyrum smithii</i> (Rydb.) Á. Löve	western wheatgrass	PASM	G	Native
<i>Psathyrostachys juncea</i> (Fisch.) Nevski	Russian Wildrye	PSJU	G	Introduced
<i>Pseudoroegneria spicata</i> (Pursh) Á. Löve	bluebunch wheatgrass	PSSP	G	Native

Results and Discussion

Preliminary results suggest fire elicited the most dramatic responses. In particular, persistence of grasses generally responded positively to mechanical and fire treatments, but was significantly higher in fire treatments for four of those grasses (three native, one introduced) (Figure 1). Similarly, one shrub species, forage kochia (*Bassia prostrata*), responded positively to all treatments, but was significantly higher in the fire treatment (Figure 1). Of the five forb species, on the other hand, two increased following fire, but not in mechanical treatments. We also found that introduced grasses and shrubs had much higher establishment and persistence than their native species counterparts (Figure 2). Furthermore, the introduced species, crested wheatgrass (*Agropyron cristatum*) and forage kochia, had the highest establishment of any species (Figure 1). Overall, we also found that establishment and persistence of shrubs and grasses were highest in Wyoming sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) sites.

Overall, this project will assess the success of restoration plant materials over a broad range of ecological sites throughout Utah. Our assessment will provide critical information to compare the cost effectiveness of restoration treatments and seeding. Our effort will also quantitatively assess the performance of species based on biological traits, which can be used to enhance plant material development and influence seeding success over both short and long-term periods. This project will provide land managers with information to restore their rangeland with revegetation projects. We have already shared preliminary results at the Utah Division of Wildlife Resources/Utah State University Brown Bag Luncheon Seminar Series.

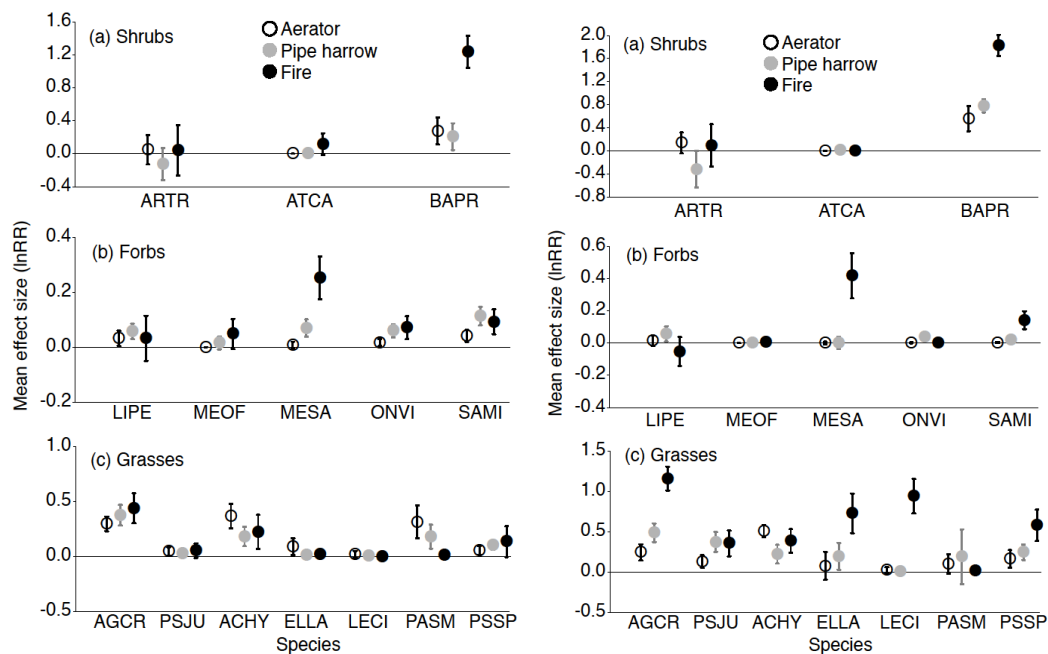


Figure 1. Effect sizes of species performance 1-4 years (left panel, “establishment”) and 5-10 years (right panel, “persistence”) after aerator, pipe harrow, and fire treatments for seeded shrubs, forbs and grasses. See Table 1 for species abbreviations. Error bars represent 95% confidence intervals.

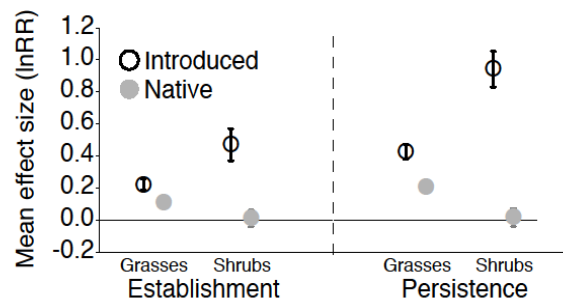


Figure 2. Effect sizes for species establishment (1-4 years post-treatment) and persistence (5-10 years post-treatment) for introduced vs. native grasses and shrubs. Forbs were excluded from analysis because they were all introduced. Error bars represent 95% confidence intervals.

Management Applications and/or Seed Production Guidelines

Mixed seedings are a feasible method to establish numerous species in a single event (Hoelzle et al. 2012). However, mixed seedings run the risk that a few species may establish rapidly and interfere with the establishment of other species that emerge slower. While we cannot directly attribute the differences we are finding in species establishment to interference, introduced grasses and shrubs had much higher establishment and persistence than their native species counterparts. Furthermore, the introduced species, crested wheatgrass and forage kochia, had the highest establishment of any species, and both are recognized as highly competitive species known to reduce native species establishment (Waldron et al. 2005) or widely spread beyond where they are seeded, respectively (Gray et al. 2013).

Fire has fundamentally different effects on soil surface and seedbed conditions compared to mechanical treatments. Fire typically removes litter and seeds of invasive species but generally does not alter the soil surface microtopography. In contrast, mechanical treatments cause a greater physical disturbance to the soil surface and may create more suitable safe sites for seeds than fire by partially burying them or improving soil seed contact. Although both treatment types generally improved species establishment in our study, our results suggest that post-fire seeding provides much greater persistence of seeded species than the mechanical treatments. However, we cannot discount the possibility that topographic differences and/or biophysical attributes of sites such as slope, aspect, elevation, or soil depth may be partially responsible for greater seeded species establishment on fire-treated sites.

Presentations

Wilder, L. 2016. Effects of three shrub reduction treatments on seeded species establishment and persistence in Utah. Presentation at USU Dept. of Wildland Resources Pre-Project Symposium; 2016 April 15; Logan, UT.

Publications

Wilder, L.E.; Veblen, K.E.; Thacker, E.; Robins, J.G.; Gunnell, K.L.; Summers, D.; Vernon, J.; Monaco, T.A. [In preparation]. Effects of three shrub reduction treatments on seeded species establishment and persistence in Utah: a broad-scale assessment.

Additional Products

Fact sheet on effects of shrub reduction treatments (in preparation)

References

Chambers, J.C.; Bradley, B.A.; Brown, C.S.; D'Antonio, C.; Germino, M.J.; Grace, J.B. 2014. Resilience to stress and disturbance, and resistance to *Bromus tectorum* L. invasion in cold desert shrublands of western North America. *Ecosystems* 17:360-75.

Gray, E.C.; Muir, P.S. 2013. Does *Kochia prostrata* spread from seeded sites? An evaluation from southwestern Idaho, USA. *Rangeland Ecology & Management* 66: 191-203.

Hardegree, S.P.; Jones, T.A.; Roundy, B.A.; Shaw, N.L.; Monaco, T.A. 2011. Assessment of range planting as a conservation practice. In Briske, D.D. ed. *Conservation Benefits of Rangeland Practices: Assessment, Recommendations, and Knowledge Gaps*. Allen Press, Lawrence, KS, USA. pp. 171-212.

Hoelzle, T.B.; Jonas, J.L.; Paschke, M.W. 2012. Twenty-five years of sagebrush steppe plant community development following seed addition. *Journal of Applied Ecology* 49: 911-918.

James, J.J.; Svejcar, T. 2010. Limitations to postfire seedling establishment: the role of seeding technology, water availability, and invasive plant abundance. *Rangeland Ecology and Management* 63:491-5.

Knutson, K.C.; Pyke, D.A.; Wirth, T.A.; Arkle, R.S.; Pilliod, D.S.; Brooks, M.L.; Chambers, J.C.; Grace, J.B. 2014. Long-term effects of seeding after wildfire on vegetation in Great Basin shrubland ecosystems. *Journal of Applied Ecology* 51:1414-1424.

Waldron, B.L.; Monaco, T.A.; Jensen, K.B.; Harrison, R.D.; Palazzo, A.J.; Kulbeth, J.D. 2005. Coexistence of native and introduced perennial grasses following simultaneous seeding. *Agronomy Journal* 97: 990-996.



APPENDIX I – PLANT INDEX

	Species	Pages
A	<i>Achillea millefolium</i>	63, 243, 245
	<i>Achnatherum hymenoides</i>	24, 25, 26, 27, 31, 32, 42, 46, 60, 83, 84, 93, 96, 269, 283, 284, 295
	<i>Achnatherum thurberianum</i>	42, 45
	<i>Agoseris grandiflora</i>	47, 95, 260, 263
	<i>Agropyron cristatum</i>	268, 295, 296
	<i>Agropyron fragile</i>	269
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	<i>Astragalus filipes</i>	84, 261, 262
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P (cont.)	<i>Penstemon pachyphyllus</i>	91, 92, 94, 96, 210, 251, 260, 263
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	<i>Penstemon speciosus</i>	81, 82, 83, 209, 210, 242, 245, 251, 260, 263
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	<i>Phacelia linearis</i>	234, 235, 245, 251
	<i>Pleuraphis jamesii</i>	20
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	<i>Poa secunda</i>	20, 42, 46, 63, 96, 97, 269
	<i>Psathyrostachys juncea</i>	295
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	<i>Sanguisorba minor</i>	258, 263, 295
	<i>Sisymbrium altissimum</i>	270
	<i>Sphaeralcea coccinea</i>	251, 263
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	<i>Sphaeralcea munroana</i>	98
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