

Great Basin Native Plant Project

2015 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

2015 PROGRESS REPORT

USDA FOREST SERVICE, ROCKY MOUNTAIN RESEARCH STATION AND
USDI BUREAU OF LAND MANAGEMENT, BOISE, ID
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GREAT BASIN NATIVE PLANT PROJECT 2015 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. We especially thank Alexis Malcomb for the many hours she spent carefully editing and compiling this report and other outreach materials and Jessica Irwin for help in editing, as well as Corey Gucker for help in managing our financial reporting. Special thanks also to our resident technicians and volunteers: Nancy Shaw, Matt Fisk, Jameson Rigg, and Kristof Bihari for managing our field and laboratory research.

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Great Basin Native Plant Project
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FY2015 Summary

GBNPP PROJECTS	
Closing Projects	6
Continuing Projects	17
New Projects	11

PROJECT ACTIVITY	
Presentations	38
Publications	30
Webinars	2

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TABLE OF CONTENTS

I. GBNPP PROJECT OVERVIEW

COOPERATORS.....	i
PROGRESS REPORT INTRODUCTION.....	ii
FY2015 SUMMARY.....	iii
DISCLAIMER.....	iv

II. PROJECT HIGHLIGHTS

NEW PROJECTS.....	1
CONTINUING PROJECTS.....	6

III. GENETICS AND CLIMATE CHANGE

Testing the Efficacy of Seed Zones for Re-Established and Adaptation of Bluebunch Wheatgrass (<i>Pseudoroegneria spicata</i>) <i>Holly Prendeville, Francis Kilkenny, and Brad St. Clair</i>	15
Conservation, Adaptation, and Seed Zones for Key Great Basin Species <i>Richard C. Johnson, Elizabeth Leger, Mike Cashman, and Ken Vance-Borland</i>	22
Ecophysiological Analyses of Common Gardens to Inform Seed Transfer Guidelines <i>Matthew J. Germino, Martha Brabec, and Bryce Richardson</i>	31
Species and Population-level Variation in Germination Strategies of Cold Desert Forbs <i>Elizabeth A. Leger and Sarah Barga</i>	39
Dynamics of Cold Hardiness Accumulation and Loss in Sulphur-flower Buckwheat (<i>Eriogonum umbellatum</i>) <i>Anthony S. Davis, Matthew R. Fisk, and Kent G. Apostol</i>	47

NEW PROJECTS

Morphological and Genetic Characterization of Blue Penstemon (<i>Penstemon cyaneus</i>) <i>Mikel Stevens and Robert Johnson</i>	54
--	----

A Field Test of Local Adaptation in Bluebunch Wheatgrass (<i>Pseudoroegneria spicata</i>) <i>Kathryn Alexander, Matt Orr, Ron Reuter, Francis Kilkenny, Brad St. Clair, and Holly Prendeville</i>	58
Genetic and Environmental Regulation of Functional Traits: New Approaches for Restoration in Climate Change <i>Brad Butterfield and Troy Wood</i>	63
Climate Change Effects on Native Plant Establishment and Annual Grass Invasion: Implications for Restoration <i>Beth Newingham and Keirith Snyder</i>	67
Evaluation of Local Adaptation in <i>Achnatherum hymenoides</i> and <i>Artemisia</i> spp.: Implications for Restoration in a Changing Regional Climate <i>Lesley DeFalco, Daniel Shyrock, and Todd Esque</i>	70

IV. **PLANT MATERIALS AND CULTURAL PRACTICES**

Smoke-Induced Germination of Great Basin Native Forbs <i>Robert Cox</i>	78
Developing Protocols for Maximizing Establishment of Great Basin Legume Species <i>Douglas A. Johnson and B. Shaun Bushman</i>	83
Bee Pollination and Breeding Biology Studies <i>James H. Cane</i>	93
Native Forb Increase and Research at the Great Basin Research Center <i>Kevin Gunnell and Danny Summers</i>	96
Plant Material Work at the Provo Shrub Sciences Lab <i>Scott Jensen</i>	109
Aberdeen Plant Materials Center Report of Activities <i>Derek Tilley</i>	112
Seed Production of Great Basin Native Forbs (7 Reports) <i>Clint C. Shock, Erik B. Feibert, Joel Felix, Nancy Shaw, and Francis Kilkenny</i>	
1. Irrigation Requirements for Native Buckwheat Seed Production in a Semi-Arid Environment	116
2. Irrigation Requirements for Seed Production of Five <i>Lomatium</i> Species in a Semi-Arid Environment	124
3. Irrigation Requirements for Seed Production of Five Native <i>Penstemon</i> Species in a Semi-Arid Environment	137
4. Prairie Clovers and Basalt Milkvetch Seed Production in Response to Irrigation	149
5. Native Beeplant (<i>Cleome</i> spp.) Seed Production in Response to Irrigation in a Semi-Arid Environment	155

6. Irrigation Requirements for Seed Production of Various Native Wildflower Species Started in Fall of 2012.....	160
7. Direct Surface Seeding Systems for the Establishment of Native Plants in 2015.....	168

NEW PROJECTS

Characterizing Germplasm Relationships and Maximizing Seedling Establishment of Utah Trefoil (<i>Lotus utahensis</i> Ottley) <i>B. Shaun Bushman and Douglas A. Johnson</i>	177
---	-----

V. SEED INCREASE

Coordination of Great Basin Native Plant Materials Development, Seed Increase, and Use <i>Berta Youtie</i>	182
Seed Increase of Great Basin Native Forbs and Grasses for Restoration Research Projects <i>Clint C. Shock, Erik B. Feibert, Joel Felix, Nancy Shaw, Francis Kilkenny, Holly Prendeville, Brad St. Clair, and Anne Halford</i>	186

VI. SPECIES INTERACTIONS

Drought Effects on the Symbiosis Between Wyoming Big Sagebrush Seedlings and Arbuscular Mycorrhizal Fungi <i>Marcelo D. Serpe and Bill E. Davidson</i>	190
---	-----

NEW PROJECTS

Comprehensive Assessment of Restoration Seedlings to Improve Restoration Success <i>Kari Veblen and Thomas Monaco</i>	197
Impacts of Climate Change and Exotic Species to Native Plant-Microbial Interactions <i>Kevin Grady, Paul Dijkstra, Catherine Gehring, Egbert Schwartz, and Hillary Cooper</i>	199

VII. SCIENCE DELIVERY

Science Delivery for the Great Basin Native Plant Project <i>Corey Gucker</i>	206
--	-----

NEW PROJECTS

SeedZone Mapper Smartphone App Development <i>Andrew Bower and Charlie Schrader-Patton</i>	207
---	-----

CRESTED WHEATGRASS DIVERSIFICATION

Presence of Native Vegetation in Crested Wheatgrass (<i>Agropyron cristatum</i>) Seedlings and the Influence of Crested Wheatgrass on Native Vegetation <i>Krik Davies and Aleta Nafus</i>	210
---	-----

VIII. RESTORATION STRATEGIES

Herbicide Impacts on Forb Performance in Degraded Sagebrush Steppe Ecosystems <i>Marie-Anne De Graff and Aislinn Johns</i>	218
---	-----

NEW PROJECTS

Restoring Sagebrush After Large Wildfires: An Evaluation of Different Restoration Methods Across a Large Elevation Gradient <i>Kirk Davies</i>	229
Forb Islands: Possible Techniques to Improve Seedling Establishment for Diversifying Sagebrush-Steppe Communities <i>Douglas Johnson and Thomas Monaco</i>	231

IX. APPENDIX I

PLANT INDEX.....	235
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2015 HIGHLIGHTS

NEW PROJECTS

GENETICS AND CLIMATE CHANGE

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

Mikel Stevens and Robert Johnson.....54

- Our overall objective is to characterize the morphological and genetic variation within blue penstemon (*Penstemon cyaneus* Pennell).
- We will develop a genetic “fingerprint” of each the blue penstemon accessions using recent “next-generation DNA sequencing” techniques. The genetic variation will be evaluated for specific genotypes correlating between geography and morphological traits that may have value in plant restoration.
- In order to evaluate morphological variability of blue penstemon we plan to establish at least two common gardens to assess variation between collected accessions of this species.
- Tissue samples were collected and stored for later DNA isolation during the 2015 growing season, from broadly distributed sites ranging from near Boise, ID on the west, to just north of Challis, ID on the north, across to several areas near Cody and Dubois, WY on the east, and samples collected south of Twin Falls, ID on the south.
- Seeds were also collected from one to over a hundred plants from 50 of the accessions in which we had collected leaf tissue earlier in the season.
- It is anticipated that this project will take approximately four years to complete as part of a graduate students dissertation. We will be initiating both the first steps of common gardens of at least 20 accessions and molecular fingerprinting of more than 50 accessions of blue penstemon beginning January, 2016.

A Field Test of Local Adaptation in Bluebunch Wheatgrass (*Pseudoroegneria spicata*)

Kathryn Alexander, Matt Orr, Ron Reuter, Francis Kilkenny, Brad St. Clair, and Holly Prendeville.....58

- Objectives of this project are to quantify early development and above ground traits (leaf shape, biomass, root to shoot ratio, and stomatal density) across seed zones 1, 3a, 4, & 7b for bluebunch wheatgrass. 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.
- Test for local adaptation to soil texture and water holding capacity. We expect that soil variation within a seed zone may be a significant driver of local adaptation for this species.

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

Brad Butterfield and Troy Wood.....63

- Functional traits – organismal characteristics that mediate responses to and effects on the environment – are useful predictors of plant population establishment as well as the effects of those populations on the ecosystem services that are targeted in restoration activities.
- In order for functional traits to be useful predictors of restoration success, an understanding of the broad-sense heritability in those functional traits (i.e. how genetically entrained they are) and the environmental drivers of that heritability are necessary. We are taking a two-pronged approach to addressing this need.
- First, we are conducting a meta-analysis of functional trait broad-sense heritability, and its environmental dependence, from published literature on grasses.
- Second, we will measure broad-sense heritability of root functional traits in a common environment across a suite of grass species that are important for restoration across the western United States. Despite their importance in establishment, root traits are rarely measured, and the broad-sense heritability of those traits is completely absent from the literature on grasses. Thus, our proposed research will fill a critical need in understanding the diversity of available resources for restoration.

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

Beth Newingham and Keirith Snyder.....67

- 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 *Bromus tectorum* or *Bromus rubens* with and without various native grass and forb mixtures.
- To date, we have explored various field sites but are still in the site selection process.
- Our results will provide information on: 1) the basic biology and competitiveness of native and invasive plant species under future climate scenarios, and 2) the ability of *Bromus rubens* 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.

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

Lesley DeFalco, Daniel Shyrock, and Todd Esque 70

- 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 Great Basin restoration species to climate change by placing populations in common gardens located within the arid Mojave Desert. Transplanting Great Basin populations to warmer conditions will mimic future climate changes.
- We developed a novel sampling design for Indian ricegrass (*Achnatherum hymenoides*), incorporating empirically-derived climate zones, climate change velocity predictions, and ecological distances to evaluate the degree to which Great Basin populations exhibit intraspecific variability in response to climate change and in restoration of arid sites.
- We classified the southern Great Basin into six climate zones based on precipitation and temperature. We ranked climate zones according to their predicted velocity of climate change. Three zones showing both high climate change velocities and a gradient of decreasing ecological similarity to the Mojave Desert were selected for sampling.
- Based on our approach, ricegrass populations will be sampled in 2016 and planted in up to five Mojave Desert common gardens. These experiments will develop management guidelines for selecting germplasm suitable for the restoration of arid sites in transition to warmer, drier conditions.

PLANT MATERIALS AND CULTURAL PRACTICES

Characterizing Germplasm Relationships and Maximizing Seedling Establishment of Utah Trefoil (*Lotus utahensis* Ottley)

B. Shaun Bushman and Douglas A. Johnson 177

- Collections of Utah trefoil (*Lotus Utahensis*) were transplanted in two locations in Northern Utah and the first year's data from the common garden plots was collected. The second year is underway.
- Due to the high tannin content of other trefoil species, we are collaborating with Utah State University to measure tannin content in these collections.
- AFLP marker genotyping has been completed and analysis of relationships among collections is underway.

SPECIES INTERACTIONS

Comprehensive Assessment of Restoration Seedings to Improve Restoration Success

Kari Veblen and Thomas Monaco 197

- 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.

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

Kevin Grady, Paul Dijkstra, Catherine Gehring, Egbert Schwartz, and Hillary Cooper.....199

- We propose to investigate the importance of maintaining community interactions for restoration using a common garden provenance approach.
- This research will build upon current research in which we are investigating the effectiveness of adding live and commercial soil microbial inoculum during revegetation of *Artemisia tridentata*, *Elymus elymoides*, and *Achnatherum hymenoides* with and without competition by *Bromus tectorum* at three common gardens (Mountain Home, Idaho; west Salt Lake, Nevada; Fredonia, Arizona).
- This study will increase our knowledge of both abiotic and biotic adaptations and the importance of both to restoration.
- Collected all germplasm samples needed to run experiment.
- Planted and growing all germplasm samples at NAU greenhouse facility with preparation to transplant to common garden Spring/Summer of 2016.

SCIENCE DELIVERY

SeedZone Mapper Smartphone App Development

Andrew Bower and Charlie Schrader-Patton.....207

- Development of prototype SeedZone mapper app for use in an on-line environment.
- Solicitation of proposals from app developers.
- Research and testing of multiple “off-the-shelf” apps for suitability.

RESTORATION STRATEGIES

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

Kirk Davies.....229

- Evaluate five different methods to restore sagebrush after wildfires across a 3,000 ft. elevation gradient.
- Determine 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 A. Johnson and Thomas Monaco 231

- Experimental designs were finalized for establishing 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 (pure live seed) basis during November 2015. Thirty-three rows were seeded in each site treatment/replication combination with rows being 3-m (10 ft.) long and 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*) and 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 for each species compared to two check species.



2015 HIGHLIGHTS

CONTINUING PROJECTS

GENETICS AND CLIMATE CHANGE

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

Holly Prendeville, Francis Kilkenny and Brad St. Clair.....15

- A reciprocal transplant experiment is being conducted in the Interior Northwest with 16 common garden sites in two transects in regions with different environmental conditions. Each site was planted with 20 replicates from 39 populations plus two propagated lines of bluebunch wheatgrass (*Pseudoroegneria spicata*).
- First year survival was high with 80% of plants surviving through the 2015-growing season. Only one garden site failed shortly after planting due to extreme weather. A new site was planted in October 2015 to replace the site.

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

Richard C. Johnson, Elizabeth Leger, Mike Cashman, and Ken Vance-Borland.....22

- Seed zones for Sandberg bluegrass across the Inter-mountain West and the Great Basin have been mapped, published and posted at Seed Zone Mapper. (http://www.fs.fed.us/wwetac/threat_map/SeedZones_Intro.html).
- Seed zones for Thurber's needlegrass for the Great Basin have been completed and submitted for publication.
- Seed zones for Basin wildrye have been completed and submitted for publication.
- Sulfur-flowered buckwheat evaluation data were collected from a common garden study of populations from the Intermountain West and Great Basin.

Ecophysiological Analyses of Common Gardens to Inform Seed Transfer Guidelines

Matthew J. Germino, Martha Brabec, and Bryce Richardson.....31

- A quantitative tool has been developed for assessing weather/climate effects on native perennial establishment in seeding or planting trials done for science or actual restoration. This tool allows learning about adaptation even when trials have little or no survival.
- Physiological differences freezing and water-deficit thresholds are being identified for populations of sagebrush species and bluebunch wheatgrass (*Pseudoroegneria spicata*) in existing or new GBNPP common gardens.
- Common gardens arrayed across elevation gradients on the 2015 Soda Wildfire site are being established for big and low sagebrush species, local seeds from remnant/unburned plants inside the burn area, seeds collected by volunteer groups from around the

perimeter of the burn area, and seed sources originating from surrounding regions procured by the BLM for aerial seeding.

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

Elizabeth A. Leger and Sarah Barga 39

- We identified the dominant germination strategies of ten Great Basin annual and perennial herbaceous species.
- A majority of species had no preference for after-ripening temperature, but species exhibited differences in their preference for cold stratification.
- Five species were identified as facultative winter germinators by their ability to germinate at cold (2° C) temperatures, including: *Agoseris grandiflora*, *Blepharipappus scaber*, *Collinsia parviflora*, and *Cryptantha pterocarya*.
- We found that *Agoseris grandiflora*, *Collinsia parviflora*, *Cryptantha pterocarya*, and *Microsteris gracilis* were able to germinate under a wide range of conditions.
- In contrast, *Gilia inconspicua*, *Mentzelia albicaulis*, and *Phacelia hastata* possessed high levels of dormancy.
- Nine out of ten species displayed population level differences in germination strategies.
- Preliminary habitat maps were created for each species using herbarium data.
- The environmental variables that were most predictive were found to be unique to each species; though precipitation in summer, winter, and spring, a relative drought index, and winter maximum temperatures were important for multiple species.
- Accurate habitat maps can improve the efficiency of forb restoration efforts, increasing the likelihood that valuable seeds are planted into habitats where establishment is most likely to be successful.

Dynamics of Cold Hardiness Accumulation and Loss in Sulphur-flower Buckwheat (*Eriogonum umbellatum*)

Anthony S. Davis, Matthew R. Fisk, and Kent G. Apostol 47

- Results indicate geographic, seasonal, and date*population interaction differences among accessions. Statistical significance was found between the two October collection periods and the wildland/common garden location.
- Between the populations there was a low LT50 cold hardiness resistance level ranging from -10 to -16° C during the spring collection months and a high LT50 cold hardiness resistance level ranging from -56 to -58° C in December.
- December was the sample collection that appeared to be the most cold resistant, whereas April – August months tended to be similar in their lack of cold hardiness resistance.

PLANT MATERIALS AND CULTURAL PRACTICES

Smoke-induced Germination of Great Basin Native Forbs

Robert Cox 78

- Extensive literature reviews for all focal species have been conducted and species have been prioritized by germination requirements and potential for smoke response.

- 19 species have been tested for smoke response in germination, with results being analyzed now.

Developing Protocols for Maximizing Establishment of Great Basin Legume Species

Douglas A. Johnson and B. Shaun Bushman 83

- A series of greenhouse studies were conducted to determine the effects of scarification, planting depth, and soil composition on germination and seedling emergence in western prairie clover (*Dalea ornata*), Searls' prairie clover (*Dalea searlsiae*), and basalt milkvetch (*Astragalus filipes*). A planting depth of 19 mm (0.75 inches) retarded the rate of emergence for all species compared to a depth of 6 mm (0.25 inches), but only reduced total seedling emergence for basalt milkvetch.
- With seed scarification in sandy soils, prairie clover seedling emergence exceeded 80%, while basalt milkvetch was less than 10%. With seed scarification in soils with higher clay content, total seedling emergence for prairie clover was reduced to 58-70%, while basalt milkvetch increased to about 30%.
- Laboratory studies showed that the combination of seed scarification, pre-chilling, and a sand substrate increased germination of basalt milkvetch to 35% compared to only 10% for non-pre-chilled, unscarified seeds.
- Field studies at two sites in northern Utah showed that pre-chilled, scarified seed of basalt milkvetch established considerably better than unscarified or non-chilled seed. The pre-chilled, scarified seed treatments for basalt milkvetch could be scaled up to produce large quantities of germinable seed.
- Seed collections of Utah trefoil (*Lotus utahensis*) were made in southern Utah, Nevada, and Utah. These collections were evaluated for biomass production, phenology, flowering, seed production, tannin content, and forage quality at three common garden sites in northern Utah during 2014 and 2015. A DNA marker technique was used to evaluate genetic diversity among collections. Data are currently being analyzed from these studies.

Bee Pollination and Breeding Biology Studies

James H. Cane 93

- Bees are necessary pollinators for seed production by silverleaf phacelia, *Phacelia hastata*.
- Silverleaf phacelia is self-compatible, with isolated individuals setting abundant seeds. Variable seed set among individuals masked any possible gain from outcrossing.
- Silverleaf phacelia attracts the most abundant and richly diverse fauna of native bees of any of the 15 common native sage-steppe forbs systematically sampled for its wild bee guilds.

Native Forb Increase and Research at the Great Basin Research Center

Kevin Gunnell and Danny Summers 96

- Finalized data collection from the cushion buckwheat (*Eriogonum ovalifolium*) common garden study. Initial data analysis suggests that seed production may be too low in cushion buckwheat for commercial production, but could potentially be

increased with irrigation. Despite low seed production, the species does exhibit good drought tolerance in most accessions.

- Finalized data collection from the forb island, N-Sulate fabric study. Initial analysis suggests that the use of N-Sulate fabric in wildland settings has the potential to increase the initial emergence of native forb species, but the treatment has limited impact on the long-term persistence of most species tested in this study.
- Finalized data collection from the wildland forb seeding study. Initial analysis suggests that survival of seeded forb species can be improved in a Wyoming big sagebrush (*Artemisia tridentata* var. *wyomingensis*) community with the appropriate seeding methodology. However, selection of the best methodology is contingent on a number of factors including: species to be seeded, objectives in sagebrush reduction, and weedy species that may be released.
- Continued work to increase seed from wildland collections to support further research and increase distribution of native seed to commercial growers.

Plant Material Work at the Provo Shrub Sciences Lab

Scott Jensen.....109

- 26 wildland seed collections representing four species.
- Distributed 60 sources of seed to accommodate a variety of cooperative projects.
- Study installation for the research project “Forb Islands: Possible Techniques to Improve Forb Seedling Establishment for Diversifying Sagebrush-Steppe Communities”.

Aberdeen Plant Materials Center Report of Activities

Derek Tilley.....112

- Release of Amethyst Germplasm Hoary Tansyaster.
- Progress towards release of Wyeth buckwheat.
- Development of 21 NRCS Plant Guides.
- Development of 7 Propagation Protocols.
- Modification to the Flail-Vac ® harvester for light airborne seed.

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

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

1. Irrigation Requirements for Native Buckwheat Seed Production in a Semi-Arid Environment.....116

- The seed yield of *Eriogonum umbellatum* and *E. heracleoides* were evaluated over multiple years in response to four biweekly irrigations applying either 0, 1 inch of water, or 2 inches of water (total of 0, 4 inches, or 8 inches/season).
- *Eriogonum umbellatum* seed yield was maximized by 5 to 8 inches of water applied per season in warmer, drier years and no irrigation was needed in cooler, wetter years.
- Averaged over ten years, seed yield of *Eriogonum umbellatum* was maximized by 6.5 inches of water applied per season.
- Over five seasons, seed yield of *Eriogonum heracleoides* was only responsive to irrigation in 2013, a dry year when seed yield was maximized by 4.9 inches of applied water.

2. Irrigation Requirements for Seed Production of Five *Lomatium* Species in a Semi-Arid Environment.....124
 - The seed yield response to four biweekly irrigations applying either 0, 1 inch of water, or 2 inches of water (total of 0, 4 inches, or 8 inches/season) was evaluated for four *Lomatium* species over multiple years starting in 2007.
 - Over seven seed production seasons, *Lomatium dissectum* (fernleaf biscuitroot) seed yield was maximized by 5 to 6 inches of water applied per season in cooler, wetter years and by 8 inches of water applied per season in warmer, drier years.
 - Over nine seed production seasons, *Lomatium grayi* (Gray's biscuitroot) seed yield was maximized by 0 to 5 inches of water applied per season in cooler, wetter years and by 5 to 8 inches of water applied per season in warmer, drier years.
 - Over nine seed production seasons, *Lomatium triternatum* (Nineleaf biscuitroot) seed yield was maximized by 4 to 8 inches of water applied per season in cooler, wetter years and by 8 inches of water applied per season in warmer, drier years.
 - Over four seed production seasons, *Lomatium nudicaule* (barestem biscuitroot) seed yield did not respond to irrigation.
 - In the two seed production seasons observed, seed yield of *Lomatium suksdorfii* (Suksdorf's desert parsley) responded to irrigation in 2015.
3. Irrigation Requirements for Seed Production of Five Native *Penstemon* Species in a Semi-Arid Environment.....137
 - 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.
 - *Penstemon acuminatus* (sharpleaf penstemon), *Penstemon speciosus* (royal penstemon), and *Penstemon cyaneus* (blue pentstemon) seed yields were maximized by 4 to 8 inches of water applied per season in warmer, drier years and were not responsive to irrigation in cooler, wetter years.
 - *Penstemon pachyphyllus* (thickleaf beardtongue) seed yields were maximized by 8 inches of water applied per season in warmer, drier years and were not responsive to irrigation in cooler, wetter years.
 - In 6 years of testing, seed yields of *Penstemon deustus* (scabland penstemon) only responded to irrigation in 2015, with 5.4 inches of water applied resulting in the highest yields.
4. Prairie Clover and Basalt Milkvetch Seed Production in Response to Irrigation.....149
 - 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 inches, or 8 inches/season) were tested.
 - Over the five year period of study, *Dalea searlsiae* (Searl's prairie clover) seed yield was maximized by 6 - 9 inches of water applied per season in warmer, drier years and by 0 inches of water applied per season in cooler, wetter years.
 - *Dalea ornata* (western prairie clover) seed yield was maximized by 4-8 inches of water applied per season in warmer, drier years and by 0 inches of water applied per season in cooler, wetter years.
 - *Astragalus filipes* (basalt milkvetch) seed yield was not responsive to irrigation.

5. Native Beeplant (*Cleome* spp.) Seed Production in Response to Irrigation in a Semi-Arid Environment.....155
 - The seed yield response of *Cleome serrulata* (Rocky Mountain beeplant) and *Cleome lutea* (yellow spiderflower or yellow beeplant) to four biweekly irrigations applying either 0, 1 inch of water, or 2 inches of water (total of 0, 4 inches, or 8 inches/season) was evaluated over multiple years.
 - *Cleome serrulata* 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.
 - *Cleome* 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.....160
 - 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 2015.....168
 - In 2015, the seven planting systems were tested for emergence of 11 important species, most of which are problematic to establish.
 - 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.

SEED INCREASE

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

- Berta Youtie*.....182
- Preparation and planting of bluebunch wheatgrass (*Pseudoroegneria spicata*) test sites in recently burned areas within seed zones to test the efficacy of using species-specific provisional seed zones and seed transfer guidelines in native plant restoration efforts after fires.
 - Increase of native seed collections for the Great Basin Native Plant Project (GBNPP) in Eastern Oregon and Northern Nevada.

Seed Increase of Great Basin Native Forbs and Grasses for Restoration Research Projects

Clint Shock, Erik Feibert, Joel Felix, Nancy Shaw, Francis Kilkenny, Holly Prendeville, Brad St. Clair, and Anne Halford.....186

- Seed was to be increased of selected Great Basin native forbs and grasses for restoration research projects.
- During the last year seed was increased for bluebunch wheatgrass (*Pseudoroegneria spicata*) and winterfat (*Krascheninnikovia lanata*).

SPECIES INTERACTIONS

Drought Effects on the Symbiosis Between Wyoming Big Sagebrush Seedlings and Arbuscular Mycorrhizal Fungi

Marcelo D. Serpe and Bill E. Davidson.....190

- *Artemisia tridentata* spp. *wyomingensis* (Wyoming big sagebrush) seedlings were exposed to a gradual and terminal drought to investigate the effect of water stress on colonization by the arbuscular mycorrhizal fungus (AMF) *Rhizophagus irregularis*.
- Per unit root length, no differences in total and arbuscular colonization were detected between well-watered and water-stressed seedlings. This was observed after the water-stressed seedlings had fully closed their stomata, thus indicating that Wyoming big sagebrush seedlings did not exclude *R. irregularis* under drought.
- The pattern of colonization observed combined with results from seedling survival suggest that the association between Wyoming big sagebrush and *R. irregularis* ranges from mutualistic under mild water stress to parasitic under severe water deficits.

SCIENCE DELIVERY

Science Delivery for the Great Basin Native Plant Project

Corey Gucker.....206

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

CRESTED WHEATGRASS DIVERSIFICATION

Presence of Native Vegetation in Crested Wheatgrass (*Agropyron cristatum*) Seedlings and the Influence of Crested Wheatgrass on Native Vegetation

Kirk Davies and Aleta Nafus.....210

- We measured basal cover, density, species richness and diversity on 121 sites that spanned a 54230 km² (20.166 mi²) area in southeastern Oregon.
- Plant community composition of crested wheatgrass (*Agropyron cristatum*) stands was quite variable. Some seedings were a monoculture of crested wheatgrass while others contained a more diverse assemblage of native species.
- Environmental factors explained a range of functional group variability ranging from 0% of annual grass density to 56% of large bunchgrass density.
- Soil texture appeared to be the most important environmental characteristic explaining functional group cover and density 10-50 years post seeding and was included in the best regression models for all plant functional groups.
- All native vegetation functional groups were positively correlated with soils lower in sand content.
- Pre-seeding treatments/disturbance and precipitation in the year following seeding have long-term effects on plant community dynamics.
- Moderate grazing reduced crested wheatgrass monoculture characteristics relative to ungrazed sites.

RESTORATION STRATEGIES

Herbicide Impacts on Forb Performance in Degraded Sagebrush Steppe Ecosystems

Marie-Anne De Graff and Aislinn Johns.....218

- Fuel load reduction treatments (i.e. mowing, herbicide applications, a combination of mowing and herbicide applications, and grazing) had no impact on soil microbial activity and soil nitrogen availability.
- Imazapic applications significantly impacted performance of *Astragalus filipes*, *Achillia millefolium*, and *Sphaeralcea grossularifolia*, regardless of concentration and timing of application, suggesting that imazapic is not specific to cheatgrass, and that the use of imazapic could negatively impact native forbs.
- Although imazapic negatively impacted *Astragalus filipes*, *Achillia millefolium*, and *Sphaeralcea grossularifolia*, the response of *Astragalus filipes* to imazapic applications was significantly less negative than that of the other species.



GENETICS AND CLIMATE CHANGE



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 managing 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 rain forest 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. Thus, federal agencies have directives to use genetically appropriate materials that are locally adapted to ensure success in restoration activities and healthy ecosystems. To guide the movement of appropriate plant materials in restoration and reforestation, seed zones have been developed (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 for a particular species and incorporate climatic data along with 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

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

Methods

Bluebunch wheatgrass is a C3, long-lived perennial bunchgrass native to the western United States. It exists in 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 cool, somewhat wet climates of the transverse ranges of the Great Basin to the cold, dry climates of the upper Snake River Plain, and (2) a transect from 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.

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. 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 2015 to record leaf length, width and roll, survival, reproductive phenology, herbivory, root crown diameter, and number of reproductive stalks. Reproductive stalks were collected from a subset of individuals per population at each site to estimate seed production. Sites will be revisited in 2016 and 2017. Weather data loggers were installed at plant height 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 associated with local climates.

Expected Results and Discussion

Since there is genetic differentiation among populations of bluebunch wheatgrass (St. Clair et al. 2013) and these populations exist in a wide range of environmental extremes, we expect that bluebunch wheatgrass is locally adapted. We focus on the regional level of adaptation (ref. regional adaptation) as restoration on this level is more logistically and financially feasible to procure, produce and disseminate native seeds.

Across 16 common garden sites, survival through the 2015-growing season was high (>80%). However, the majority of plants at one common garden site did not survive a month after transplant due to an extreme weather event. Among the remaining sites, we found differences in traits (except leaf length) due to transect; which is likely due to different regional climatic patterns between transects. This variation between transects allows us to investigate how plants perform within a seed zone with natural environmental variation (i.e. deviations from average temperature and/or precipitation). Populations varied in survival and reproduction within many sites, which is evidence of genetic differentiation among populations for these traits. We observed plants from local seed zones with statistically different phenology and reproduction than plants from non-local seed zones. Bluebunch wheatgrass is a perennial plant that can live for decades; thus, it is challenging to interpret variation observed in reproductive phenology, leaf traits, size, and reproduction in year one among plants from different seed zones planted in various seed zones. For instance, high reproduction in year one may reduce future survival. Data collected in 2016 and 2017 will clarify the implications of results.

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 will examine the efficacy of seed zones for bluebunch wheatgrass to ensure successful establishment and allow for long-term adaptation by maintaining genetic diversity. The results of this study will help land managers 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.

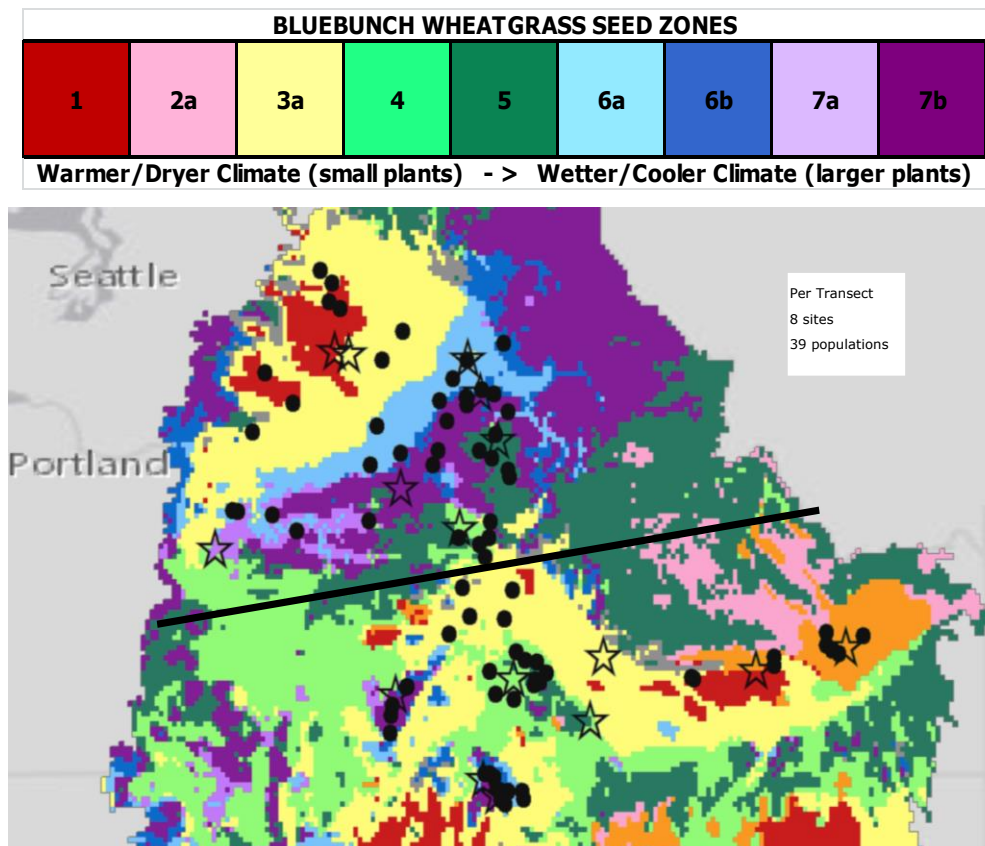


Figure 1. Map of bluebunch wheatgrass (*Pseudoroegneria spicata*) populations (black circles) used in eight common gardens (stars) in each transect (delineated) in the northwest US.

Presentations

Conferences

Prendeville, H. R.; Kilkenny, F.; St. Clair, J. B. 2015. Reciprocal transplant study to test adaptation of bluebunch wheatgrass. Great Basin Consortium Conference; 2015 February 17-19; Boise, ID.

Prendeville, H. R.; St. Clair, J. B. 2015. Geographic variation in adaptation and population movement guidelines in restoration species in the western United States. Ecological Society of America Annual Meeting; 2015 August 9-14; Baltimore, MD. Organized Oral Session; Native Plant Materials Development Research: Synthesis, Cutting Edge and Use Implications.

Abstract: Populations are often adapted to local environments. Restoration efforts on public lands in the Western U.S. have had mixed success for a number of reasons including the extreme climatic conditions. To yield successful outcomes in restoration efforts the use of native plant

material from areas similar to the restoration site is essential. Thus, seed transfer zones have been developed to guide restoration efforts. A provisional seed zone map has been developed for species without species-specific seeds zones. This provisional map integrates climatic variables along with level III ecoregions and has been found to account for the majority of variation among populations of grass and forb species. For a handful of species, seed zone maps specific to the species have been developed, but have yet to be tested. Here we present a summary of seed transfer guidelines for restoration in the western United States. We then focus on our current investigation of the efficacy of seed zones for bluebunch wheatgrass (*Pseudoroegneria spicata*) to ensure successful establishment and allow for long-term adaptation by maintaining genetic diversity. We test the hypothesis that in the long-term populations from local seed zones will better establish, survive, and reproduce. To test this hypothesis, we established a reciprocal transplant study in two broad regions each with eight seed zones with each seed zone represented by four to five wild populations.

To increase the success of restoration, we suggest that land managers use provisional or species specific seed zones in conjunction with species-specific information and knowledge of microsite differences to guideline seed transfers/population movements. Results from previous works and this study support this suggestion and will improve success rates of restoration in the Western United States. Focusing on one species we examined the effectiveness of seed zones by comparing differences in establishment, survival, and reproduction of bluebunch wheatgrass from local seed zones compared to non-local seed zones planted in 16 common gardens. In the first year of this study, we found that overwinter survival was high among all source populations planted in different seed zones. This likely is due to above average temperatures and precipitation among sites. By substituting space for time to evaluate different populations in different climates, this study explores the consequences of changing climates for adaptation. Population movement guidelines and associated seed zones can be adjusted based on results from this study and management objectives.

St. Clair, J. B. 2015. The development and use of seed zones to ensure adapted plant materials for sustainable restoration. Society of Ecological Restoration 6th World Conference; 2015 August 24-27; Manchester, United Kingdom.

Abstract: A seed zone is an area in which plant material collected from native stands can be transferred with little risk of being poorly adapted to the new location. Seed zones and population movement guidelines have a long history in forestry in the western United States to help ensure successful reforestation and productivity of forest stands. More recently seed zones have been developed for shrubs, grasses and forbs based on knowledge of geographic genetic variation in adaptive traits. Initially seed zones may be delineated using the best available knowledge of environmental factors driving adaptation. For example, provisional seed zones based on winter temperature and aridity have been developed in the United States for species which lack genetic information. But the specific environmental factors and the scale to which populations are adapted to their local climates may vary among species (generalists versus specialists). Empirical seed zones for specific species may be developed using short-term genecology studies in which population variation in adaptive traits as determined in common gardens is modeled as a function of the seed-source climates in which the populations evolved. Seed zones based on genecology studies, however, assume local adaption. Local adaptation is best tested using reciprocal transplant studies in which samples of genotypes from local

populations are compared with samples from distant populations in a series of common garden trials. Reciprocal transplant studies also provide the best information of the long-term consequences of maladaptation. Researchers in the western United States have used genecology studies to develop seed zones for many restoration species, and are testing the efficacy of those seed zones using reciprocal transplant studies. Resource managers in federal agencies in the western United States are now using both provisional and empirical seed zones to guide the collection, storage, increase, and deployment of native plant materials in restoration projects.

Webinars

Kilkenny, F. F. 2015. Seed zones and climate change. May 20, 2015. Available: <https://youtu.be/c1944poBtr8>

St. Clair, J. B.; Erikson, V.; Bower, A. 2015. The development and use of seed zones, use of seed zones in procurement and deployment of native plant materials, and provisional seed zones for native plants; 2015 January 29. Available: <http://greatbasinfirescience.org/events-webinars/2015/1/29/the-development-and-use-of-seed-zones-use-of-seed-zones-in-the-procurement-and-deployment-of-native-plant-materials-and-provisional-seed-zones-for-native-plants?rq=seed%20zone>

Publications

Kilkenny, F. F. 2015. Genecological approaches to the effects of climate change on plant populations. *Natural Areas Journal* 35: 500-512.

Additional Products

- Plant materials development for eight seed zones for bluebunch wheatgrass at Oregon State University Malheur Experimental Station.
- Field tour at Oregon State University Malheur Experimental Station on seed zones, native seed production, and bluebunch wheatgrass; May 14, 2015.
- Seed zone maps and map layers for bluebunch wheatgrass are available for download and use at the USFS Western Wildland Environmental Threat and Assessment Center at: http://www.fs.fed.us/wwetac/threat_map/SeedZones_Intro.html

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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 Conservation, Adaptation and Seed Zones for Key Great Basin Species

Project Agreement No. 14-IA-11221632-013

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Project Description

Native plant species are critical for wildlife habitat, livestock grazing, soil stabilization, and ecosystem function in the Western U.S. and the Great Basin. Yet current germplasm releases of these species do not specifically match natural genetic diversity with local climates, which often drive adaptation. Seed zones that match climate with genetic variation have been developed that will facilitate management decisions, ensure restoration with adapted plant material, and promote biodiversity needed for future natural selection with climate change. Over the course of this project seed zones have been completed and published for Tapertip onion (*Allium acuminatum* Hook.), Indian ricegrass (*Achnatherum hymenoides* (Roem. & Schult.) Barkworth), Bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) Á. Löve)) and Sandberg bluegrass (*Poa secunda* J. Presl (Johnson et al. 2012, 2013, 2015; St. Clair et al. 2013). This year seed zones have been completed for Basin wildrye (*Leymus cinereus* (Scribn. & Merr.) Á. Löve) and Thurber's needlegrass (*Achnatherum thurberianum* (Piper) Barkworth). Also, evaluation of plant traits for Sulfur-flowered buckwheat (*Eriogonum umbellatum* Torr.) in a common garden was initiated and will continue into 2016.

Objectives

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

Thurber's needlegrass

Thurber's needle grass common gardens were established at Central Ferry, WA and Reno, NV in 2010. The study consisted of 67 source populations predominantly from the Northern, Central Basin, and Range ecoregions. Data was collected in 2012 and 2013 on numerous phenology, production, and morphological traits. Analyses revealed extensive genetic variation in Thurber's needlegrass across the Great Basin sampling region (Table 1). This was consistent with other grasses and forbs from the Great Basin and Intermountain West (Johnson et al. 2010, 2012, 2013, 2015; St. Clair et al. 2013), and is generally observed in species' other regions (St. Clair et al. 2005, Leimu and Fischer 2008, Horning et al. 2010).

Traits were averaged over sites and years when correlations between specific traits were positive and significant ($p < 0.01$), indicating considerable correspondence for plants growing in different environments. This process reduced traits from a potential of 48 for all site-year combinations (12 traits times 4 environments) to 24. These were used for canonical correlation with 17 'annual' climate variables (Table 2) as defined by Wang et al. (2012). Canonical variates 1 and 2 explained 60% of the total variation between plant traits and climate variables, 42% for variate 1, and 18% for variate 2 with p -values for canonical variate 1 and 2 of $p < 0.0002$ and $p < 0.0424$, respectively. No combination of variates were significant. Thus canonical variates 1 and 2 established a strong link between genetic variation in common gardens and climate variables at source populations.

Regression models with canonical variates 1 and 2 were exceptionally strong, explaining 94% and 87% of the variation in plant phenotypes, respectively. Thus, those canonical variates effectively represented the association of plant traits with different climates, and provided a strong basis for mapping seed zones.

The seed zone map was derived by dividing the range of canonical scores predicted by regression models into segments and then overlaying the results. Regression with canonical scores for variate 1 was divided into 4 segments, and those for variate 2 into 3 segments resulting in an overlay with 12 seed zones (Figure 1). Canonical variate 1 was given somewhat more weight than variate 2 as it explained more of the total trait variation.

These models were used to map 12 seed zones encompassing 465,079 km² in the Great Basin and surrounding areas. We recommend using these seed zones to guide restoration of Thurber's needlegrass. Just six zones (4, 5, 7, 8, 11, and 12) represented 90% of the mapped area and predominated in semi-arid to arid climates. The wetter and cooler zones (1, 2, 3, and 6) represented only 6% of the mapped area. Zones 4, 7, and 10 had relatively small differences in climate, but with genetic variation it was enough to result in different seed zones. Still, those zones were often juxtaposed, suggesting potential coalescence could be considered by land

managers. Thus, the number of populations needed for restoration by zones is within practical limits. This has also been the case in other genecology studies on perennial bunchgrasses in the intermountain West (Johnson et al. 2010, 2012, 2015; St. Clair et al. 2013). Likely more limiting to seed availability of Thurber's needlegrass than the number of seed zones are difficulties in seed cleaning presented by the extensive awns. Although initially more labor intensive, transplanting seedlings in one way to obtain more viable, surviving plants with fewer seeds. Since the scope for future selective adaption and evolution depends on the availability of genetic variation, we also recommend numerous wild populations be collected and used as a restoration population within each seed zone.

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

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

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

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

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

Basin wildrye

Collections of Basin wildrye were made in the Columbia Plateau in Washington state where octoploids are common, and in the Great Basin where both tetraploids and octoploids are found. We expected ploidy to have an important effect on ecological differentiation in relation to climate, so ploidy for all collections were determined as described by Jakubowski et al. (2011). The analysis of field collected sources revealed 57 octoploids and 52 tetraploids.

Common gardens of Basin wildrye were established at Pullman and Central Ferry, WA sites in 2010 with plants from 109 wild populations plus the cultivars Trailhead (tetraploid) and Magnar

(octoploid) were randomized in complete blocks with six replications. Data collection for phenology, production, and morphology traits was completed in 2012 and 2013. Data analyses indicated strong differences in ploidy and also in population within ploidy (Table 3).

Octoploids had larger leaves, longer culms, and greater crown circumference than tetraploids but the numerical ranges of plant traits and their source climates overlapped between ploidy forms. Still, octoploids often had greater genetic variation for traits among collections and occupied more diverse climates than tetraploids. A single canonical correlation analysis linked climate and genetic variation for both ploidy types. Regression of canonical variates 1 and 2, which explained 70% of the variation, with seed source climate variables produced models that explained 64% and 38% of the variation, respectively, and were used to map 15 seed zones covering 673258 km² (Figure 2). Utilization of these seed zones will help ensure restoration with adaptive seed sources for both ploidy types. The higher trait variation and diverse climates occupied by octoploids suggests a higher capacity for adaptation than observed for tetraploids.

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

Final plant traits†	Climatic traits
Heading	Mean average temperature (MAT)
Blooming	Mean warmest monthly temperature (MWMT)
Maturity CF	Mean coldest monthly temperature (MCMT)
Maturity RE	Continentality, MWMT-MCMT (TD)
Leaf length x width (leaf area)	Mean Annual Precipitation (MAP)
Leaf length to width CF 2012 (leaf ratio)	Mean summer precipitation (MSP)
Leaf length to width CF 2013 (leaf ratio)	Annual heat moisture index, (MAT+10)/(MAP/1000)
Leaf length to width RE 2012 (leaf ratio)	Summer heat moisture index ((MWMT)/(MSP/1000))
Leaf length to width RE 2013 (leaf ratio)	Frost free period (FFP)
Culm length CF	Day of year when FFP ends (FFPe)
Culm length RE	Precipitation as snow (PAS)
Panicle length CF	Extreme minimum temperature over 30 years (EMT)
Panicle length RE12	Extreme maximum temperature over 30 years (EXT)
Panicle length RE13	Hargreaves reference evaporation (Eref)
Awn length	Hargreaves climatic moisture index (CMD)
Survival CF	Mean annual solar radiation (MAR)
Survival RE	Mean annual relative humidity (%)
Panicle number CF	
Panicle number RE	
Biomass CF	
Biomass RE	
Crown area CF	
Crown area RE 2012	
Crown area RE 2013	

Sulfur-flowered buckwheat

Collection of Sulfur-flowered buckwheat was completed by the Western Regional Plant Introduction Station (WRPIS) in 2012 resulting in 21 accessions. There has also been ongoing collection through the BLM Seeds of Success (SOS) program resulting in 48 accessions. Seeds from the WRPIS and SOS collections were used to establish plants in the greenhouse in 2014. In the fall of 2014, these were transplanted to a common garden at the WRPIS farm at Pullman,

WA. The first year of data collection was completed in 2015. Taxonomy will be verified and data collected continue in 2016 on phenology, production, and morphology plant traits in 2016.

Table 3. Summary of analyses for 109 Basin wildrye source populations growing in common gardens at Central Ferry and Pullman, WA in 2012 and 2013.

Trait	Ploidy	Population	Site	Site x ploidy	Site x
		within ploidy			Population
					within ploidy
F (P-values)					
Heading day	62.6 (<.002)	4.0 (<.003)	2082 (<.001)	15.5 (<.004)	1.5 (<.005)
Blooming day	61.7 (<.001)	3.7 (<.001)	1901 (<.001)	12.5 (<.001)	2.1 (<.001)
Maturity day	29.3 (<.001)	3.2 (<.001)	13376 (<.001)	2.5 (0.112)	1.3 (0.013)
Morphology					
Leaf weight	472 (<.001)	10.3 (<.001)	16.8 (0.002)	18.9 (<.001)	2.4 (<.001)
Leaf ratio	0.16 (0.69)	1.8 (<.001)	0.21 (0.65)	0.12 (0.72)	0.94 (0.64)
Leaf area	359 (<.001)	11.0 (<.001)	21.7 (0.001)	25.9 (<.001)	2.7 (<.001)
Specific leaf wt.	108 (<.001)	2.3 (<.001)	3.9 (0.076)	2.9 (0.088)	1.5 (<.001)
Culm length	150 (<.001)	2.8 (<.001)	20.2 (<.001)	1.3 (0.25)	1.5 (0.001)
Head length	22.0 (<.001)	3.0(<.001)	11.1 (0.007)	0.0 (0.95)	1.7 (<.001)
Production					
Survival	41.4 (<.001)	2.0 (<.001)	46.3 (<.001)	14.2 (<.001)	2.6 (<.001)
Head number	64.0 (<.001)	2.2 (<.001)	0.7 (0.44)	19.1 (<.001)	1.9 (<.001)
Crown circum.	272 (<.001)	6.0 (<.001)	7.7 (0.019)	71.2 (<.001)	3.1 (<.001)

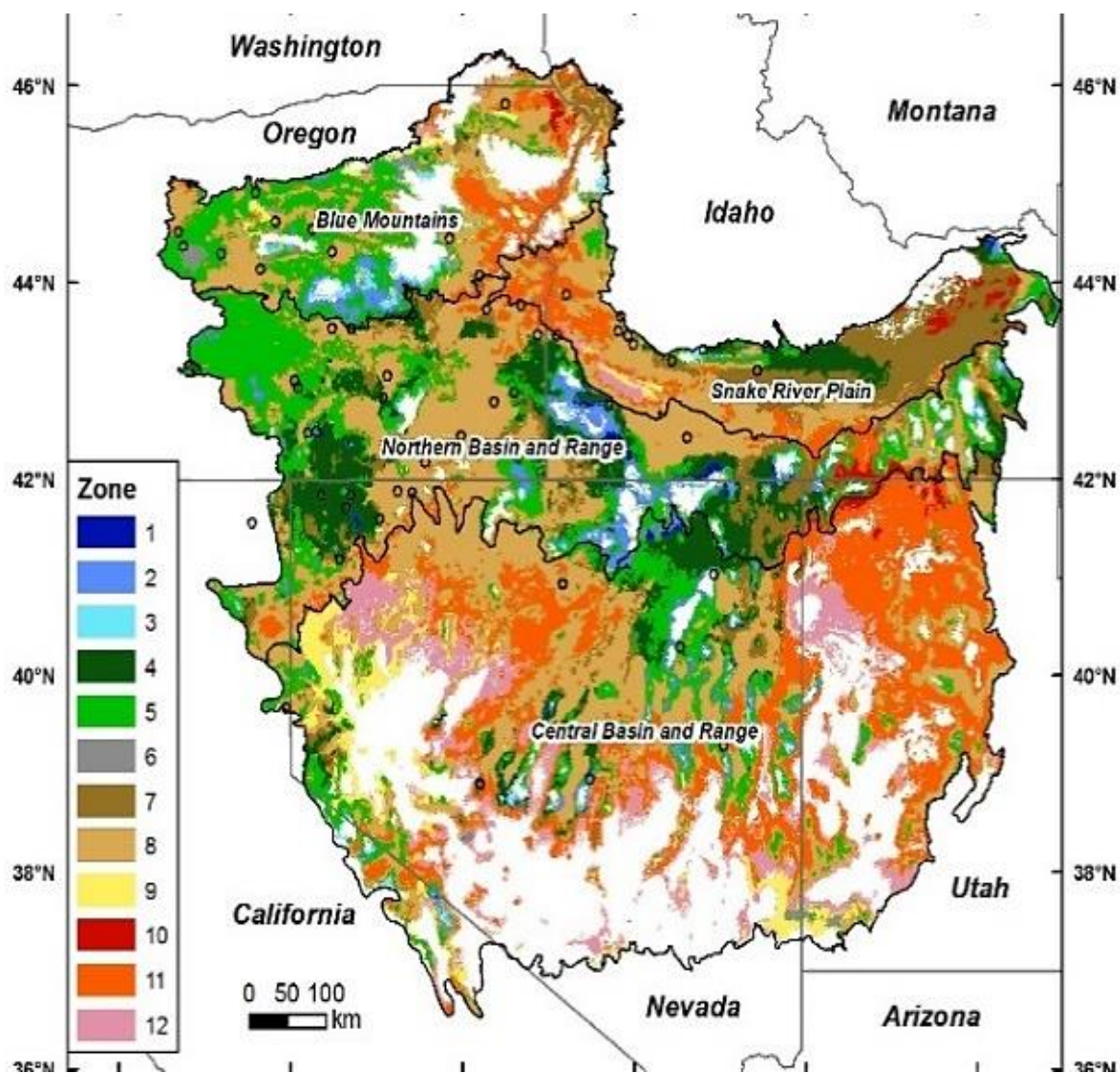


Figure 1. Proposed seed zones for Thurber's needlegrass resulting from an overlay of canonical scores from regression models of canonical variates 1 and 2 with climate variables in the Great Basin. The canonical variates were derived from canonical correlation of plant traits and climate variables. Ecoregion boundaries are shown as black lines. Model predictions outside two times the data range for observed values of canonical scores were not mapped, and are shown in white.

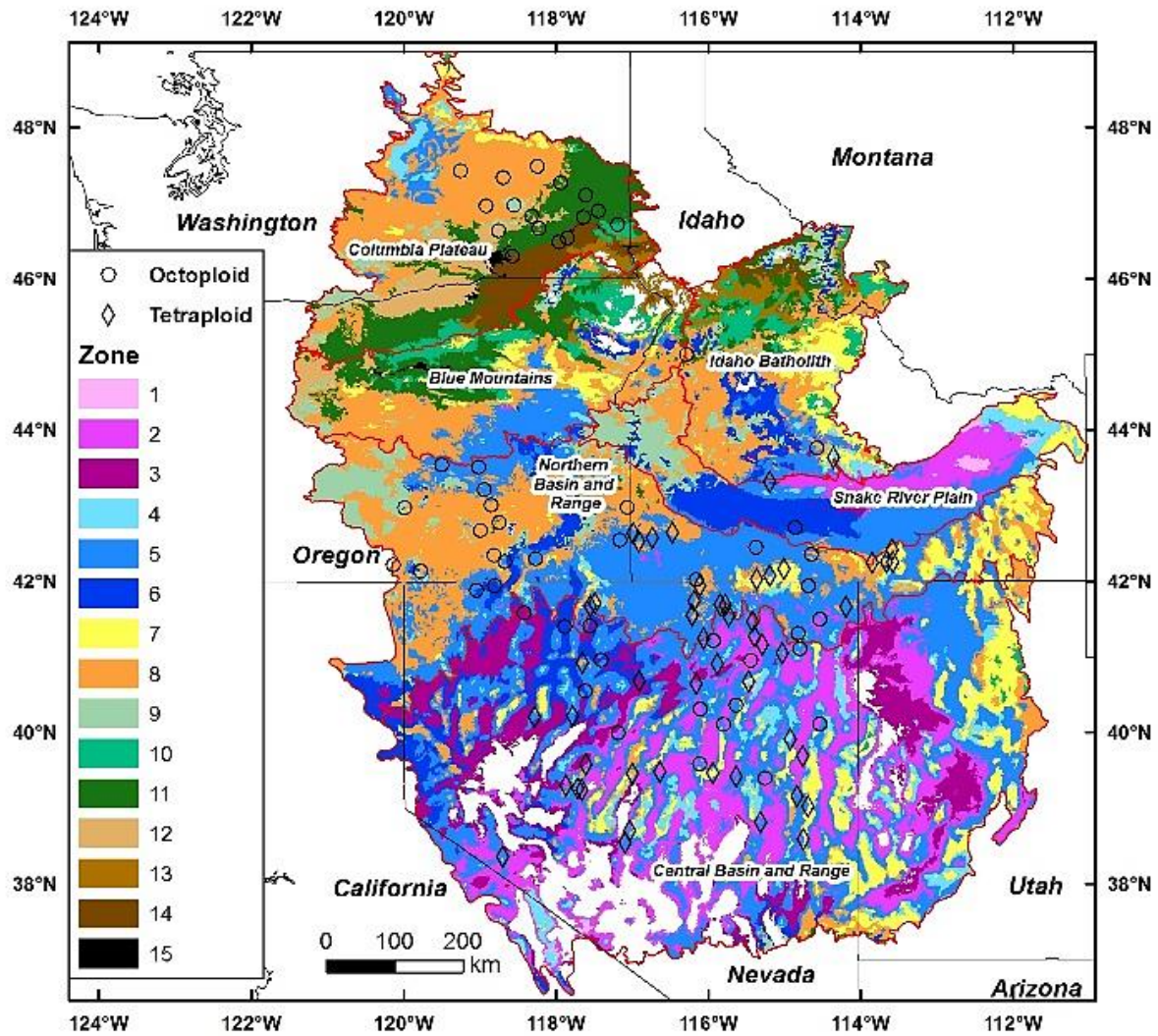


Figure 2. Proposed seed zones for basin wildrye based on regression models of canonical variates 1 and 2 with climate variables over intermountain west. The canonical variates were derived from canonical correlation of plant traits and climate variables. Ecoregion boundaries are shown as red lines. Model predictions outside the data range for observed values of canonical scores were not mapped, and were shown in white.

Management Applications and Seed Production Guidelines

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

Publications

Espeland, E. K.; Perkins, L. B.; Horning, M. E.; Johnson, R. C. [Accepted August 2015]. Seed production farms affect germination and emergence of native grass materials: the source by planting environment interaction. *Crop Science: (Accepted 5 August 2015)*.

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.

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Presentations

Johnson, R. C. 2015. Seed zones for Sandberg bluegrass and friends. Great Basin Consortium Conference; 16-18 February; Boise, ID.

Products

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

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Project Title Ecophysiological Analyses of Common Gardens to Inform Seed Transfer Guidelines

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Project Description

Determining how different seed sources, or plant provenances, vary in their physiological response to climate is an important component of common-garden studies and contributes substantially to the basis for seed-transfer guidelines for restoration. We are measuring a comprehensive set of variables that provide relatively quick insight on how seed provenances of foundational restoration species, specifically sagebrush species and bluebunch wheatgrass (*Pseudoroegneria spicata*), differ in their climate responses. Measurements focus on how different populations from around the Great Basin vary in their threshold responses or resistances to water and temperature stresses. Publications from 2015 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 GBNPP common gardens around the Great Basin continues to be developed.

Introduction

Increased wildfire activity poses a major challenge for big and low sagebrushes (*Artemisia* sp.) communities. Seeding and plantings of sagebrushes and desirable bunchgrasses, such as bluebunch wheatgrass, have been extensive and will continue as a central part of the Department of Interior 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. Consideration of these factors may improve seeding or planting success and therefore they are the focus of our GBNPP research and extension/outreach.

We are continuing to develop techniques and applications for laboratory capable high-throughput “phenotyping” of the many plants in GBNPP 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. This increases 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.
- 2) Determine how the climate adaptation varies among populations, subspecies or cultivars, seed zones, and species.

Methods

Our efforts are done 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 cone-tainer 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).

This approach is partially applied to sagebrushes and is being fully applied to bluebunch wheatgrass. 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 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. Furthermore, this information will provide data 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:

1. Carbon isotopes as an indicator of differences in water use efficiency and stress.
2. Pressure-volume relationships to identify minimum water status thresholds.
3. Freezing point and photosynthetic resistance to freezing (and heating; temperature thresholds).
4. Standard allometric measures that indicate growth strategy, inform interpretation of ecophysiological variables, and relate to water and temperature responses (e.g., 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 are 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; and Baker, OR.
- 3) Intensive effort at Orchard, ID is assessing differences in photosynthesis, water status, phenology, chlorophyll fluorescence (a measure of stress response), and leaf curling (a stress avoidance mechanism).

Big Sagebrush

Two studies are referred to here: Brabec et al. (2015) and Brabec et al. (in review, which is from the Brabec thesis (2014)). We established common gardens of young seedlings in the Birds of Prey National Conservation Area in Idaho, including: 1) five replicate gardens for physiological measurements and frequent survival counts to enable correlation of survival with weather (Brabec et al. 2015), and 2) replicate gardens in areas that had been treated with herbicide, mowing, or drill seeding (Brabec et al. in review and 2014).

One of the most significant outcomes of these experiments with young sagebrushes was the development of a new statistical approach that enables learning from mortality patterns in seedlings. Many planting or seeding trials in the Great Basin have few surviving plants owing to harsh growing conditions, and most often nothing is learned from the trials- as is common with negative results in general. The temperature or precipitation/moisture parameters that often coincide with mortality are rarely incorporated with mortality because standard Cox survival statistics cannot incorporate time-varying factors, such as weather data. We were able to overcome this limitation by adding logistic models to analyze survival-weather relationships.

New Sagebrush Seed Collections and Common Gardens

We made over 10 seed collections from Wyoming big sagebrush and low sagebrushes on the 2015 Soda Wildfire, and several more assisting the Idaho Fish and Game's lead collections on other sites. For all seed sources, we verified the identity of the sagebrush using morphology and leaf chemical traits.

Expected Results and Discussion

In the Brabec et al. (2015) study, mowing the site prior to planting seedlings led to greater initial survival probabilities for sagebrush outplants, except where seeding also occurred, and these effects were related to corresponding changes in bare soil exposure (Table 1). Initial survival probabilities were >30% greater for the local population of big sagebrush relative to populations imported to the site from typical seed transfer distances of ~320-800 km (199-497 mi) (Table 1).

In the Brabec 2014 and Brabec et al. (in review) studies: 1) *A.t. 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, and 2) temperatures required to induce ice formation were up to 6° C more negative in 4n-*A.t. tridentata* and *A.t. wyomingensis* than other subspecies/cytotypes, indicating greater freezing avoidance. In contrast, freezing resistance of photosynthesis varied only 1° C among subspecies/cytotypes, being greatest in *A.t. wyomingensis* and least in the subspecies normally considered most cold-adapted, *A.t. 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.

Table 1. Coefficients of sagebrush seedling survival model results from outplantings into treatment plots (averaged across treatments) at the Birds of Prey National Conservation Area (BOP NCA). Hazard ratios >1 indicate increased hazards of death relative to the base level of the explanatory variable (i.e., similar to a relative death rate). The base level is unseeded control for the treatment factor and the local Idaho seed source for the population factor. Seed sources and their mean annual temperatures and precipitation were as follows: 1) Idaho, BOP NCA, 10.8° C / 297 mm · yr⁻¹, diploid, 2) New Mexico, San Luis Mesa, 9.9° C / 265 mm · yr⁻¹, tetraploid, 3) California, near Benton, 8.9° C / 250 mm · yr⁻¹, diploid, 4) Oregon, near Echo, 11.5° C / 239 mm · yr⁻¹, diploid (from Brabec et al. 2015).

Variable	Parameter Estimate	Hazard Ratio	SE	z	p-Value
Population: California	0.487	1.628	0.156	3.120	0.002
Population: New Mexico	0.276	1.318	0.153	1.800	0.072
Population: Oregon	0.260	1.298	0.154	1.690	0.090
Seeded	-0.160	0.852	0.220	-0.730	0.467
Mowed	-0.634	0.530	0.218	-2.920	0.004
Mowed x Seeded	0.797	2.219	0.309	2.580	0.010
Herbicide	0.066	1.068	0.221	0.300	0.765
Herbicide x Seeded	-0.430	0.650	0.311	-1.380	0.166
Mowed+Herbicide	-0.200	0.819	0.219	-0.910	0.361
Mowed+Herbicide x Seeded	0.708	2.029	0.314	2.250	0.024

We concluded from the Brabec 2014 and Brabec et al. (in review) studies 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

The combination of our ecophysiological measurements with growth and survival of sagebrushes or perennial grasses in common gardens provides key insights for seed selection. Our tests clearly indicate geographic transfer of seed can have important effects on survival (Brabec et al. 2015). Physiological avoidance and tolerance of freezing varies considerably among different populations of big sagebrush, justifying a focus on minimum temperatures in seed transfer guidelines (Brabec 2014, Brabec et al. in review).

Our preliminary data on bluebunch wheatgrass will provide key insight on 1) the relative importance of winter/cold compared to summer/drought to adaptation and which climate parameters most distinguish seed sources, and 2) if/how the empirically determined seed zones (based on phenology, leaf width, and plant height) differ in physiological climate adaptation; and how the very commonly used cultivars differ from natural seed sources in response to temperature stress and water deficit.

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, Matthew. 2015. Climate, weather, and sagebrush seed sources: experimental insights on challenges and opportunities. The Right Seed in the Right Place at the Right Time: Tools for Sustainable Restoration; 13 May; webinar series.

Germino, Matthew. 2015. Climate adaptation in dominant plants of the sagebrush steppe. Seminar to Department of Biological Sciences; 1 October; Boise, ID.

Brabec, Martha; Germino, Matthew; Richardson, Bryce. 2015. Response of seedlings of each big sagebrush subspecies to experimental warming reveals importance of minimum temperatures to establishment. GBNPP session at the Great Basin Consortium, 4th annual meeting; 17-19 February; Boise, ID.

Germino, Matthew; Brabec, Martha; Raymondi, Ann Marie; Richardson, Bryce. 2015. Climate adaptation of big sagebrush revealed from success of 24 historic post-fire seedlings: insights for assisted migration. GBNPP session at the Great Basin Consortium, 4th annual meeting; 17-19 February; Boise, ID.

Richardson, Bryce A.; Chaney, Lindsay; Shaw, Nancy L.; Germino, Matthew J. 2015. Clines in growth, seed yield and survivorship among subspecies of big sagebrush: relationships to climate

and development of seed transfer zones. Great Basin Consortium, 4th annual meeting; 17-19 February; Boise, ID. Poster.

Abstract: Plant species that occupy large geographic distributions contend with highly varied climates. Such climatic differences frequently require genetic adaptation. Failure to understand how these species are adapted to climate will impede restoration. In this study we assess the growth, seed yield and survivorship of big sagebrush (*Artemisia tridentata* subspecies *tridentata*, *vaseyana*, and *wyomingensis*) from three common gardens over four years. Using linear-mixed models (growth and seed yield) and survivor analysis (survivorship), trait variation is associated with source-location derived climate variables (temperature, precipitation, and their interactions). Seed yield and growth showed similar significant clines affected by summer dryness and winter precipitation. Seed yield and growth climate models were highly correlated ($r = 0.73$, $p < 0.0001$). However, survivorship showed clines affected by winter temperatures and the ratio of winter to summer precipitation. Overall, continentality strongly affects climate adaptation in big sagebrush. We discuss the development of seed transfer zones based on these data.

Brabec, Martha; Germino, Matthew; Richardson, Bryce; Shinneman, Doug; McIlroy, Susan; Arkle, Robert. 2015. Response of young sagebrush seedlings to management of herbs. Great Basin Consortium, 4th annual meeting; 17-19 February; Boise, ID. Poster.

Abstract: Seeding or planting of big sagebrush in post-fire rehabilitation or restoration projects involves alteration of a variety of plant community, soil, and site conditions. Herbicide application, mowing, drill seeding with forbs and grasses, and combinations of any of these treatments often happen with or before seeding or out-planting big sagebrush, and could affect herb competition or hydrological conditions for successful sagebrush establishment. The objective of this study was to evaluate how initial establishment of big sagebrush seedlings is influenced by management treatments on the herb layer, and to determine how these effects vary among different populations (seed sources) of big sagebrush. Results suggest that seedling survival may be negatively affected by land management treatments that alter the herb layer and soil surface, including drill seeding. Survival probabilities were relatively greater for the local and fast-growing populations of big sagebrush relative to other populations in an extremely dry spring at the lower edge of the sagebrush steppe ecosystem (Birds of Prey National Conservation Area in Southwestern Idaho).

Germino, Matthew J.; Davidson, Bill; Brabec, Martha; Halford, Anna. 2015. Establishing islands of sagebrush in an early-seral, post-fire landscape: effects of topographic position, cluster plantings, and artificial microclimate shelters. Great Basin Consortium, 4th annual meeting; 17-19 February; Boise, ID. Poster.

Abstract: Methods to increase post-fire restoration of big sagebrush are needed, particularly in relatively dry regions of its range where annual exotic and other early seral grasses and harsh wind exposure often prevail. Patchy establishment of sagebrush within such landscapes is increasingly recognized as an appropriate target for restoration or rehabilitation treatments. We planted replicate clusters of Wyoming Big Sagebrush seedlings using the collaborative nursery and planting team and research area designation in the Birds of Prey National Conservation Area in Idaho. Over 1000 seedlings were planted over many hectares. One year after planting, survival was near 90% in drainages, 65% on slopes, and 40% on flat areas. Use of straw wattle, snow fences, or both to decrease windspeed reduced survival from 60% to as low as 23%, contrary to

our expectations. There were no effects of planting clusters in rows or grids of various sizes and configurations. Insect defoliation was inversely related to survival and was as high as 70% of foliage. Whereas wind sheer is presumed to be a stress factor for sagebrush in this relatively flat landscape, we did not find evidence for it. Instead, our data suggests that targeting certain topographic positions and allowing for non-uniform and non-random post-fire establishment may be realistic.

Publications

Brabec, Martha; Germino, Matthew; Pilliod, David; Shinneman, Doug; McIlroy, Susan; Arkle, Robert. 2015. Challenges of establishing Big sagebrush (*Artemisia tridentata*) in rangeland restoration: effects of herbicide, mowing, whole-community seeding, and sagebrush seed sources. *Rangeland Ecology & Management* 68(5): 432-435.

Brabec, M.; Germino, M.; Richardson, B. [Revision submitted November 2015]. 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*. (Submitted).

Additional Products

- We made many seed collections from Wyoming Big Sagebrush (and, unwittingly, Basin big sagebrush, as inferred from diploid status) and early sagebrush (*A. longiloba*) in and around the 2015 Soda Wildfire sites, and assisted the Idaho Fish and Game (led by Michael Young) on 5 Saturday volunteer collection days. We made voucher specimens and confirmed taxonomic identity at all collection sites.
- Assessment of all in-house sagebrush seed sources at Lucky Peak Nursery (fall 2015) and of all sources from the 2014 and 2015 BLM seed buys to be applied on the Soda Wildfire site.
- Consultations on Soda Fire rehabilitation and monitoring, to BLM and FWS, five meetings with BLM and partner groups, and six phone discussions/interviews.
- Developed proposals that leverage GBNPP research, specifically to the Department of Interior FWS “SSP” program and to Joint Fire Sciences Program.
- Invited presentations on soil stability and restoration in field tours on Soda Fire site, for 20-30 BLM and partner agency staff (including DOI Assistant Secretary Janice Schneider).
- Lead organizer of Great Basin Consortium meeting (GBC#4), February 2015 in Boise.
- Initiated, motivated, and arranged incorporation of GBNPP into the GBC.
- Conceived of and convened symposia on “Restoration of Dry Sites” and “Water in the Desert” and combined poster-oral presentation sessions involving GBNPP research at GBC#4.
- Developed high-throughput protocols for assessing freezing point, resistance, carbon isotopes, and other plant traits.
- Discovery and first-time application of tools for learning about factors contributing to establishment of seedlings even when plantings or seedings are not successful, drawn from epidemiology and applied to sagebrush seedling common gardens (in review at *Journal of Applied Ecology*).
- Cover feature article in *Rangeland Ecology and Management* (Brabec et al. 2015).
- 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.
- Participant in the Department of Interior 2015 Weed Summit meeting (November 17-19, Boise, ID).

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

Project Agreement No. 10-CR-11221632-174

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Project Description

Background

Native forbs are an important component of sagebrush plant communities and provide resources for native pollinators and other wildlife in these systems. Native forbs not only provide forage and cover to native wildlife, they also potentially suppress annual invasive plants such as cheatgrass (*Bromus tectorum*). Degraded sagebrush communities often lack this important plant component, and active restoration may be required to return forbs to altered communities. Though germination requirements of some forb species have been investigated, many native forbs from the Great Basin are unstudied. The lack of information about the germination strategies of many cold desert forbs makes it difficult for growers to increase seeds of these species, and difficult for land managers to successfully incorporate herbaceous species into their restoration protocols.

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

In our continuing work, we are attempting to identify environmental variables and other factors that are correlated with population-level variation in germination strategies, which might allow for generalizations about species for which information is lacking. For example, we may find more population-level variation in species with larger geographic ranges, or less variation in species that occupy only very specific set of environmental conditions. Creating range maps for potential restoration species is the first step in the process of identifying these key environmental variables. We used herbarium data to create fine-scaled range maps that can be used for this purpose, as well as provide indications of suitable habitat for restoration with this important component of sagebrush steppe ecosystems.



Figure 1. Seeds of forb species used in this experiment, from left to right: *Mentzelia albicaulis*, *Chaenactis douglasii*, *Blepharipappus scaber*, *Phacelia hastata*, *Crepis intermedia*, *Cryptantha pterocarya*, *Microsteris gracilis*, *Collinsia parviflora*, *Gilia inconspicua*, and *Agoseris grandiflora*.

Objectives

The main objective of this project was to assess the seed germination strategies of ten cold desert forbs (Fig. 1), including identifying their dominant germination strategies and their level of within-species variation in germination cues. We determined seed germination requirements for some common species that have not yet been studied and identified species which possess high levels of seed dormancy.

We were also interested in whether there is a relationship between population-level variation at a small scale and environmental variability at a large scale. For example, do species with high environmental variability across their range experience a higher degree of population-level variation in germination strategies?

Methods

Seed Germination Experiment

This study focused on ten species of annual and short-lived native forbs that are commonly found in sagebrush steppe ecosystems and are of interest due to their potential importance as a food source for sage-grouse during early life stages. Species investigated were: *Agoseris grandiflora* (bigflower agoseris), *Blepharipappus scaber* (rough eyelashweed), *Chaenactis douglasii* (Douglas' dustymaiden), *Collinsia parviflora* (blue eyed mary), *Crepis intermedia* (limestone hawksbeard), *Cryptantha pterocarya* (wingnut cryptantha), *Gilia inconspicua* (shy gilia), *Mentzelia albicaulis* (whitestem blazingstar), *Microsteris gracilis* (slender phlox), and *Phacelia hastata* (silverleaf phacelia).

Seeds were collected from multiple populations in the vicinity of Reno, NV and Carson City, NV in the spring and summer of 2013. Seeds were placed in petri dishes on wet germination paper, and treatments varied after-ripening temperatures (either room temperature or 40° C) and exposure to wet, cold conditions (2° C for 0, 2, 4, or 6 weeks) before placement in a moderate

(15° C) temperature in a factorial design, with each treatment replicated in five dishes. These treatments were designed to determine if seeds require warm or cold temperatures to break dormancy, which are both common dormancy mechanisms in desert plants. The *Survival* package within Program R (2.12.2) was used to perform survival analysis using the germination data.

Range Mapping

We created range maps for each of our ten species using herbarium data from online resources. We used points from the Intermountain Region Herbarium Network, the Jepson Herbarium, and The University of Washington's Burke Museum Herbarium in order to acquire points from across the entire range of each species. We limited our points to those representing plants that were found from 1950 to the present. With our collaborator Tom Dilts, University of Nevada, Reno, we tabulated 29 biologically relevant variables for use in our range models, including: annual and seasonal minimum temperatures, maximum temperatures, precipitation, and annual temperature range. We also calculated actual evapo-transpiration (AET), potential evapo-transpiration, climate water deficit (CWD), water supply (WS), and soil water balance (SWB) (see Dilts et al. 2015 for methods). We used these variables directly in our model and also used them to calculate other complex variables based on bioclimatic variables (Booth et al. 1989) for use in our models, including: water from the soil (i.e., water remaining from previous years - ratio of SWB:AET), water from the sky (i.e., precipitation as snow or rain from a given year's events - ratio of AET:SWB), relative drought (ratio of PET:AET), precipitation seasonality (the coefficient of variation of monthly precipitation), annual water use efficiency (ratio of WS:AET), cumulative unused water (positive difference between WS and the greater of either AET or SWB), relative unused water in the spring (ratio of water supply to AET or SWB, whichever is higher, for spring season only), and atmospheric source of moisture (positive difference between AET and SWB). We created these variables using climate data from PRISM for the past 64 years (Daly et al. 2008), along with soil, elevation, and data for other topographic variables (aspect, slope, etc.). We mapped the ranges for each of the species using Maxent modeling and ArcMap 10.1 software. We prepared the points for modeling by verifying point location information, thinning points using a 20 kilometer buffer, creating a bias file for unequal sampling across states, and splitting the points into training (65%) and test (35%) samples. We performed model optimization using Maxent software by running factorial combinations of all feature types and regularization multipliers. We performed model selection using Area Under the Curve (AUC) values and AIC values. We are using county maps for each of our species from the Biota of North American Plants website as a coverage guide for our range maps and calculating omission error and standard deviation maps to examine model fit.

Results and Discussion

Species varied in preference for after ripening temperature and cold stratification, and our ten focal species represented a variety of germination strategies (Table 1). Hot after-ripening stimulated earlier germination in *A. grandiflora*, *M. gracilis*, and *P. hastata*; however, the total number of germinated seeds did not differ between after-ripening treatments. Cool after-ripening resulted in both earlier and higher total number of germinated seeds for *C. douglasii*. Species with high levels of germination during cold stratification (potential fall germinators) included: *A. grandiflora*, *B. scaber*, *C. parviflora*, *C. pterocarya*, and *M. gracilis*. Other species germinated best in warmer temperatures after exposure to cold, including: *B. scaber*, *C. douglasii*, *C. intermedia*, and *P. hastata*. Those that germinated best when placed directly into 15° C included *M. albicaulis* and *G. inconspicua*.

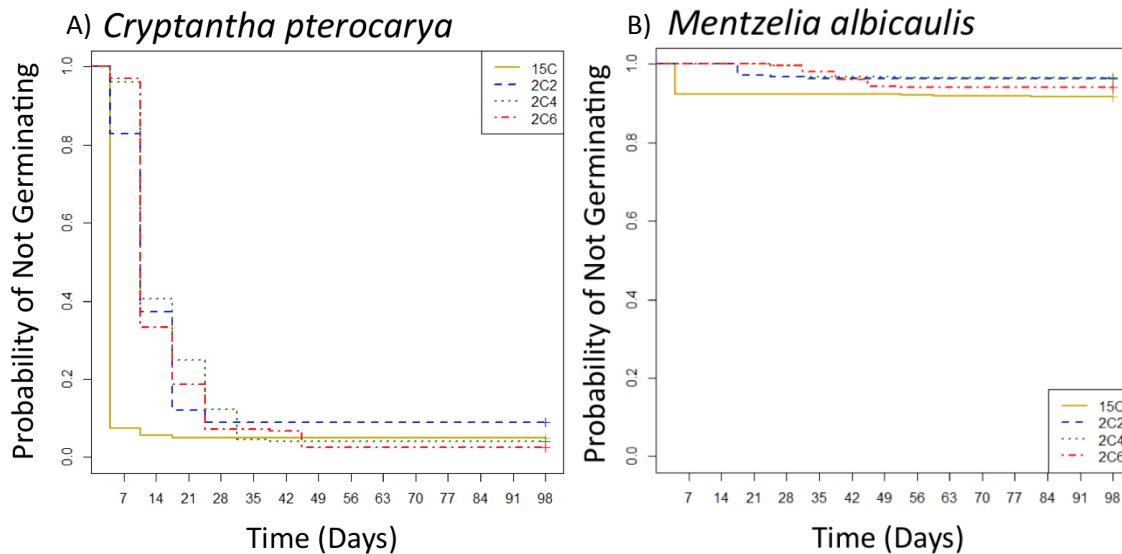


Figure 2. Examples of survival analysis using the results of cold stratification for A) a generalist species, and B) a species with high dormancy. As the colored lines decline from left to right, they indicate an increase in total seed germination with time. Almost all *C. pterocarya* seeds germinated under every treatment combination, while almost no *M. albicaulis* seeds germinated under any treatment.

Using survival analysis, we found differences among species in both the timing of germination and the overall quantity of germinated seeds based on different treatments (Fig. 2). We identified four generalist species (*A. grandiflora*, *C. parviflora*, *C. pterocarya*, and *M. gracilis*) that germinated under a broad range of conditions, and others that possess high levels of dormancy, including *G. inconspicua*, *M. albicaulis*, and *P. hastata* (Fig. 2). While seed dormancy is a strategy that can increase plant fitness over longer time scales, it can be undesirable when restoration outcomes depend on seed germination over shorter time scales. We also identified population level differences in germination strategies for nine out of ten of our study species, although some differences were more dramatic than others (Fig. 3). *Collinsia parviflora* was the only species that did not experience population-level differences in germination strategies, perhaps due to the fact that it is a broad generalist. This high level of population-level differentiation may indicate that seeds may possess germination strategies that are closely associated with the environmental conditions at their collection location, or they may be the result of genetic drift. Field plantings would be required to differentiate between these two possibilities.

Additionally, we have created potential habitat maps for each of the focal species included in this study (Fig. 4). While some of the maps closely parallel the ranges predicted by the county maps provided by the Biota of North American Plants database (www.bonap.org), others still require optimization. We found only 19 of the 29 variables included in our modeling efforts were highly predictive of the range for any of our species though some variables (precipitation in summer, winter, and spring, a relative drought index, and winter maximum temperatures) were important for multiple species (Table 2). In addition, although species responded similarly to a specific variable, no two species were predicted by the same combination of variables. We will use these maps in future research to identify which environmental characteristics are correlated with

variation within a species. Specifically, we are asking whether higher levels of variation in different environmental variables over the range of a species are correlated with increased population-level variation in germination requirements.

Management Applications

Screening plants for their ability to tolerate a variety of field growing conditions will provide seed developers with promising species to add to production fields. Further, knowledge about species-specific germination preferences can help managers identify methods for incorporating native forbs into restoration protocols and help growers germinate seeds of species with high levels of dormancy.

This work has provided information on how to germinate forb species of interest for improving sage-grouse nesting habitat, which has the potential to improve recruitment success in areas where food resources are limiting for chick development. Additionally, the population-level differences in germination strategies we observed confirms that seed collection source can have a large influence on restoration outcomes. In the case of the forb species studied here, it would be possible to select populations with different degrees of dormancy, and managers should be aware of this possibility when selecting seeds for increase.

Finally, our area of occupancy maps provide new information on likely habitat for these important sagebrush steppe species, and can help provide information on appropriate habitat for seeding these forbs in areas where surveys may be lacking, or in highly disturbed sites where no evidence remains of the former native forb community.

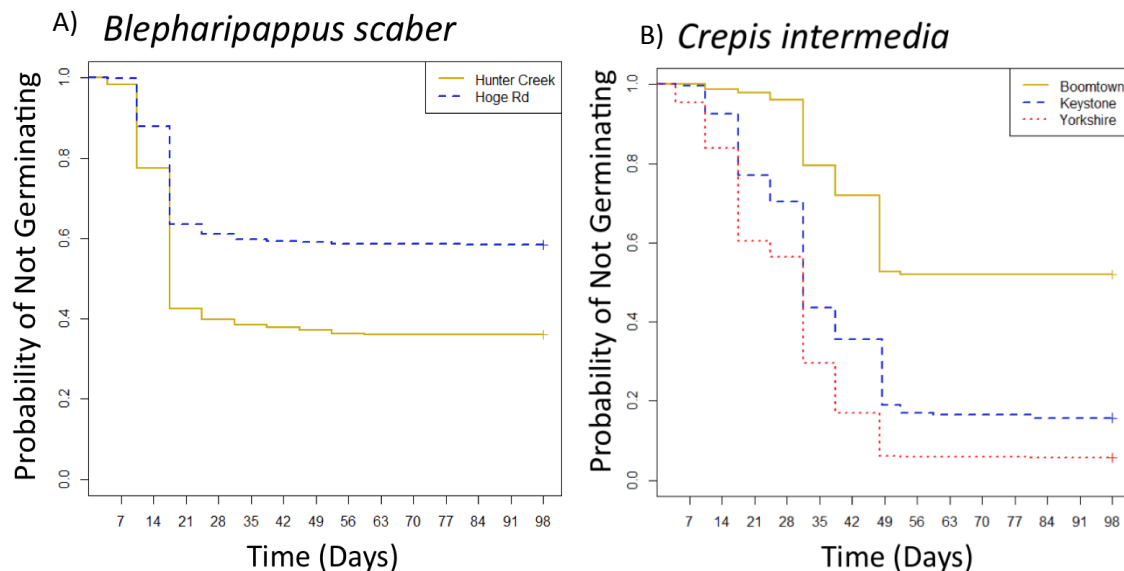


Figure 3. Example of survival analyses showing dramatic population-level difference for an annual (*Blepharipappus scaber*) and a perennial (*Crepis intermedia*) species studied in this experiment. As the colored lines decline from left to right, they indicate an increase in total seed germination with time.

Table 1. Results of germination experiment for three populations per species and estimated area of occupancy estimations based on modeling efforts. For spring germinators, “Cold” indicates that the species would germinate better after being seeded in the fall, so it can experience winter conditions, and “No Cold” indicates that it would germinate better if it were seeded in the spring. Habitat area is based on our current best Maxent model for each species; values may change as models are refined.

Species	After Ripening	Winter Germ.	Spring Germ.	Variation Among Pops.	Life Form	Habitat Area (km ²)
<i>Agoseris grandiflora</i>	Hot	Yes	Yes	Yes	Peren.	483,160
<i>Blepharipappus scaber</i>	None	Yes	No	Yes	Ann.	257,126
<i>Chaenactis douglasii</i>	Cool	No	Yes, Cold	Yes	Peren.	1,400,344
<i>Collinsia parviflora</i>	None	Yes	Yes	No	Ann.	1,507,658
<i>Crepis intermedia</i>	None	No	Yes, Cold	Yes	Peren.	1,599,704
<i>Cryptantha pterocarya</i>	None	Yes	Yes	Yes	Ann.	805,189
<i>Gilia inconspicua</i>	None	No	Yes, No Cold	Yes	Ann.	1,082,895
<i>Mentzelia albicaulis</i>	None	No	Yes?	Yes	Ann.	1,792,732
<i>Microsteris gracilis</i>	Hot	Yes	Yes	Yes	Ann.	1,663,505
<i>Phacelia hastata</i>	Hot	No	Yes?	Yes	Peren.	1,388,650

*Germ. = Germination; Pops. = populations; Peren. = perennial; Ann. = annual

Table 2. Model variables most predictive of area of occupancy for focal species represented by four letter codes, separated by A) water-related variables, and B) temperature-related variables. Minus signs (-) represent negative relationships, plus signs (+) represent positive relationships, blank indicates no association, and “mid” indicates an asymptotic relationship. Variables with threshold values, meaning there is a specific value at which the species increases or decreases dramatically, are indicated with “T.” A list of the environmental variables included in the models can be found in the Methods section.

A.

Water-related variables													
Species	Sum ppt	Fall ppt	Win ppt	Spr ppt	Cum drought	Rel drought	Season ppt	Culm soil water	Water from sky	Water from soil	Annual water use efficiency	Unused water	
AGGR	-					-							
BLSC	-					-			-				
CHDO	-				-	-	-						
COPA		T+								T +	T +		
CRIN	-				-	-							
CRPT			T +	T -									
GIIN				T -			-						
MEAL			T +	T -									
MIGR			T +					+		T +		T +	
PHHA													

*Ppt = precipitation; Sum = Summer (June, July, August), Fall = September, October, November; Win = Winter (December, January, February); Spr = Spring (March, April, May); Cum drought = cumulative drought; Rel drought = relative drought; Season ppt = Seasonality of precipitation; Culm soil water = cumulative soil water.

B.

Temperature-related variables								
Species	Fall min temp	Win min temp	Win max temp	Spr min temp	Spr max temp	Min temp	Temp range	
AGG	+							
R								
BLSC				mid				
CHD								
O								
COP						T -		
A								
CRIN								
CRPT		mid						
GIIN		mid	+		-			
MEA								
L								
MIG			T +				mid	
R								
PHH			mid	+				
A								

*Temp = temperature; Min = minimum; Max = maximum; see Table A for other abbreviations.

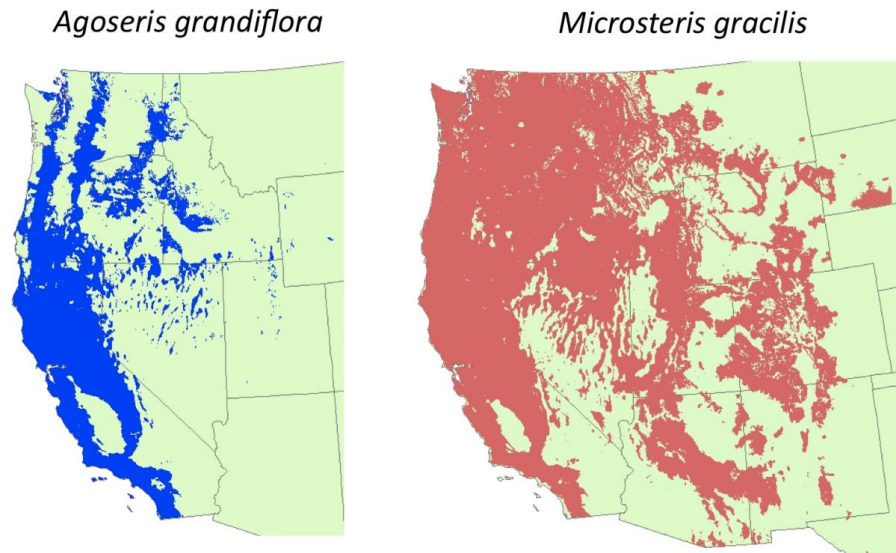


Figure 4. Examples of habitat maps for a perennial (*Agoseris grandiflora*) and an annual (*Microsteris gracilis*) species included in this study created using herbarium records and Maxent modeling.

Presentations

Barga, Sarah. 2015. Estimating the geographic distribution of cold desert forbs using Maxent. Ecology, Evolution, and Conservation Biology Program Ecolunch; 4 December; Reno, NV.

Barga, Sarah; Leger, Elizabeth A. 2015. Germination strategies and geographic distribution of cold desert forbs. Nevada Native Plant Society meeting; 4 October; Reno, NV.

Barga, Sarah; Leger, Elizabeth A. 2015. Species and population-level variation in germination strategies of cold desert forbs. National Native Seed Conference; 13-16 April; Santa Fe, NM.

Barga, Sarah; Leger, Elizabeth A. 2015. Species and population-level variation in germination strategies of cold desert forbs. Great Basin Native Plant Project Annual Meeting; 17-19 February; Boise, ID.

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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.

Project Title Dynamics of Cold Hardiness Accumulation and Loss in Sulphur-flower Buckwheat (*Eriogonum umbellatum*)

Project Agreement No. 13-JV-11221632-066

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Project Description

Objectives

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

The current research goals are to provide a streamlined strategy for plant producers and

restoration specialists in the Great Basin to test cold hardiness of forb species and specific genetic sources in an effort to provide better guidelines for developing and testing seed zones, as well as producing a greater understanding of the influence of changing climatic conditions on plant populations. Using common and valuable candidate Great Basin species, we are working with public and private collaborators to build a short guide to cold hardiness. This will greatly enhance our ability to both understand the role cold temperatures play in native plant establishment following planting, as well as potential implications of changing climatic conditions for restoration in the Great Basin.

Materials and Methods

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

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



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

Table 1. Sulphur-flower buckwheat population site details.

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

The freeze-induced electrolyte leakage (FIEL) technique was deployed to evaluate the cold tolerance of leaf tissue samples. Index of injury, that is the relative amount of electrolytes leaked, was calculated across a range of temperatures and used to determine LT_{50} values. LT_{50} , the temperature at which 50% of cell damage occurs, was selected as the basis of population comparison. Tissue samples were collected from the field across an entire calendar year, starting in October 2013 on a 6 week cycle. Nine sets of samples were collected and processed to complete the year. All samples were transported to Moscow, ID for processing at the University of Idaho Seedling Quality Assessment laboratory. Sample collection and processing all took place within 48 hours. Figure 2 shows variation in leaf morphology between the different populations and tissue sample selection and processing for evaluation.

Data Analysis and Results

Using the calculated Index of Injury for each sample, statistical models were designed to calculate LT_{50} values based on fitting 3-parameter logistic sigmoidal functions to each plant. Repeated measure analysis of variance was used to identify significance between the collection date*population, Tukey's honest Significance test was deployed to separate means describing differences between populations within sample dates (Figure 3), and a two-way analysis of variance was conducted to compare location effects on cold hardiness between the common garden and the wildland site as well as differences between the two October sample dates.

Results indicate geographic, seasonal, and date*population interaction differences among accessions. Statistical significance was found between the two October collection periods and the wildland / common garden location.

Between the populations there was a low LT_{50} cold hardiness resistance level ranging from -10 to -16°C during the spring collection months and a high LT_{50} cold hardiness resistance level ranging from -56 to -58°C in December (Table 2). December was the sample collection that appeared to be the most cold resistant, whereas April – August months tended to all be similar in their lack of cold hardiness resistance.

Future Plans

The remaining tissue samples from field collections not used in the FIEL tests have been oven dried, organized, and stored with the future potential to further investigate cold tolerance

acclimation and loss via carbohydrate analysis or other means. These types of analysis are not time sensitive and can be completed at any future date. Interest in further investigation will be based on the results from the FIEL work.

A Master's thesis and manuscripts are expected to come out of this work in 2016.

Management Applications and/or Seed Production Guidelines

The techniques from this work can easily be deployed to other species. Upon further investigation on plant materials across geographic distributions, we will be able to determine the degree to which cold hardiness results can be extrapolated and applied across species and populations. This project will provide a streamlined strategy for plant producers and restoration specialists in the Great Basin to test cold hardiness of native species, particular genetic sources, and other plant materials in an effort to provide better guidelines for developing and testing seed zones. These techniques will also provide a greater understanding of the influence of changing climatic conditions on plant distributions. In order to fill major knowledge gaps, there is a definite need for further developed guidelines on cold hardiness.

Table 2. LT50 high and low values for nine sampling dates from October 25, 2015 to October 16, 2015 for five ERUM populations at the Boise Common Garden.

ERUM Population					
	M	J	B	C	W
-°C					
LT50 low	10	14	16	13	16
LT50 high	56	56	56	56	58



Figure 2. Left photo shows variation in size of healthy, complete representative *Eriogonum umbellatum* leaves from five common garden populations and one wildland site used for cold hardiness investigation. Three photos on the right show sampling selection of a leaf and sampled discs used in freezing tolerance evaluation.

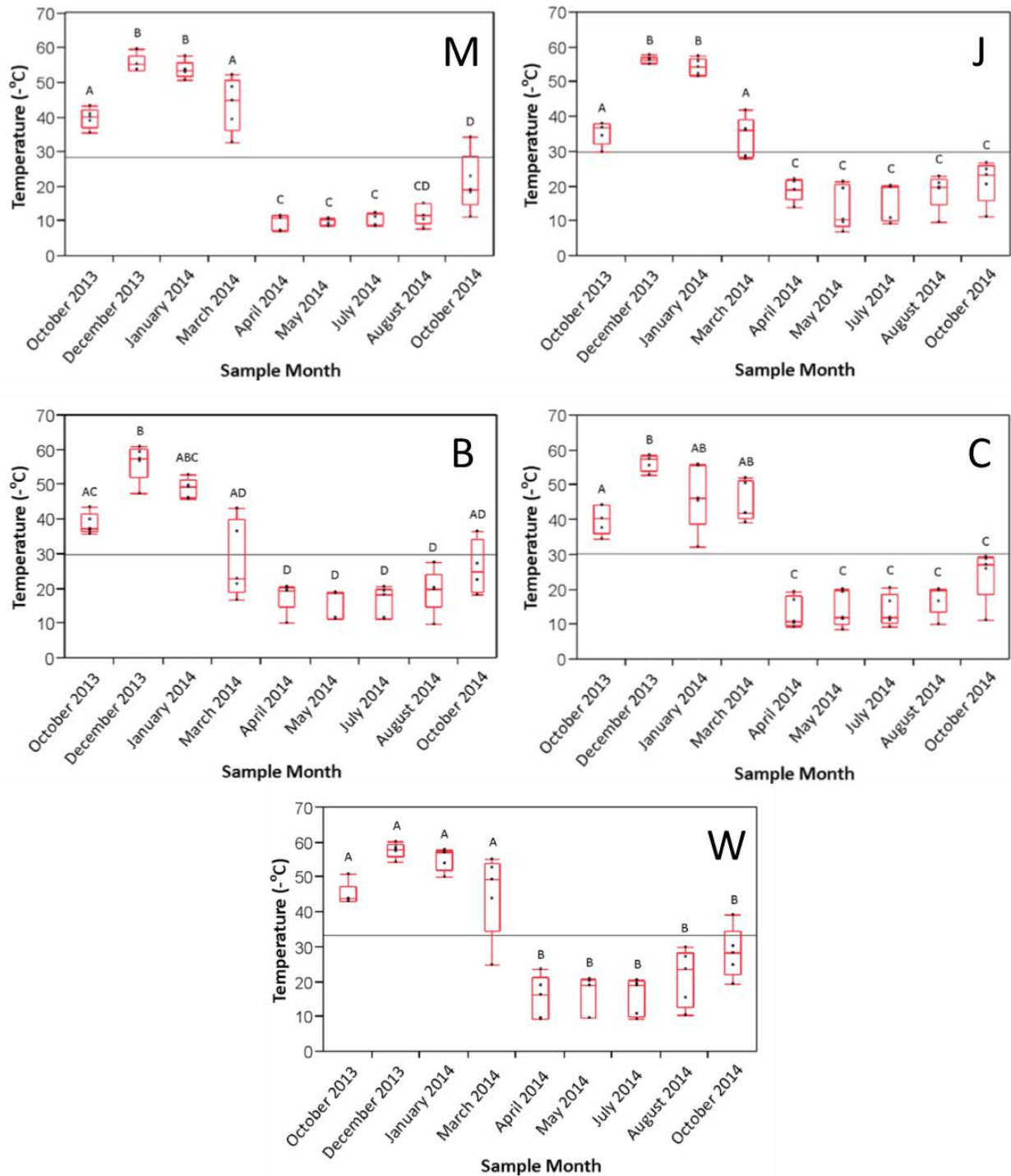


Figure 3. October 2013 - October 2014 population M, J, B, C, and W LT50 Tukey's honest significance (HSD) mean separation box and whisker plots for *Eriogonum umbellatum*. Mean values not sharing a letter within population differ significantly at $P < 0.05$. Whiskers represent standard error of the mean (SEM).

Presentations

Fisk, M. F. 2015. The right plants, in the right place, at the right time: a decade's effort in native plant materials development and restoration research in the Great Basin (and beyond). Idaho Outdoor Association Meeting; 2015 May 12; Boise, ID.

Fisk, M. F.; Davis, A. S.; Apostol, K. G.; Shaw, N. L. 2015. To freeze or not to freeze? An investigation into sulphur-flower buckwheat. Great Basin Consortium Conference; 2015 February 17-19; Boise, ID.

Instructor

Fisk, M. F. 2015. Native plants: selection-collection-processing. Tree Nursery Improvement Project - Target Plant Concept Workshop; 2015 March 1-5; Amman, Jordan.

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 (*Penstemon cyaneus* Pennell) 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 assessments of blue penstemon genetic diversity across the landscape.

Blue penstemon has a latitudinal range over 350 miles with an elevational distribution between 4700 and 8700 ft. 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 posts 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

Our objectives in this study are to: 1) characterize the morphological variation in blue penstemon, and 2) gain an understanding of the genetic variation within the taxon. To achieve these objectives we will collect both tissues and seeds from wild plant populations. Seeds will be used for common garden evaluation which will provide vital data for the morphological questions we are aiming at evaluating. Plant tissues will be used for molecular genetic analysis in order to assess genetic variation across the range of *P. cyaneus*. It is anticipated that this project will take approximately four years to complete.

It is our intention to collect up to 50 collections of blue penstemon across its known ecological and geographical distribution. Herbarium records reveal the occurrence of blue penstemon in 23 counties in central Idaho, two in Montana, and four in Wyoming. It is our objective to collect samples scattered across this entire region. The collected seed will be used to assess phenotypic variation between the collected accessions of blue penstemon. We will establish at least two common gardens in separate sites representing unique geographies and climates. At present, we have tentative agreements to plant one garden at the Aberdeen, ID Research and Extension Center, in cooperation with Dr. Stephen Love, and a second at the Brigham Young University Life Science Greenhouses field plots in Provo, UT. These common gardens will be used not merely as additional replications, but to quantitatively measure the interaction between genotype and environment.

The field of molecular genetics is rapidly changing in a minimum of two ways. First, the cost to accomplish an objective is steadily declining, and second the depth in which a question can be probed is greatly increasing; but, so is the cost to analyze the resulting data. Application of molecular techniques such as amplified fragment length polymorphism (AFLP), simple sequence repeats (SSRs or microsatellites), and genotype by sequencing (GBS) have all demonstrated the ability to genotype large numbers of samples (Hardesty et al. 2008; Bushman et al. 2010; Elshire et al. 2011). These techniques vary in the amount of effort required and the depth of information provided; however, the cost for doing the most powerful technique mentioned, that is, GBS, has steadily decreased and the computational requirements to do such a project are now available at Brigham Young University (BYU). While the costs are essentially the same per sample with each of these techniques, GBS provides much higher resolution for each sample by orders of magnitude. Therefore, the objective of this portion of the study will be to use GBS, unless, other more cost effective methods are developed. In using these techniques we will assess the genetic variation in order to determine if specific genotypes exist and if those genotypes are correlated both geographically and with morphological traits that may have value in plant restoration.

Methods

At each of the wild collection sites we collected 4-6 young healthy leaves (200 mg dry weight) from at least eight plants and preserved them in the freezer in silica gel desiccant. A representative specimen from each site was preserved as a voucher to correlate genetic variation with morphological variation and confirm taxon identity. Voucher specimens will be deposited at the Stanley L. Welsh Herbarium, Brigham Young University. Seed was also harvested from multiple plants at each site for the common garden trial. The collected seed will be used to establish at least two common gardens in separate sites. Each common garden will be a completely randomized block design with four replicated blocks. Each block will consist of five plants from each seed collection site. Replications within each common garden will provide a range of phenotypic measurements for each trait at each seed collection site. The differences

between the common garden sites for each seed collection site will allow us to quantify the interaction of genotype by environment for each phenotypic trait. The measurements we will take will include survival, days to flower, number of flowering stems, number of flowers per inflorescence, seed production, leaf area of last vegetative node, and plant height at maturity.

Information relating to the genetic population structure and diversity of blue penstemon is critical to wisely proceed in the germplasm development for seed production for reseeding uses in revegetation projects. In this study we are investigating either using GBS or a closely related genomic reduction technique such as RADseq (restriction associated DNA sequencing), or GR-RSC (genomic reduction based on restriction-site conservation), (Maughan et al. 2009; Peterson et al. 2012). Once we have the molecular data we will then analyze it with Bayesian clustering analysis and related computational analytic tools.

Expected Results and Discussion

The molecular data in combination with the common garden results planned in this study will allow for the identification of morphological and genetically differences in native 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 statistical 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.

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Project Title A Field Test of Local Adaptation in Bluebunch
Wheatgrass (*Pseudoroegneria spicata*)

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, and local adaptation to soil texture. Our project is part of a larger effort designed to test the efficacy of seed zones in bluebunch wheatgrass (Kilkenny and 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 hypothesis is that bluebunch wheatgrass populations sourced and grown at a test site within a previously delineated seed transfer zone will exhibit early developmental traits that indicate greater fitness than populations gathered from other zones. We also hypothesize that declines in plant fitness will correlate with increasing soil and climatic differences among sites. Lastly, we hypothesize that a single-pass approach to harvest in the seed production setting will limit the genetic diversity of the harvest and may impair the future survival of these propagules in restored areas.

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, and 3) an overview of soil variability among bluebunch wheatgrass seed zones and an understanding of how soil texture and water holding capacity contribute to local adaptation and early success of 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 three 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. A stomatal impression will be taken from the center of the longest leaf on each plant to quantify stomatal density. 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. The 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 the role soils play in terms of local adaptation, we will collect bluebunch wheatgrass seeds from native populations as well as representative soil samples from the top 15 cm at each collection site. Collections will be made within one or more seed zones in Central Oregon. The soils will be textured using the Particulate Organic Matter method (Kettler et al. 2001), and the USDA's soil texture calculator. The soil water holding capacity will also be measured in the field. The soils from each collection area will be homogenized and placed into pots to be used as a growth medium. The bluebunch wheatgrass seeds will then be grown outdoors starting in fall 2016 and monitored for germination and pre-frost survival. The plants will then be monitored for spring germination and survival after winter dormancy. An analysis of variance will be used to determine if there are differences in traits that correspond to soil texture and water holding capacity.

Expected Results and Discussion

We expect to find that the variability in certain early developmental traits such as root to shoot ratio, leaf length, stomatal density, early survival, and germination can be partially explained by local adaptation. We also expect to find that geographic distances over which these phenomena occur correspond to the empirically delineated seed zones for bluebunch wheatgrass and the soil gradients that exist within and among these zones. By measuring these traits in detail, we will be able to determine how large an impact local adaptation 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. The three studies proposed here will answer questions regarding the early development of bluebunch wheatgrass, and how local adaptation, soils, and propagation protocols may impact restoration outcomes.

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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 in the future. 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 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). 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.

Objectives

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 *Bouteloua gracilis* (blue grama grass) grown in a common garden, and is strongly correlated with source location temperature (Butterfield and Wood 2015). 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.

To this end, our specific objectives are to:

- Conduct a meta-analysis of broad-sense heritability in functional traits of grasses.
- Perform measurements of root traits on multiple species and populations in a common environment.

Methods

A literature search for functional trait measurements on multiple populations of a species in a common environment has been conducted. This literature search has yielded more than 50 studies with suitable data, which includes at a minimum of: (1) information on the source locations of the experimental populations in order to extract data on the source environment from WorldClim (Hijmans et al. 2005), and (2) population mean values for functional traits. These data will be used to assess correlations between functional traits and source environment. The strength of the correlations will be positively related to the ratio of between- versus within-population trait variance, which is in turn proportional to broad-sense heritability. More direct estimates of broad-sense heritability will be calculated when sufficient data are provided (means and variances for each population) in order to support the correlative data. Confidence intervals for correlation coefficients will be back-transformed from Fisher’s-Z estimates, and grand means and confidence intervals will be calculated from the correlation coefficients to determine: (1) which functional traits exhibit greater or lesser broad-sense heritability, and (2) the environmental dependence of that heritability.

When available, existing common gardens will be used to measure a suite of aboveground functional traits. An additional experiment will be conducted with plants grown in containers in a common environment in order to measure root and whole-plant functional traits as well (Table 1). 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). 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.

Table 1. Functional traits to be measured in the controlled-environment container experiment.

Organ	Functional trait	Relevance	References
Whole plant	Root-to-shoot ratio	Competition, grazing tolerance	Monk 1966
	Height	Light competition	Westoby 1998
	Lateral spread	Space competition, clonality	Navas and Moreau-Richard 2005
Leaf	Specific leaf area	Photosynthetic capacity, heat tolerance	Wright et al. 2004
	Leaf dry matter	Water use efficiency	Butterfield and Briggs 2011
	Leaf size	Aridity tolerance	Niklas 1994
Stem	Stem density	Frost tolerance	Zanne et al. 2013
Root	Specific root length	Belowground competition	Cornelissen et al. 2003
	Root density	Drought tolerance	Butterfield and Suding 2013

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

Based on our experimental work with blue grama grass (Butterfield and Wood 2015) and preliminary assessment of studies for the meta-analysis, we anticipate that some functional traits exhibit significant broad-sense heritability and that there is a strong environmental dependence to that heritability. We anticipate our proposed measurement of root traits will help to identify patterns of variation that should be highly relevant to restoration success in dryland ecosystems. We also expect to identify traits that will be critical in determining population establishment success under a combination of climatically-regulated (e.g. aridity, growing degree days, etc.) conditions.

The results of this research will provide the basis for experimental restorations to test the applicability of functional traits in predicting restoration success. If reinforced through such out-planting experiments. Our research could help guide seed increase efforts and seed zone guidelines to maximize population establishment, as well as to tailor seed use to specific ecosystem service targets, such as erosion control and forage quality.

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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 *Bromus tectorum* (Ziska et al. 2005) and *Bromus rubens* (Smith et al. 2000, Nagel et al. 2004), little is known about how warming or drought may affect either invasive grass. *Bromus rubens* has been found to be as cold tolerant as *Bromus tectorum* but does not survive rapid temperature drops (Bykova and Sage 2012). Considering that *Bromus rubens* is currently dominant in warm deserts and sensitive to drastic temperature drops, increased temperatures in the Great Basin cold desert, may result in further invasion. When growing individually, preliminary results found that drought and warming reduced *Bromus tectorum* emergence, specific leaf area, and biomass to a greater extent than *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 *Bromus tectorum* (Leger 2008, Uselman et al. in review) and *Bromus rubens* (Abella et al. 2012). These studies suggest that early seral natives (*Poa* and *Elymus* grasses for *B. tectorum* and early seral forbs for *Bromus rubens*) 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 *Vulpia octoflora*, which is an early season, annual native, with *B. tectorum*. Although there are limited studies on competitive interactions

between *Vulpia octoflora* and *Bromus rubens*, 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 *Vulpia octoflora* – *Bromus rubens* or *Vulpia octoflora* – *Bromus tectorum* 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 *Bromus tectorum* or *Bromus rubens* 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-3 x 3 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 15x15cm 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*; ELEM5), and 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) ELEM5-forbs-BRTE, 3) VUOC-forbs-BRTE, 4) POSE-forbs- BRRU2, 5) ELEM5-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.

Expected Results and Discussion

We have commenced site selection, which has included a common garden area on the University of Nevada, Reno campus and various locations on Bureau of Land Management land. Site selection will continue until an appropriate site is found; shelter construction and obtaining seed will begin in the spring. 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.

Additional Products

- Additional project funds were obtained for a technician through the USDA-Agricultural Research CRIS project.

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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 et al. 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 indeed be vulnerable to such changes (Breshears et al. 2005, Miriti et al. 2007). It is also increasingly apparent that climate change effects will 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 in regions where complex topography creates gradients in exposure intensity (Loarie et al. 2009).

Characterizing local adaptation in plants of the southern 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. Low elevation, arid sites in the Great Basin have met with unsuccessful restoration efforts, particularly burned areas (Knutson et al. 2014). Understanding whether drier ecotypes exist that may 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 relative to the Great Basin. These experiments will develop management guidelines for selecting Great Basin ecotypes suitable for restoration of arid sites in transition to warmer, drier conditions.

Objectives

The project will support tissue and seed collections for two Great Basin taxa that are used in restoration and are important for wildlife habitat (Connelly et al. 2000, 2011), particularly in the southern Great Basin: Indian ricegrass (*Achnatherum hymenoides*) and sagebrush (*Artemisia nova* and/or *A. tridentata*). Great Basin populations of these species will be sampled and placed in common garden experiments located in the arid Mojave Desert, mimicking potential future climates.

The sample design will incorporate Great Basin populations from a gradient of representative climate zones – from least to most arid - and will explicitly consider climate change predictions to evaluate at-risk populations. To do so, we will classify the southern Great Basin into contrasting climate zones. Each zone will be ranked according to its predicted velocity of climate change (*sensu* Loarie et al. 2009; Hamann et al. 2015). Plant populations will then be selected from leading- and trailing-edge areas (high and low climate change velocity, respectively) in up to three climate zones. Our experimental design addresses three key questions:

- (1) Do populations exhibit genetic differentiation in performance traits, 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?
- (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 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 EPA's "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 three climate zones with low to moderate ecological distances to the Mojave Desert common gardens and with high predicted climate change velocities as suitable for sampling.

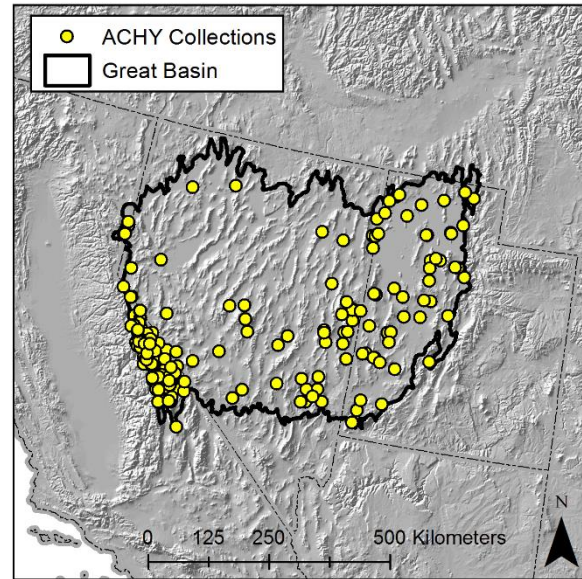


Figure 1. Potential ricegrass (ACHY) populations drawn from herbaria records.

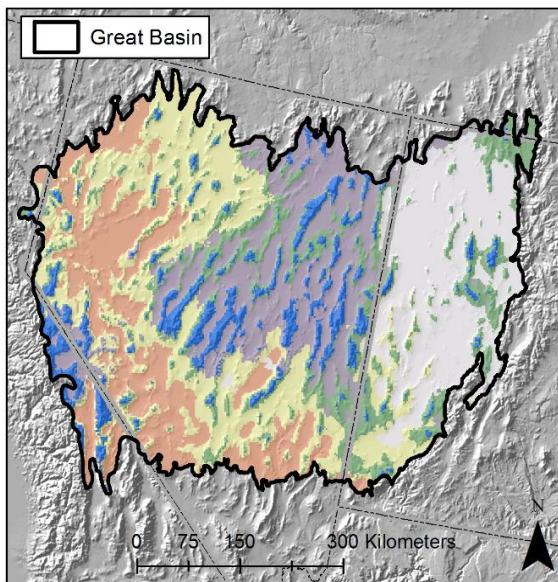


Figure 2. Six climate zones in the southern Great Basin derived through cluster analysis of temperature and precipitation characteristics.

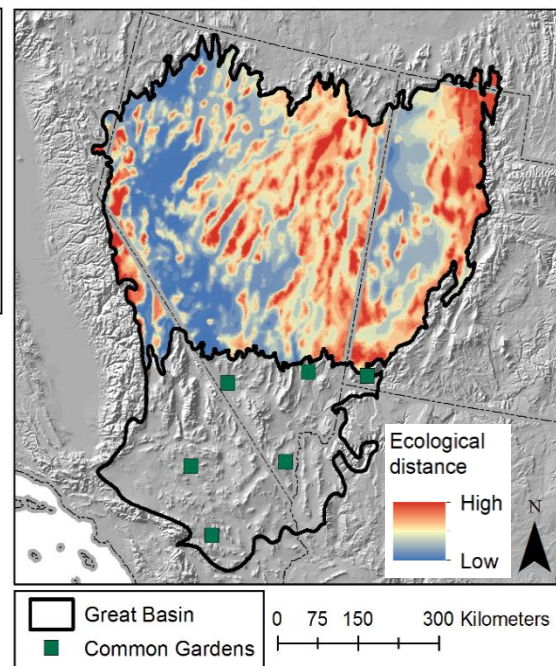


Figure 3. Ecological distances between the southern Great Basin (northern polygon) and Mojave (southern polygon) common gardens.

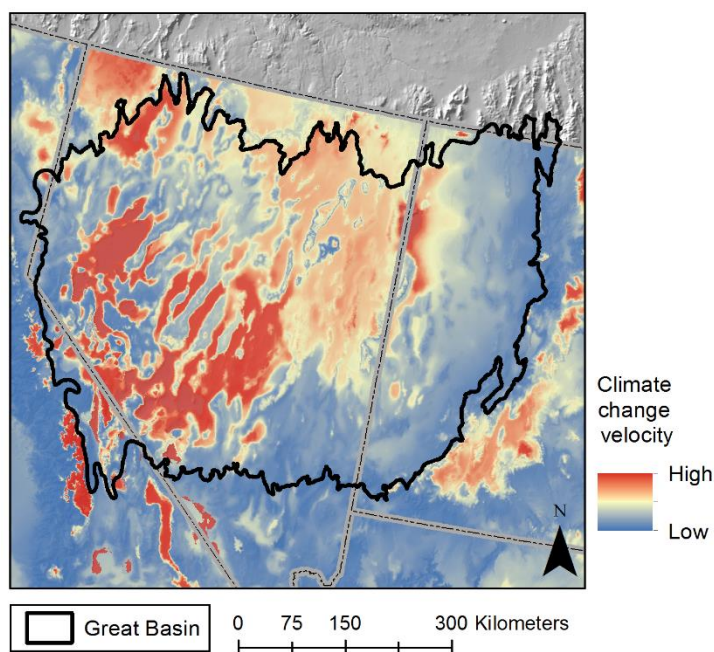


Figure 4. Velocity of climate change predicted for the southern Great Basin (Hamann et al. 2015).

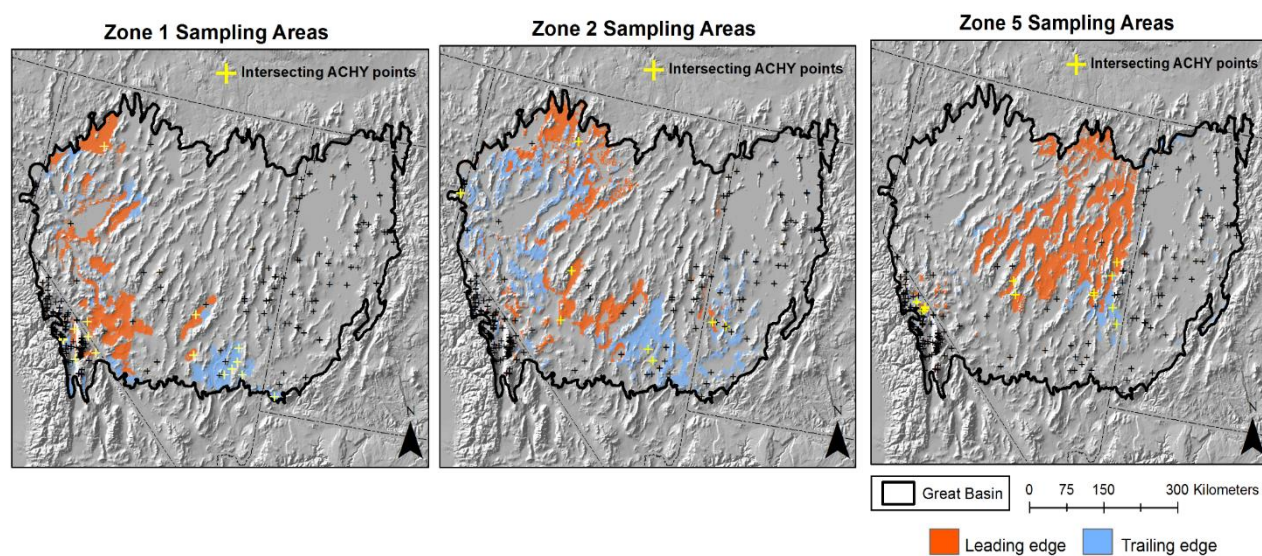


Figure 5. Leading- and trailing-edge areas within 3 climate zones from which ricegrass populations will be sampled.

Greenhouse and Common Gardens

Following the sampling design described above, we will: 1) collect leaves (for genetic analysis) and tillers (for common gardens) from 4-6 Great Basin populations of ricegrass that will be combined with current Mojave collections (N~20 populations), 2) propagate ricegrass plants from tillers that will be transplanted into five Mojave Desert common gardens during 2016, and 3) collect seeds of sagebrush for propagation and evaluation in three Great Basin-Mojave gardens during FY2016 pending funding. Ricegrass tillers will be grown in the U.S. Geological Survey greenhouse (Boulder City, Nevada) in 10.2 cm x 10.2 cm x 30.5 cm (4" x 4" x 12") plant bands prior to transplanting.

Expected Results and Discussion

Of the six climate zones we identified (Figure 2), zones 1, 2, 6, and 5 were most similar to the Mojave Desert (in decreasing order) and are suitable for collections. Zones 3 and 4 were very dissimilar in both precipitation and temperature. In terms of climate change velocity, Zones 1, 5, 4, and 2 had the highest predicted climate change velocities (in decreasing order).

We therefore selected Zones 1, 2, and 5 as suitable for sampling, representing a gradient of climatic conditions from most arid to cooler, moister sites. Within each zone, we identified both leading-edge (high climate change velocity) and trailing-edge (lower velocity) areas (Figure 5). Sampling within each climate zone will include one leading edge population and one trailing edge population.

Sampled populations will be placed in up to five Mojave Desert common gardens reflecting a gradient of decreasing ecological similarity to their source sites (the Mojave common gardens include both arid and cooler / moister sites). In each common garden, we will measure performance traits, including growth, survival, and reproductive characteristics. This 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.

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PLANT MATERIALS AND CULTURAL PRATICES



Project Title Smoke-Induced Germination of Great Basin Native Forbs

Project Agreement No. 11-CR-11221632-005

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Project Description

Introduction

Smoke-induced germination of native seeds has been described in several ecosystems, but little is known about whether smoke may influence the germination of species native to the Great Basin. However, an understanding of smoke-induced germination has the potential to increase the success of restoration and revegetation seedings.

Smoke-induced germination has been relatively well studied for certain ecosystems, including areas in California, South Africa, and Australia (Keeley and Fotheringham 2000). Species in these areas respond to smoke because it represents a cue that fire has prepared a suitable site for new growth (Crosti et al. 2006). The ability of smoke to enhance the germination of native species has also been suggested as a way to increase the density, diversity, and success of native seedings (Roche et al. 1997).

There are several reasons for suspecting that species native to the Great Basin might respond to smoke. First, the climate of the Great Basin is similar to the Mediterranean climates where smoke-induced germination has been observed. Second, periodic fires are prominent in each of these regions. Third, many of the native forbs in the Great Basin belong to genera that are known for having smoke responses, including *Astragalus*, *Cryptantha*, *Erigeron*, *Penstemon*, *Phacelia*, *Salvia*, and others.

In order to investigate the possibility of smoke response in Great Basin species, we first conducted a wide screening through as many species as possible. We asked Great Basin Native Plant Project (GBNPP) collaborators for small lots (approximately 500-1000 seeds) of as many species as were available. From each seedlot, we took a random sample of 400 seeds, and divided those into sublots of 25 seeds each. Four replicates of each subplot (for a total of 100 seeds) were to be soaked in one of three different concentrations of smoke-water, plus a control distilled water only. Smoke-water was purchased from Regen 2000™, which is derived from commercial food flavoring products (see Baldwin et al. 1994). Smoke water concentrations were 1:10, 1:100, 1:1000. After soaking, seeds were germinated according to established protocol (i.e. AOSA or ISTA).

Objectives

The objective of this study was to test species native to the Great Basin for germination response to smoke. We hypothesize that some species may be responsive, as other shrub-dominated ecosystems also display frequent responsiveness. Responsive species could be useful for management of imperiled Great Basin sagebrush ecosystems.

Methods

Each species was tested for smoke response at 4 levels of smoke dilution with distilled water: 1:0 (the control of no smoke, just distilled water), 1:10, 1:100, 1:1000. This was done by creating a volume of each smoke dilution beforehand, which was then stored in laboratory containers for use in the tests. Species were tested for response to smoke both without pretreatments, as we were interested in determining whether smoke exposure could ameliorate the need for pretreatments. For each tested species we: 1) counted out the required numbers of seeds, and placed them in manila coin envelopes until ready to treat and test. Each species was counted into packs of 25 seeds each. When the smoke test was ready, we placed each group of 25 seeds into separate beakers, and added enough of the proper dilution to each beaker to cover the seeds with ample fluid. Seeds were soaked for 20 hours, after which the smoke solution was drained from the seeds, and each separate group of 25 seeds were placed into a separate germination boxes (lined with 2 layers of germination paper).

Germination papers were moistened until they were at capacity. Each box was placed into the germination chamber programmed with the proper temperature and light/dark cycles. The boxes were stacked in groups, and an empty box (no seeds but with germination papers) was placed on top of each stack to ensure all boxes have the same light environment. Each box was observed to record germinating seedlings. When a seed was observed to have germinated, it was recorded and removed from the box. Germination was considered to have occurred when at least 1mm of radicle (root) could be seen on the outside of the seed coat. Observations were continued until no germination was observed for 1 week. Final germination totals were tallied, and data were analyzed via JMP™ to determine treatment effects. Species were analyzed separately, with treatment (smoke dilution) as the independent variable, and total germination as the dependent variable.

Results and Discussion

We tested 19 species, including grasses, forbs, and shrubs, for smoke response. Grasses tested were: *Achnatherum*

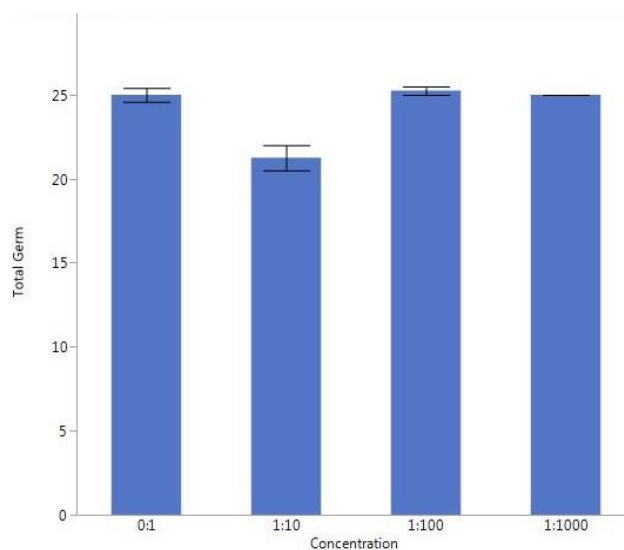


Figure 1. Germination of *Agoseris glauca* under different levels of smoke exposure. Error bars represent standard error. Germination was significantly less under the 1:10 level of smoke exposure.

hymenoides, *Achnatherum thuberianum*, *Poa secunda*, and *Pseudoroegneria spicata*. Forbs tested included: *Achillea millefolium*, *Agoseris glauca*, *Balsamorhiza hookeri*, *Balsamorhiza sagittata*, *Lomatium dissectum*, *Lomatium grayi*, *Penstemon speciosus*, and *Phacelia hastata*. Shrubs tested were: *Artemisia tridentata*, *Atriplex canescens*, *Chrysothamnus nauseosus*, *Erigeron pumilus*, *Eriogonum heracleoides*, *Eriogonum umbellatum*, and *Grayia spinosa*.

Overall, we found that seven species responded to smoke by increasing or decreasing total germination percent. Responding species were: *Agoseris glauca*, *Artemisia tridentata*, *Atriplex canescens*, *Eriogonum heracleoides*, *Eriogonum umbellatum*, *Poa secunda*, and *Pseudoroegneria spicata*. Species that did not display a germination response to smoke were: *Achillea millefolium*, *Achnatherum hymenoides*, *Achnatherum thurberianum*, *Balsamorhiza hookeri*, *Balsamorhiza sagittata*, *Chrysothamnus nauseosus*, *Erigeron pumilus*, *Grayia spinosa*, *Lomatium dissectum*, *Lomatium grayi*, *Penstemon speciosus*, and *Phacelia hastata*.

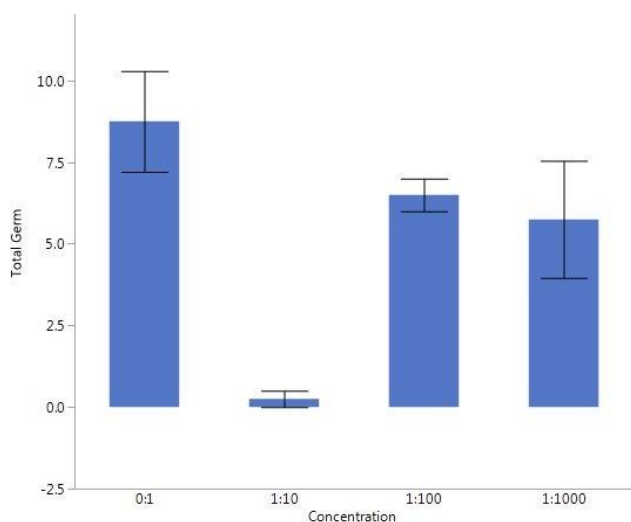


Figure 2. Germination of *Artemisia tridentata* under different levels of smoke exposure. Error bars represent standard error. Germination was significantly less under the 1:10 level of smoke exposure.

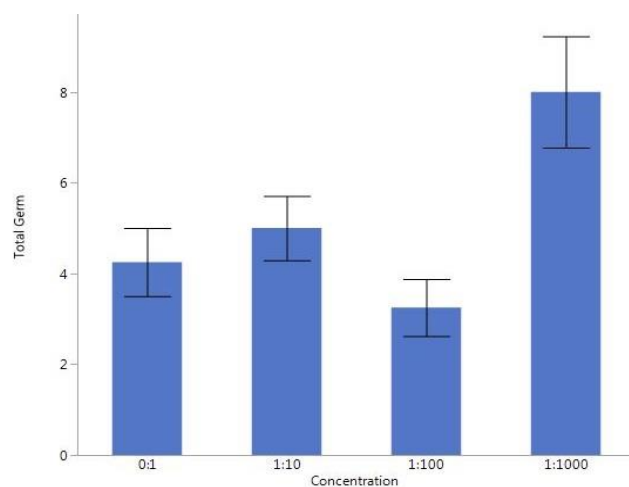


Figure 3. Germination of *Artemisia tridentata* under different levels of smoke exposure. Error bars represent standard error. Germination was significantly greater than the control at the 1:1000 level of smoke exposure. The 1:10 level did not differ from either the control or the 1:1000.

Agoseris glauca (Figure 1) experienced significantly less germination when exposed to high (1:10) levels of smoke. Germination at other exposure levels did not differ from each other, or from the control. Germination of *Artemisia tridentata* (Figure 2) was also significantly lower at high (1:10) smoke exposure, while other levels did not differ. *Atriplex canescens* displayed greater germination at very low levels of smoke exposure (1:1000) than the control, but not the 1:10 level (Figure 3). Other levels did not differ from each other. Germination of *Eriogonum heracleoides* was less at high smoke exposure (1:10) than all other levels of smoke exposure, and germination at other levels did not differ (Figure 4). *Eriogonum umbellatum* displayed less germination at the 1:10 level of smoke exposure than the control, while the 1:100 level also did not differ from the 1:10 level (Figure 5). Germination of *Poa secunda*, was different only between the 1:1000 and the 1:100 levels; no level was different from the control. Finally, germination of *Pseudoroegneria spicata* was significantly less at moderate smoke exposure (1:100) as compared to the control.

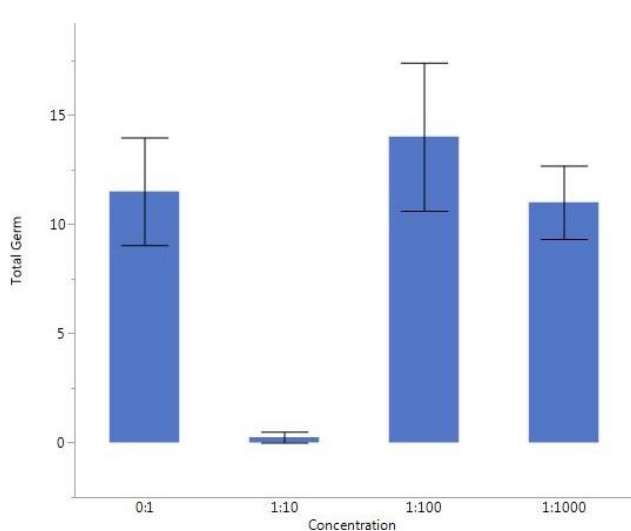


Figure 4. Germination of *Eriogonum heracleoides* under different levels of smoke exposure. Error bars represent standard error. Germination was significantly less than all other treatments at the 1:10 level of smoke exposure.

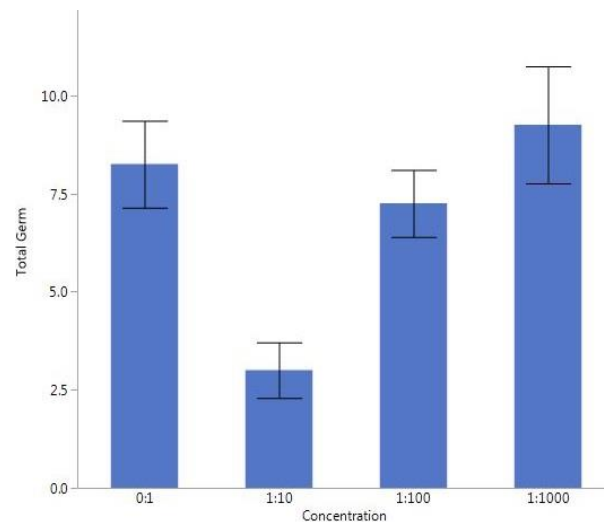


Figure 5. Germination of *Eriogonum umbellatum* under different levels of smoke exposure. Error bars represent standard error. Germination was significantly less than the control at the 1:10 level of smoke exposure. Germination at the 1:100 level of exposure also did not differ from the 1:10 level.

Management Applications and/or Seed Production Guidelines

It is apparent that smoke exposure has an effect on a wide variety of species native to the Great Basin. We found smoke response in a grass, *Pseudoroegneria spicata*, which appeared to be modestly promoted by moderate (i.e. 1:100) levels of smoke exposure. This effect is not well studied for grasses as a group and bears further study. We also found one forb (*Agoseris glauca*), and four shrubs (*Artemisia tridentata*, *Atriplex canescens*, *Eriogonum heracleoides*, and *Eriogonum umbellatum*) that responded. Germination of all appeared to be inhibited by smoke exposure.

Though smoke-stimulated germination, resulting in higher germination rates or faster germination times are perhaps more famous, smoke is also known to inhibit germination of some species, and this effect appears to predominate in the species tested from the Great Basin. This finding offers a note of caution then for adopting smoke treatments, including methods such as smoke-infused water (as used in this study), ash, or charcoal, as restoration or revegetation aids in the Great Basin.

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

Project Agreement No. 11-IA-11221632-007

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Project Description

Introduction

Grasses typically comprise the core of revegetation/restoration efforts in the Great Basin, and seed growers have been successful at producing large volumes of high quality seed for many grass species. Native forb species, however, have been disproportionately under-represented in revegetation/restoration projects in the Great Basin, both in the number of species and in the volume of seed available for each species. Establishing indigenous forbs during revegetation/restoration is central to achieving diverse systems that function sustainably and resist invasion of exotic weeds. As a result, there is a need to identify forbs from western North America that are adapted to low precipitation zones and amenable to field seed production so that these species can be more fully utilized in revegetation/restoration efforts.

Previous research has identified western prairie clover (*Dalea ornata*), Searls' prairie clover (*Dalea searlsiae*), and basalt milkvetch (*Astragalus filipes*) as leguminous forbs that have potential to augment the few existing native forb species that are currently available for commercial use. However, additional research with these species is needed to improve their germination and seedling establishment in seed production fields and rangeland sites. Seeds of species in Fabaceae are known to have that benefit from seed scarification. In addition, pre-chilling treatments in combination with seed scarification may enhance field establishment in seed production fields and on revegetation/restoration sites.

Methods

Greenhouse Experiment 1

The objective of Experiment 1 was to test the effects of seed scarification methods and planting depths. Seeds were planted into sand-filled benches (kept well-watered) with three seed treatments: acid scarification, mechanical scarification, and untreated control. Fifty seeds were planted for each of five entries (Majestic and Spectrum western prairie clover, Fanny and Bonneville Searls' prairie clover, and NBR-1 basalt milkvetch) at a depth of either 6 mm (0.25 inch) or 19 mm (0.75 inch). The study used four replications in a randomized complete block design. Numbers of emerged seedlings were counted three times a week for the duration of the experiment. Total emergence (TEM) was determined as the number of seedlings that emerged by the end of the experiment and rate of emergence (RATE) was calculated (Maguire 1962).

Greenhouse Experiment 2

The purpose of Experiment 2 was to test the effects of soil composition on seedling emergence. Majestic western prairie clover, Bonneville Searls' prairie clover, and NBR-1 basalt milkvetch were used in this experiment. Fifty seeds were planted for each species in a replicated split-plot design with soil compositions as whole plots and seed treatments as sub-plots. Seeds were planted at a 6-mm soil depth in mixtures of fine sandy loam (FSL) and silty clay loam (SCL): 100% FSL, 33% SCL/67% FSL, 67% SCL/33% FSL, and 100% SCL, which are referred to as FSL (sand), 33-SCL, 67-SCL, and SCL (clay), respectively. Seed treatments within each whole plot included acid-scarified seed and untreated seed.

Laboratory Experiment 3

The goal of Experiment 3 was to determine the effect of seed scarification (mechanical and no scarification), pre-chilling treatments, and germination substrate (blotter paper and sand) on germination in NBR-1 basalt milkvetch and Spectrum western prairie clover. Seed was mechanically scarified with sandpaper or left unscarified. Plastic germination boxes of seeds were either pre-chilled in the dark at 5° C for 3 weeks prior to the 10-week germination period or not pre-chilled. After pre-chilling, germination boxes were kept in a laboratory maintained at about 22° C under ambient daylight conditions. Six germination boxes were used for each combination of treatments. Boxes were randomized across all combinations of seed treatments before the beginning of the germination period, and then randomized again after each weekly germination count during a 10-week period.

Field Experiment

Seeds of NBR-1 basalt milkvetch were subjected to five treatments: 1) untreated control, 2) mechanical scarification, 3) immersion in boiling water for 10 seconds, 4) scarification with 97% sulfuric acid for 5 minutes, and 5) acid scarification followed by a 14-day pre-chill (4° C) in the dark after blending into moist sand (250 mg sand + 60 ml tap water). Seeds of the five treatments were planted on 16 April 2014 with a Wintersteiger seeder at a rate of 494 seeds in single-row, 5 m long plots at two locations in northern Utah (Millville and North Park). At both locations, the five treatments were arranged in a randomized complete block design with six replications. Numbers of emerged seedlings were counted periodically through the growing season.

Results

Greenhouse Experiment 1

For total emergence (TEM), the main effects of seed treatment, entry, and planting depth were significant along with the *entry*×*treatment* and *entry*×*planting depth* interactions. The

treatment × *planting depth* and the three-way interaction were not significant. For rate of emergence (RATE), the three main effects and all two-way interactions were significant, but the three-way interaction was not significant. Both acid and mechanical scarification methods resulted in significantly and substantially higher TEM than untreated seeds, and the two seed scarification methods differed significantly from each other for TEM across all entries (Fig. 1A). Majestic and Spectrum western prairie clovers had similar TEM values, with acid scarification resulting in significantly higher TEM than mechanical scarification (Fig. 1A). For Searls' prairie clover, Bonneville had higher TEM for acid compared to mechanical scarification, but for Fanny mechanical scarification had a slightly higher TEM than acid scarification. The TEM of NBR-1 basalt milkvetch was higher with mechanical compared to acid scarification, but only improved from four emerged seedlings in the untreated seed compared to 16 emerged seedlings in the mechanically scarified seed (Fig. 1A).

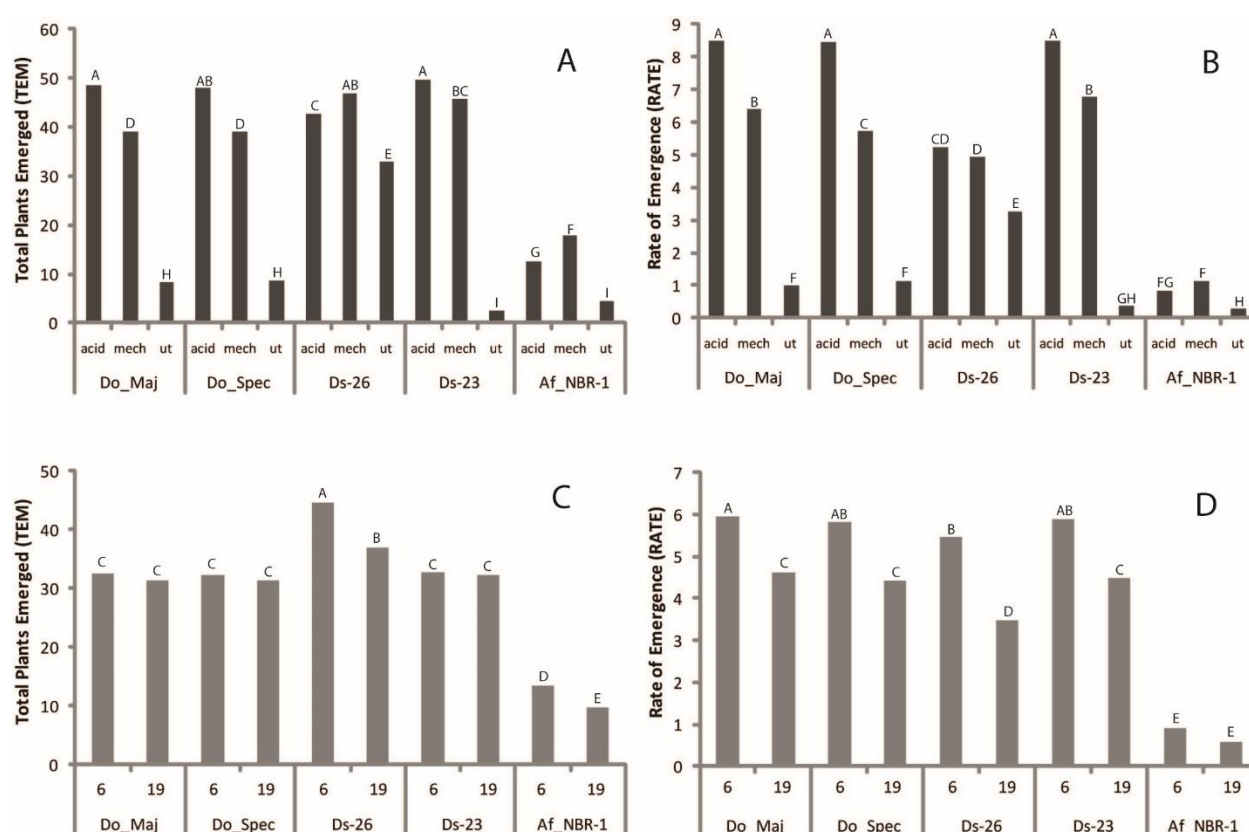


Figure 1. Total emergence (TEM) and rate of emergence (RATE) for western prairie clover (Do_Maj, Majestic; Do_Spec, Spectrum), Searls' prairie clover (Ds-26 = Fanny, Ds-23 = Bonneville), and basalt milkvetch (Af_NBR-1) entries in Greenhouse Experiment 1. (A) TEM and (B) RATE of entries for seed that was acid-scarified (acid), mechanically scarified (mech), or untreated (ut). (C) TEM and (D) RATE of entries planted at 6- or 19-mm planting depths. Bars with different letters on top are significantly different at $p < 0.05$ significance level (Bushman et al. 2015).

For RATE, acid scarification also led to the most rapid emergence in the four prairie clover entries, followed by mechanical scarification and untreated seed (Fig. 1B). Majestic, Spectrum, and Bonneville Searls' prairie clover exhibited similar patterns of response for the three seed

treatments, with acid scarification resulting in a higher (faster) RATE than mechanical scarification. Fanny Searls' prairie clover showed a trend of improvement in RATE for acid compared to mechanically scarified seeds. RATE was substantially lower (slower) for NBR-1 compared to the prairie clover entries, and NBR-1 had a trend of higher RATE for mechanically scarified compared to acid-scarified seed (Fig. 1B). Deeper planting depth did not have a significant effect on the TEM of Majestic, Spectrum, and Bonneville prairie clovers, but it reduced the TEM of Ds-26 from 90% to 74% seedlings and the TEM of NBR-1 from 28% to 20% seedlings (Fig. 1C). The deeper planting depth did result in significant reductions in RATE for all four prairie clover entries when planted at 19 mm compared to 6 mm (Fig. 1D). RATE values for NBR-1 were low, and the deeper depth did not result in a significant delay in emergence.

Greenhouse Experiment 2

Using the Majestic western prairie clover, Bonneville Searls' prairie clover, and NBR-1 basalt milkvetch, seed treatment and entry were tested along with soil composition. For both TEM and RATE, significant effect ($p < 0.0001$) were observed for seed treatment and entry. Soil composition was significant for TEM but not for RATE. For both TEM and RATE, *treatment* × *entry* and *entry* × *soil composition* interaction effects were significant. The significant *entry* × *soil composition* interaction and the significant three-way interactions for both TEM and RATE were most likely due to the varying responses of NBR-1 compared to the prairie clover species (Fig. 2).

Similar to Experiment 1, scarified seeds had significantly higher TEM values than untreated seeds for all three entries (Fig. 2A). TEM of scarified Majestic seeds was 70-82% compared to 8-12% for untreated seeds, scarified Bonneville was 60-83% compared to 2-4% for untreated seed, and scarified NBR-1 was 15-18% compared to 2-6% for untreated seeds. The four soil compositions used in Experiment 2 ranged from a FSL (sandy) composition to SCL (high clay) composition. Scarified seeds of Majestic and Bonneville prairie clovers exhibited significant decreases in TEM as the clay content in soils increased while untreated seeds of Majestic and Ds-23 showed little or no responses to soil composition (Fig. 2A). NBR-1 varied from the two prairie clover responses with an overall lower TEM, and an increased TEM in soils containing clay compared to FSL (sandy).

RATE exhibited a similar pattern of responses as those for TEM, with scarified seeds of all three entries emerging more rapidly than untreated seeds (Fig. 2B). For scarified Majestic and Bonneville, RATE was faster in FSL (sandy) soils compared to soils with higher clay content. Untreated Majestic and Bonneville exhibited a low (slow) RATE, but no significant differences as clay content increased. For NBR-1 basalt milkvetch, scarified and untreated seeds of NBR-1 showed a significant increase in RATE with higher clay content (Fig. 2B).

Laboratory Experiment

The number of germinated seeds of basalt milkvetch and western prairie clover increased linearly through time for all treatment combinations. The two species, however, differed in their germination responses with western prairie clover having a less complex germination pattern than basalt milkvetch. Scarification increased germination in western prairie clover ($p < 0.0001$) from $15.4 \pm 0.4\%$ without scarification to $29.4 \pm 0.4\%$ with scarification. However, neither pre-chilling nor substrate had significant ($p > 0.05$) effects on western prairie clover. The benefit of scarification increased across the 10-week course of germination. Despite the lack of a

significant pre-chilling main effect on germination in western prairie clover, pre-chilling increased cumulative germination as the trial progressed.

Scarification increased germination ($p < 0.0001$), though the effect was smaller for basalt milkvetch than for western prairie clover, increasing from $9.4 \pm 0.4\%$ to $19.5 \pm 0.5\%$. The effect of pre-chilling was greater than that for scarification in basalt milkvetch, increasing germination from $7.8 \pm 0.3\%$ to $22.0 \pm 0.5\%$. Basalt milkvetch germination was also greater ($p < 0.0001$) when sand was used as a substrate (averaging $18.5 \pm 0.5\%$) compared to blotter paper ($10.2 \pm 0.4\%$). Suppression of germination by blotter paper was minimal at the first-week count, but blotter paper hindered germination during later weeks. The effects of pre-chilling and scarification interacted ($p < 0.01$) and were synergistic (Fig. 3), i.e., pre-chilling increased germination of scarified seed (averaging $18.7 \pm 0.4\%$) more than unscarified seed ($10.3 \pm 0.4\%$). Pre-chilling interacted with substrate ($p < 0.01$), as the lack of pre-chilling was less of a disadvantage on sand than on blotter paper, an effect that became more pronounced through time (Fig. 3). Though the *pre-chilling* $\times$ *scarification* and *pre-chilling* $\times$ *substrate* interactions were significant ($p < 0.01$), they were much smaller in magnitude than the main effects of scarification, pre-chilling, and substrate. Neither the *scarification* $\times$ *substrate* interaction nor the *pre-chilling* $\times$ *scarification* $\times$ *substrate* interaction were significant ($p > 0.10$). In summary, germination of the pre-chilled/scarified/sand treatment combination was numerically highest at all 10 weeks ($42.3 \pm 1.6\%$ at week 10), while the non-chilled/unscarified/blotter paper treatment combination was always the lowest ($3.0 \pm 0.5\%$ at week 10).

Field Experiment

Differences between basalt milkvetch seed treatments for seedling density were dramatic at both North Park and Millville (Fig. 4). At North Park, means ($\pm$ S.E.) for acid seed treatment (6.3 ± 2.2 seedlings per row) and boiling seed treatment (6.6 ± 2.3) were not significantly different ($p > 0.05$) from the untreated control (2.5 ± 1.4). Results were similar at Millville with the acid treatment (5.6 ± 1.7) and boiling treatment (4.0 ± 1.4) being similar to the control treatment (1.9 ± 0.9) ($p > 0.05$). However, the acid + pre-chilling and sandpaper treatments were more effective ($p < 0.01$) than the control treatment at both North Park (36.7 ± 6.9 and 38.0 ± 7.1 vs. 2.5 ± 1.4 , respectively) and Millville (22.9 ± 5.5 and 22.3 ± 5.4 vs. 1.9 ± 0.9 , respectively). While seedling density for the acid, boiling, and control treatments remained stable across the evaluation period, we observed seedling mortality for acid + pre-chilling and sandpaper treatments at both locations during July and September (Fig. 4).

Discussion

Greenhouse Experiments 1 and 2

Scarification alone increased germination of western and Searls' prairie clover seeds to more than 80% (except Bonneville) while scarification did not increase germination of NBR-1 basalt milkvetch seed. Majestic and Spectrum western prairie clover responded in a similar manner. Acid scarification increased the percentage of viable seed to about 70%, increased germination to about 85%, increased TEM to 48 seedlings (96%) (Fig. 1A, 2A), and increased RATE more than eight-fold (Fig. 1B, 2B) when compared to untreated seed. Meanwhile, mechanical scarification increased viable seed to 34-43%, increased germination to 60-61%, increased TEM to 39 seedlings (78%) (Fig. 1A, 2A), and increased RATE more than five-fold (Fig. 1B, 2B). Although acid scarification was more effective than mechanical scarification for both Majestic and Spectrum, both scarification methods substantially improved seedling germination and emergence.

Neither planting depth (Fig. 1) nor soil composition (Fig. 2) exhibited effects as large as seed scarification. Planting depth had no significant effect on TEM in Experiment 1, but it did slow RATE (Fig. 1C, 1D). This slower RATE may not necessarily reduce TEM in irrigated seed production fields, but under rangeland planting conditions a slower RATE could lead to lower TEM because of missed strategic rainfall events or preemption of limited soil water and/or nutrients by invasive weedy species. Soil composition changes resulted in significant effects on TEM and RATE, with slight reductions for both traits in clay containing soils (Fig. 2A, 2B). Clay content in soils can improve the ability of soils to hold water for plant use, but can also cause crusting that impedes seedling emergence. For Majestic, the added capacity of clay to hold water was apparently unnecessary, whereas the tendency of clay soils to crust likely prevented some seedlings from emerging.

Untreated seed of Bonneville Searls' prairie clover had a high proportion of viable hard seed, a low germination percent, and negligible TEM and RATE values (Fig. 1A, 2A). Bonneville responses to scarification and planting depth were very similar to those of the Majestic and Spectrum western prairie clover, and indicated that a similar seed germination protocol could be used for both species. Interestingly, the reduction in TEM and RATE in SCL (clay) soil compositions was more pronounced for Bonneville than Majestic western prairie clover (Fig. 2A, 2B), and this deleterious effect of soil crusting was observed to a greater extent for seedlings of Bonneville, which were unable to penetrate the crust by the end of the experiment.

Compared to Majestic and Spectrum western prairie clover, Fanny Searls' prairie clover exhibited a lower viable hard percentage for untreated seeds, attenuated improvement of germination upon scarification, higher TEM and RATE values for untreated seed (Fig. 1A, 2A), and lower TEM and RATE values for scarified seed (Fig. 1A, 2A). Seed of Fanny was the only seed source not cleaned at the USDA-ARS Forage and Range Research Laboratory at Logan, UT. It underwent a more aggressive mechanical cleaning process than the other entries at the USDA-NRCS Plant Materials Center at Aberdeen, ID, which may have partially scarified the seed and led to different responses observed in this study. Despite this partial scarification of Fanny seed, the additional scarification imposed by our seed treatments still resulted in improved viability, germination, TEM, and RATE. Thus, regardless of seed cleaning method, seed scarification would further improve germination and emergence of prairie clover species.

Responses of NBR-1 basalt milkvetch in these experiments were markedly different than those of the two prairie clover species. NBR-1 exhibited 95% viable hard seed and 4% germination for untreated seed. Although scarification reduced its percentage of viable hard seed, it did not improve the germination percentage and seedling emergence, which remained below 20% (Fig. 1A, 2A). Unlike the prairie clovers, NBR-1 had a higher TEM and RATE with mechanical compared to acid scarification (Fig. 1A, 1B), showed a reduced TEM at a 19-mm planting depth (Fig. 1C), and resulted in greater TEM and higher RATE in clay containing soils (Fig. 2A, 2B). These results highlight a uniqueness of NBR-1 seedling germination and emergence compared to the prairie clover species, and underscores that a different seedling establishment protocol is required to maximize establishment of basalt milkvetch. Because NBR-1 germinates and emerges at such a slow rate, it may benefit from the increased water-holding capacity that clay soil compositions provide and emerge at a higher percentage under rangeland planting conditions in clay containing soils. The slow NBR-1 emergence, however, may also result in variable and reduced TEM at deep or variable planting depths, which often occurs in rangeland plantings.

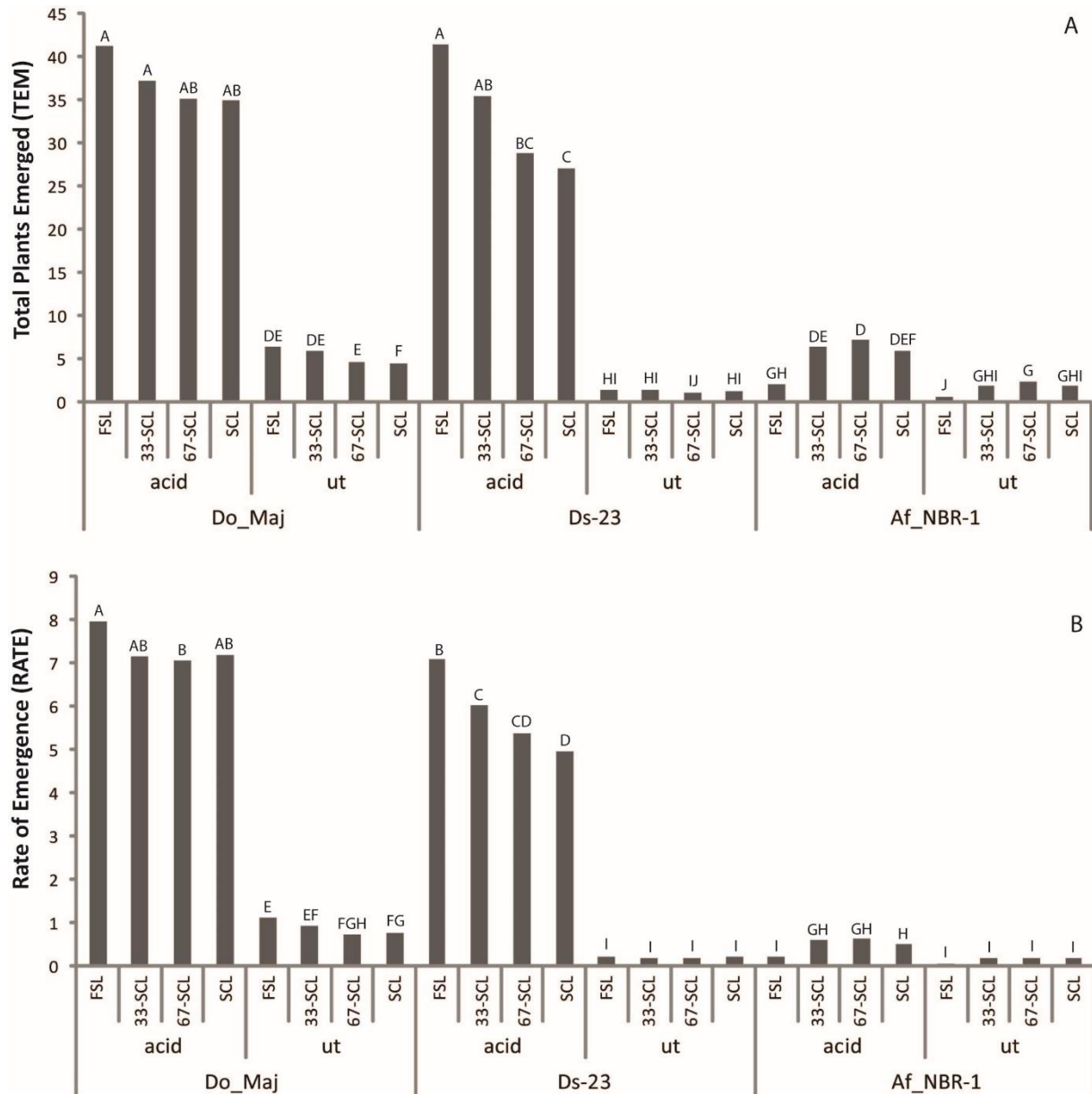


Figure 2. (A) Total seedling emergence (TEM) or (B) rate of emergence (RATE) of western prairie clover (Do_Maj, Majestic), Searls' prairie clover (Ds-23 = Bonneville), and basalt milkvetch (Af_NBR-1) entries for seed that was acid-scarified (acid) or untreated (ut) and planted in four soil compositions in Greenhouse Experiment 2. Soil compositions were 100% fine-sandy loam (FSL), 100% sandy-clay loam (SCL), 33% FSL / 67% SCL, and 67% FSL / 33% SCL. Bars with different letters on top are significantly different at $p < 0.05$ significance level (Busman et al. 2015).

Laboratory Experiment and Field Experiment

Results for western prairie clover that dormancy is alleviated by scarification is consistent with germination being controlled by physical dormancy (i.e., hard-seededness), which is common in the Fabaceae and confers seed longevity. The case for physical dormancy in western prairie clover is also supported by a 5.4% increase in imbibition after scarification. Western prairie clover did not exhibit physiological dormancy, as evidenced by a lack of response to pre-chilling. For basalt milkvetch, both scarification and pre-chilling markedly increased germination both in

the laboratory and field (Figs. 3 and 4). Thus a combination of physical dormancy and non-deep physiological dormancy (i.e., combinational dormancy) appears to be involved in germination of basalt milkvetch. Physical dormancy usually results from impermeability of seed to water. Increased germination percentage and rate is an advantage for fall establishment of a seed field; however, for seedling establishment on rangelands, it is less clear.

To establish seed production fields and restore rangelands with western prairie clover (Majestic and Spectrum) or Searls' prairie clover (Fanny and Bonneville), seed scarification is critical. Planting depth differences, which are inevitable in rangeland seeding, but less so in agronomic seed production, indicated that a shallower 6-mm depth results in a faster rate of emergence than the 19-mm depth. The utility of pre-chilling was demonstrated both in the laboratory and at two field locations. Scarification in combination with pre-chilling was substantially more effective than scarification alone, either when scarification was done mechanically (laboratory trial) or with acid (field trials). For basalt milkvetch, seed scarification and planting in soil with some clay content may marginally improve germination and emergence, but the combination of both scarification and pre-chilling would further improve its germination and seedling emergence. This is critical information, especially for the establishment of seed fields. For rangeland revegetation and restoration, where an immediate stand is desirable for soil stabilization and competition with invasive weeds, some delay in germination delay may be beneficial in years with later precipitation events. As a result, a blend of scarified and untreated seed may be beneficial for rangeland plantings.

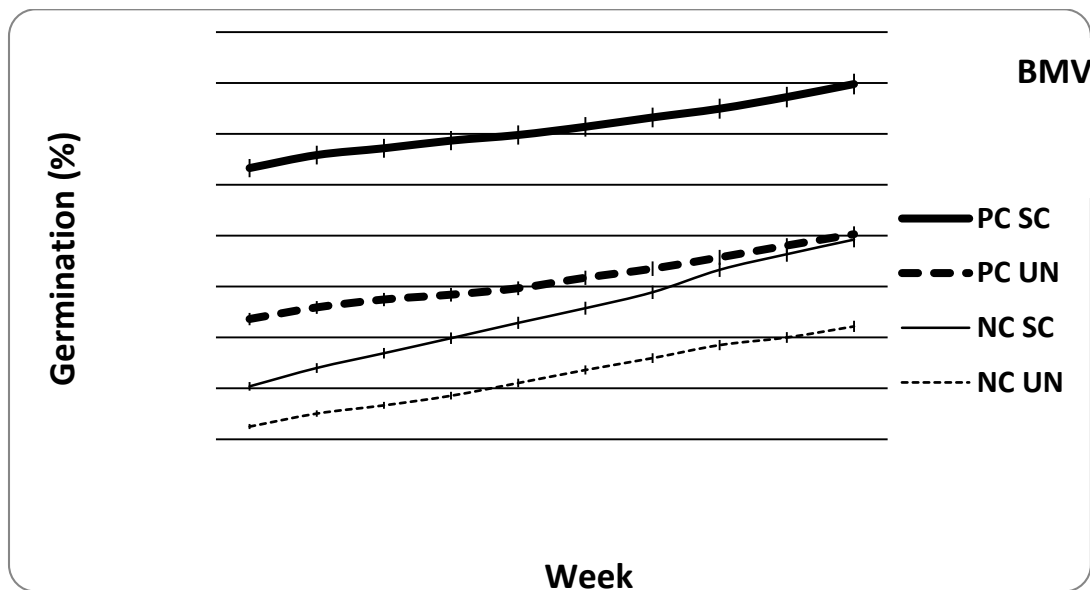


Figure 3. A description of the significant ($p < 0.01$) interaction between two prechilling and two scarification treatments for cumulative germination of seed of NBR-1 Germplasm of basalt milkvetch (BMV) across 10 weeks in Laboratory Experiment 1. Presented here are least-squares means and standard errors for cumulative germination of prechilled scarified (PC SC) seed, prechilled unscarified (PC UN) seed, nonchilled scarified (NC SC) seed, and nonchilled unscarified (NC UN) seed (Jones et al. 2016).

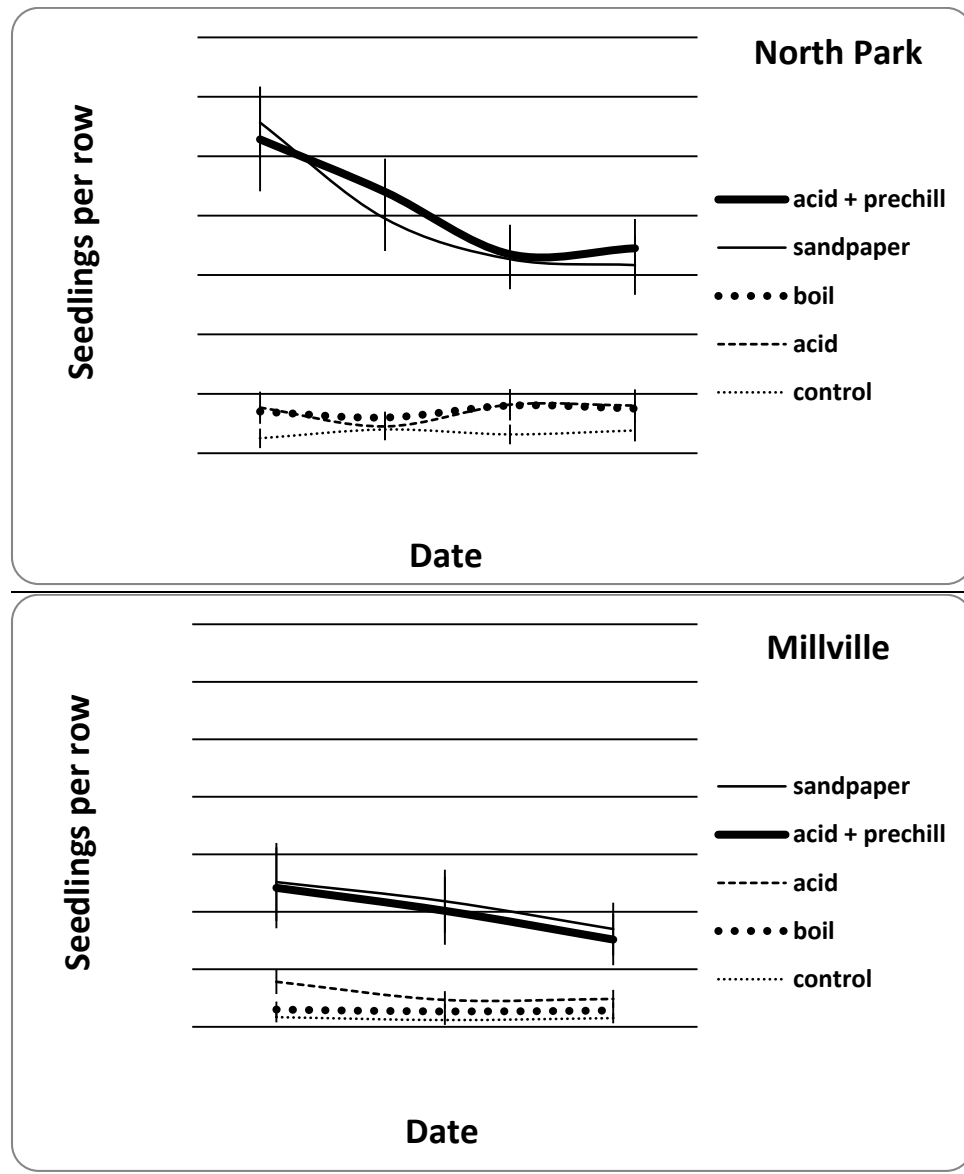


Figure 4. Mean seedling densities (seedlings per 5-m row) of NBR-1 basalt milkvetch and their standard errors for four seed treatments and an untreated control at four dates at North Park (A) and three dates at Millville (B). For both locations, the acid + pre-chilling and sandpaper treatments displayed similar seedling densities ($p > 0.05$), but both of these treatments displayed greater seedling density than 10-second boil, 5-minute 97% sulfuric acid, and control treatments ($p < 0.05$) (Jones et al. 2016).

Management Applications and Seed Production Guidelines

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

Presentations

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

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

Publications

Bushman, B. S.; Johnson, D. A.; Connors, K. J.; Jones, T. A. 2015. Germination and seedling emergence of three semiarid western North American legumes. *Rangeland Ecology and Management* 68: 501-506.

Johnson, D. A.; Bushman, B. S.; Connors, K. J.; Bhattarai, K.; Jones, T. A.; Jensen, K. B.; Parr, S. D.; Eldredge, E. P. 2015. Notice of release of Fanny Germplasm, Carmel Germplasm, and Bonneville Germplasm Searls' prairie clover: selected class of natural germplasm. *Native Plants Journal* 16: 265-275.

Jones, T. A.; Johnson, D. A.; Bushman, B. S.; Connors, K. J.; Smith, R. C. 2016. Seed dormancy mechanisms in basalt milkvetch and western prairie clover. *Rangeland Ecology and Management* 69. (Accepted 12/9/2015).

Additional Products

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

Project Title Breeding Biologies and Pollinators for Silverleaf Phacelia

Project Agreement No. 11-IA-11221632-010

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Project Description

Objectives

All of the wildflower species thus far studied for prospective plant community restoration in the Great Basin sage-steppe benefit from, or require, pollinators for ample fruit and seed production. Silverleaf phacelia, *Phacelia hastata* (Boraginaceae) is a widespread and widely adaptable perennial forb of the Intermountain West, Rockies and Sierra Nevada, found growing from sage-steppe to alpine habitats. We sought to evaluate its pollination needs and pollinators, both to inform seed growers as well as to evaluate its value to wild bee communities.

Methods

To evaluate this plant species' breeding biology, we first acquired seed from the Plant Material Center in Bridger, Montana. It was sourced from Anaconda Montana for mine tailing reclamation. When we directly seeded outside the fall before, seeds germinated readily but the tiny seedlings were easily lost to desiccation. After some trials, we developed an effective light soil mix and greenhouse propagation protocol for transplants. For the following years, transplants were installed in holes in weed barrier, and lightly shaded from sun damage with Reemay floating row cover for four weeks. Survivors came to bloom profusely the following year.

Our intent was to use hand pollinations to compare fruit and seed sets at flowering plants caged outside. We established 50 transplants that successfully wintered. They were caged before bloom and manually pollinated (selfing and outcrossing) to establish the species' breeding biology. Bloom was spectacular, enough to obscure foliage below. However, the flowers are small and worse, their stigmas are miniscule, with only enough surface area to receive a few dozen pollen grains. Even with magnifying visors, we struggled to see the stigma clearly when trying to apply self- or outcross pollen while hunched over on the ground in the cage. Probably as a consequence, our daily manual pollinations seemed rarely effective.

We therefore propagated a new set of transplants, but used a scheme to let bees do the pollinating. We transplanted trios and singletons of silverleaf phacelia on campus, at our

common garden, and at homes of colleagues with xeriscape gardens around Logan, UT. Singleton plants could only receive self-pollen from visiting bees whereas plant trios could be outcrossed by bees moving between plants. About 50% of the plants survived to flower and set seed. Racemes and spent flowers were persistent. We collected them when dry but before any losses. Dried flowers ($n = 2200$) were counted manually for 18 racemes taken from 18 plants. Kevin Connors at the USDA-ARS Forage and Range Lab then cleaned the samples individually with ease. I then manually counted the seeds.

To begin characterizing the pollinator fauna of silverleaf phacelia growing in the wild, several flowering populations in northern Utah and Nevada were sampled for floral visitors. We collected along haphazard transects counting all blooming individuals inspected, and collecting only those floral visitors seen on first glance (that is, not waiting for additional arrivals). Specimens were killed, pinned, labeled and identified. By this method, we can calculate densities of each bee species on a per plant basis and compare these values with the other 14 rangeland forbs that we have sampled in identical manner.

Results and Discussion

From 937 hand-pollinated flowers on 19 caged plants and 76 racemes, we only obtained 54 plump seeds (out of 3748 ovules, or a paltry 1.4% seed set). Clearly, the species does not auto-pollinate, but requires a pollinator's visit. With a new cohort of transplants, we then evaluated the need for outcrossing using outplanted singletons and trios of plants all accessible to free-flying pollinators. With bees doing the pollinating, the isolated singleton plants experienced 55% seed set (range 18-96%), or a seed for every two flowers. It is apparent that the species is self-fertile. Outcrossing yielded a somewhat higher average seed set (73%) but varied widely. Note that I calculate this on a per flower basis and not per ovule, as it is not apparent to me if all four ovules per flower can regularly yield a mature seed. From our data, I conclude that it is enough for a bee to visit the flowers of silverleaf phacelia for plentiful seed production.

Floral visitors were all bees plus one species of pollen wasp (*Pseudomasaris*). Of the 15 prevalent forbs whose pollinators we have sampled in the Great Basin, silverleaf phacelia is tied with *Lomatium dissectum* as the most intensely visited forb, with every 3rd plant hosting a wild bee (at the other extreme, compare with *Achillea*, which attracted one bee every 75 flowering plants). Flowering *P. hastata* attract a richly diverse bee fauna as well. From only 169 flowering individuals, we collected bees representing 13 genera of native bees, including species of bumblebees, *Osmia*, *Eucera* and *Anthidium*, bee genera that we see at many other flowering forbs in the sage-steppe and higher elevations in and around the Great Basin. We conclude that silverleaf phacelia has great potential for fostering diverse elements of Great Basin bee communities that are active in the late spring/early summer, with excellent prospects for commercial seed growing, harvest, cleaning, and later seeding into post-fire habitats.

Future plans

I will continue to seek out wild populations of *P. hastata* in the Great Basin from which to quantitatively sample their pollinator faunas, as from our small survey, it appears that the species attracts a particularly wide diversity of native bees in abundance.

Publications

Love, B.; Cane, J. H. [In press]. Direct effects of wildfire on a bee community: natural history and fire characteristics determine persistence. *Ecological Entomology*.

Cane, J. H.; Love, B. [In press]. Bee community preferences among common sage-steppe wildflowers developed for post-fire restoration. *Natural Areas Journal*.

Cane, J. H.; Tepedino, V. J. [In review]. Gauging the effect of honey bee pollen collection on native bee communities. *Ecol. Letters*.

Presentations

Cane, J. 2015. Understanding bees and some restoration forbs that feed them on the Colorado Plateau. Colorado Plateau Restoration Workshop; 29 April - 2 May; Moab, UT. Invited.

Management Applications and Seed Production Guidelines

Bees will be necessary for pollination of *P. hastata*. Without pollinators, seed set is 1% of its potential. In wild lands, the species attracts diverse bees that should be capable of pollination. In cultivation, honey bees seek this species avidly and should be good pollinators. Germination benefits from cold wet stratification. The tiny seedlings are very susceptible to desiccation and they may establish better under spun-bonded polyester row cover for the first spring.

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

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

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Project Description

Cushion Buckwheat

Cushion buckwheat (*Eriogonum ovalifolium*) is a mat forming perennial forb with distribution across the intermountain west in a wide variety of soils and plant communities in elevations from 650 - 4,120 m. Because of its wide distribution, there is potential for use of this species in revegetation and restoration efforts but there are limited amounts of commercially available seed. There is a need to assess the feasibility of seed production from this species over an extended period of time to identify populations that meet the production needs of growers, but are also adapted to the needs of revegetation and restoration projects. Seed production information will be assessed from a common garden in Ephraim, Utah. Drought tolerance adaptation will be assessed from a common garden at the Desert Experiment Range in southwest Utah.

Objectives

1. Assess seed production of multiple native collected accessions of cushion buckwheat and G1 production seed from those accessions to test if seed production is a heritable trait.
2. Evaluate drought tolerance of the same accessions with a common garden planted at the Desert Experimental Range.

Methods

In the fall of 2013 a common garden of the top 11 producing accessions (Table 1) from a prior common garden study, along with the first generation daughter plants (G1) of the same accessions, were planted on the Snow Field Station (SFS) in Ephraim, Utah and the Desert Experimental Range (DER) located in Millard County, Utah. The annual precipitation at the SFS

and DER is 13 inches and 6 inches, respectively (PRISM Climate Group 2015). At the SFS, ten plants of each accession and generation were planted in randomized blocks replicated four times. Seedlings were planted into weed barrier fabric and thoroughly watered in at the time of transplanting to minimize the effects of transplanting. No supplemental water was given after the initial transplant. The same layout was used at the DER, but the number of plants was reduced to five and no weed barrier fabric was used. Mortality, seed production and seed size were monitored on the Ephraim study site. Mortality was monitored on the DER site. Production was estimated by calculating the mean production of plants and extrapolating to a field setting with 6 inch spacing within the row and 2 foot row spacing.

Final Results and Discussion

The estimated mean production during the second growing season of 2015 ranged from 10.3 - 44.0 kg/ha (9.2-97.0 lbs/ha) (Figure 1). The highest producing accession in 2015 was U20-G1 and the lowest producing accession was U8-G1 in 2015. One accession (U13) had a significant difference between the production of the original collection generation compared with the production of the G1 generation (Figure 1). Accessions that had an estimated production greater than 25 kg/ha for both the original and G1 generations included U11, U20, U23, and U27 (Figure 1).

As was expected, survival was substantially higher on the SFS than at the DER. Only one accession (U9-G1) had less than 50% survival on the SFS, whereas all of the accessions on the DER had 50% or less survival (Figure 2). Three accessions (U11, U27, U30) had a significant difference between the survival of the original collection generation compared with the survival of the G1 generation on the DER, and four accessions (U11, U13, U20, U9) had a significant difference between survival on the SFS. In all but two accessions (U27 and U9) that showed significant difference in survival, survival was higher in the G1 generation than the original collection generation (Figure 2). Accessions that had a mean survival greater than 25% for both the original and G1 generations included U13, U20, U23, U29, and U9 (Figure 2).

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

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

The low seed production of the tested accessions suggests that cushion buckwheat has limited ability for commercial production. However, the common garden study was conducted under dryland conditions and production may be increased with increased resources such as irrigation

and fertilization. Our results also suggest that seed production remains similar across generations and is likely a heritable trait in this species.

Survival was generally good in the drought conditions found at the DER showing that this species is adapted to meet the needs of restoration in arid environments. In addition, several of the accessions with the highest survival at the DER (U20 and U23) also had some of the highest seed production (Figures 1 and 2). Survival was variable between generations in several accessions suggesting that drought tolerance may not be a heritable trait in this species (Figure 2).

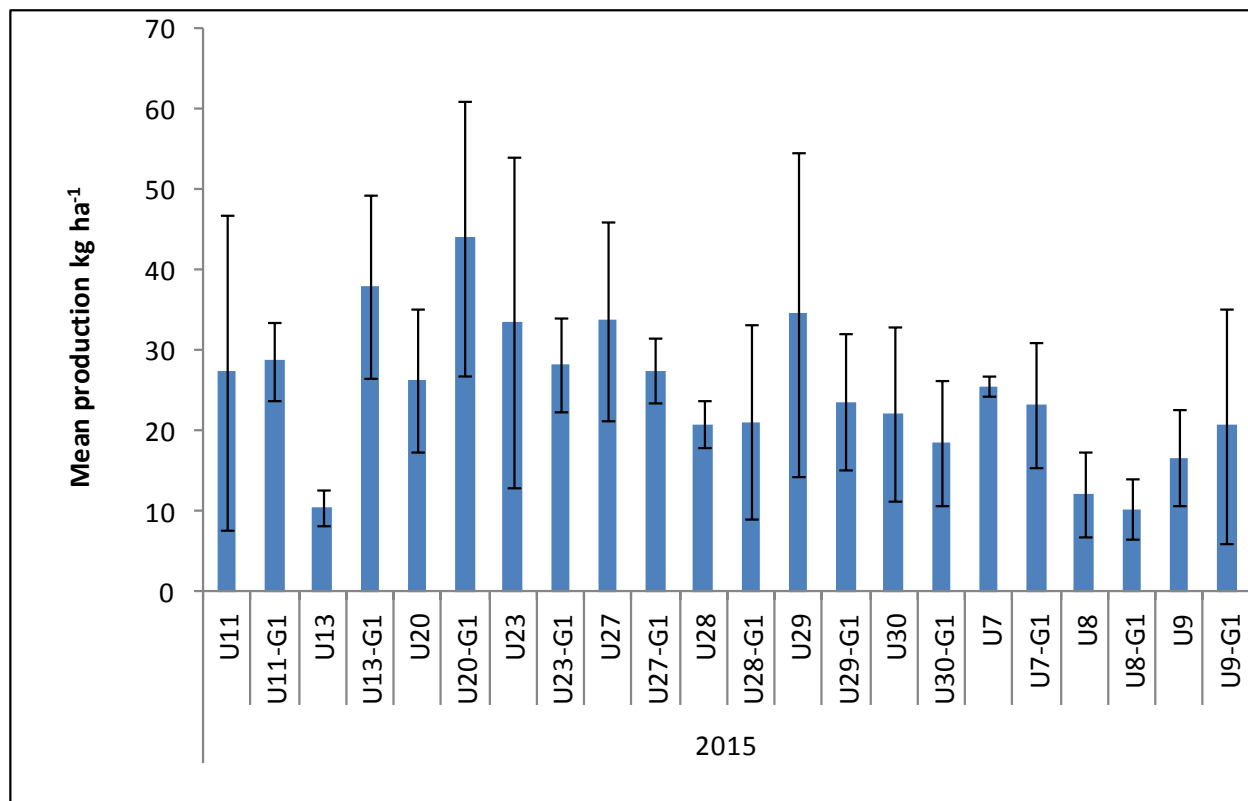


Figure 1. The 2015 mean ($\pm$ SE) estimated production of original and G1 generations of 11 different cushion buckwheat accessions on the Snow Field Station (SFS).

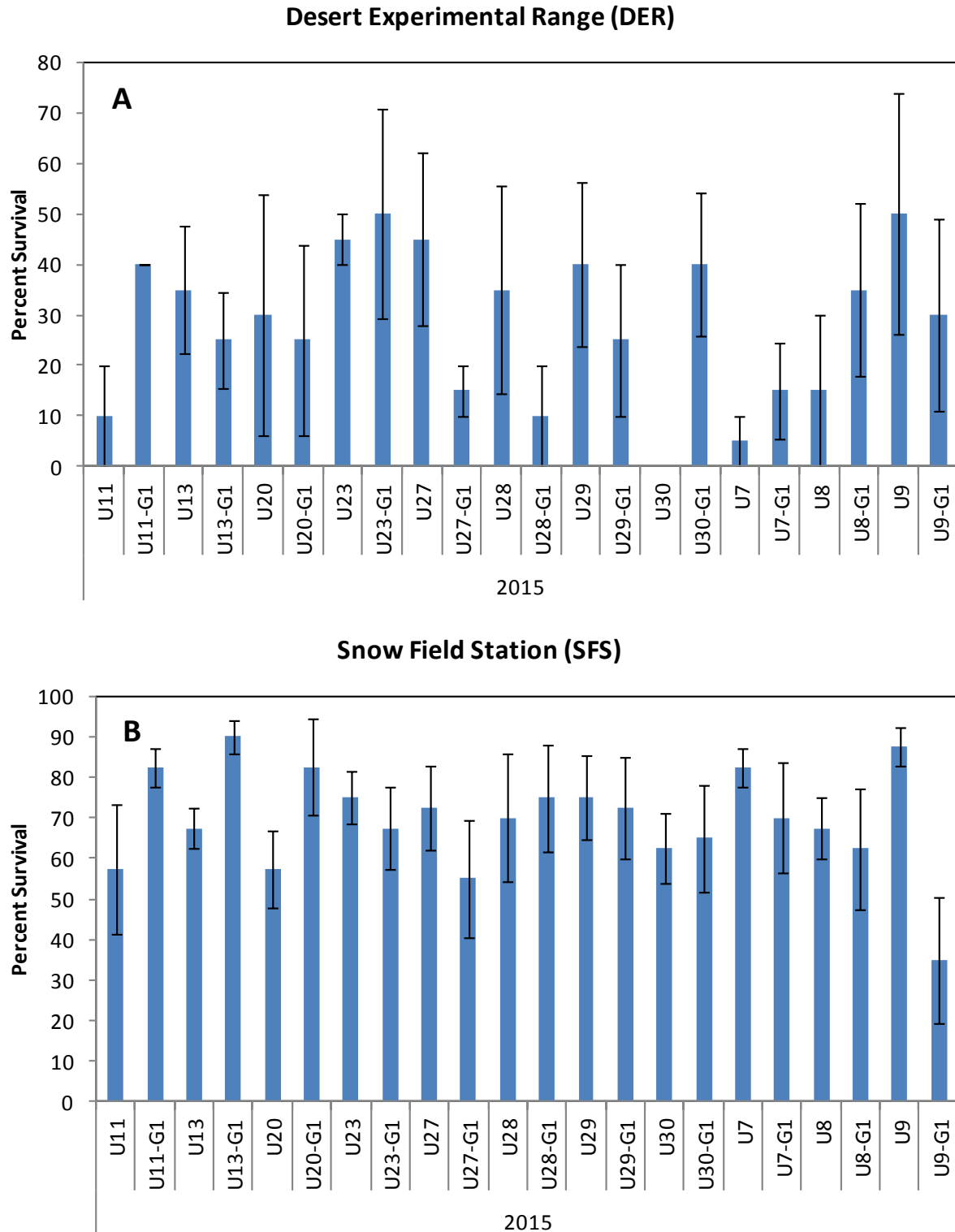


Figure 2. Mean ($\pm$ SE) 2 year survival of original and G1 generations of 11 accessions of cushion buckwheat on (A) the Desert Experiment Range (DER) and (B) the Snow Field Station (SFS).

Forb Island

Due to the high cost of native forb species land managers will be more discretionary about when and where they use this important plant material. The use of N-Sulate fabric (Dewitt Co.) on agronomic field plantings increased germination up to 1000 fold for some species. The fabric is light permeable, increases heat, and improves moisture retention during the germination period. Seed bed preparation combined with the use of N-Sulate fabric for added heat and moisture retention could improve germination and establishment in wildland settings. If germination and establishment of native forb species is increased with this methodology, there is the potential to use the method to create "islands" of plant material as a seed source for future natural dispersal across a restoration site.

Objectives

1. Assess the effects of N-Sulate fabric on the germination, establishment, and survival of 14 native forb species on four wildland sites.

Methods

The study was replicated at four sites: Hatch Ranch, Lookout Pass and Fountain Green sites are in the Great Basin, and the Gordon Creek site is in the Colorado Plateau. The annual precipitation for the Hatch Ranch, Lookout Pass, Fountain Green, and Gordon Creek sites are 13 inches, 13 inches, 12 inches, and 14 inches, respectively (PRISM Climate Group 2015). On each site two seed mixes (Table 2) and a control with covered and uncovered treatments were seeded in 1.5 x 7.6 m plots in a randomized block design with 5 replicated blocks. Plots were treated with a dixie harrow prior to seeding to remove standing plant material and prepare the seed bed. The study was replicated in 2009 and 2010 on all four sites. Density of seeded species and cover of cheatgrass (*Bromus tectorum*), annual weeds, and perennial grass was collected in twelve 0.25 m quadrats within each plot. Data was collected 1, 2, and 5 years post seeding. Seeded *Agoseris* species were combined in analysis due to difficulty in field identification.

Table 2. Seed mixes and seeding rate for N-Sulate forb island study.

Mix	Species Code	Scientific Name	Common Name	PLS m ⁻²
1	LIPE2	<i>Linum perenne</i>	blue flax 'Appar'	47.15
	POFE	<i>Poa fendleriana</i>	muttongrass	49.51
	CLSE	<i>Cleome serrulata</i>	rocky mountain beeplant	47.25
	LUAR3	<i>Lupinus argenteus</i>	silvery lupine	33.80
	SPGR2	<i>Sphaeralcea grossulariifolia</i>	gooseberryleaf globemallow	46.18
	BASA3	<i>Balsamorhiza sagittata</i>	arrowleaf balsamroot	41.87
	HEBO	<i>Hedysarum boreale</i>	northern sweetvetch 'Timp'	31.65
	PEPA6	<i>Penstemon pachyphyllus</i>	thickleaf penstemon	42.41
2	AGGR	<i>Agoseris grandiflora</i>	bigflower agoseris	31.75
	AGHE2	<i>Agoseris heterophylla</i>	annual agoseris	29.60
	NIAT	<i>Nicotiana attenuata</i>	coyote tobacco	43.06
	LONU2	<i>Lomatium nudicaule</i>	barestem biscuitroot	38.75
	ARMU	<i>Aremone munita</i>	flatbud pricklepoppy	39.93
	HEMUN	<i>Heliomeris multiflora nevadensis</i>	Nevada goldeneye	37.14
	THMI5	<i>Thelypodium milleflorum</i>	manyflower thelypody	35.95

Final Results and Discussion

Density was higher for seven of the seeded species on plots covered with N-Sulate fabric than those without in the first sample year. The greatest difference in initial germination was seen in blue flax and the *Agoseris* spp. However, there was no difference in density between treatments for any species after five years and six of the seeded species were not sampled in any plot. Blue flax, arrowleaf balsamroot, gooseberryleaf globemallow, Nevada goldeneye, and barestem biscuit root had the greatest survival over time, but survival did not appear to be influenced by treatment (Figure 3 and Figure 4). Site influenced effectiveness of the N-sulate fabric with the Gordon Creek, Hatch Ranch, and Lookout Pass sites displaying significant difference in the density of seeded species between covered and uncovered plots, but Fountain Green displaying no difference. The Hatch Ranch site had the largest difference between covered and uncovered plots after 1 year and also had the highest density in both treatments after five years (Figure 5). The weedy species cheatgrass (*Bromus tectorum*) was abundant on the Fountain Green and Lookout Pass sites. N-sulate fabric appears to have increased the cover of cheatgrass in the first sample years, but the effect was not observed in subsequent sample years (Figure 6).

The use of N-Sulate fabric in wildland settings has the potential to increase the initial germination of native forb species, but had limited impact on the long-term persistence of most species tested in this study. Site influences the success of the N-Sulate fabric treatment with indications that the method may be more effective on drier, hotter sites. Caution should be used on sites with weedy species as the method may also increase undesirable species which can compete with the desired species.

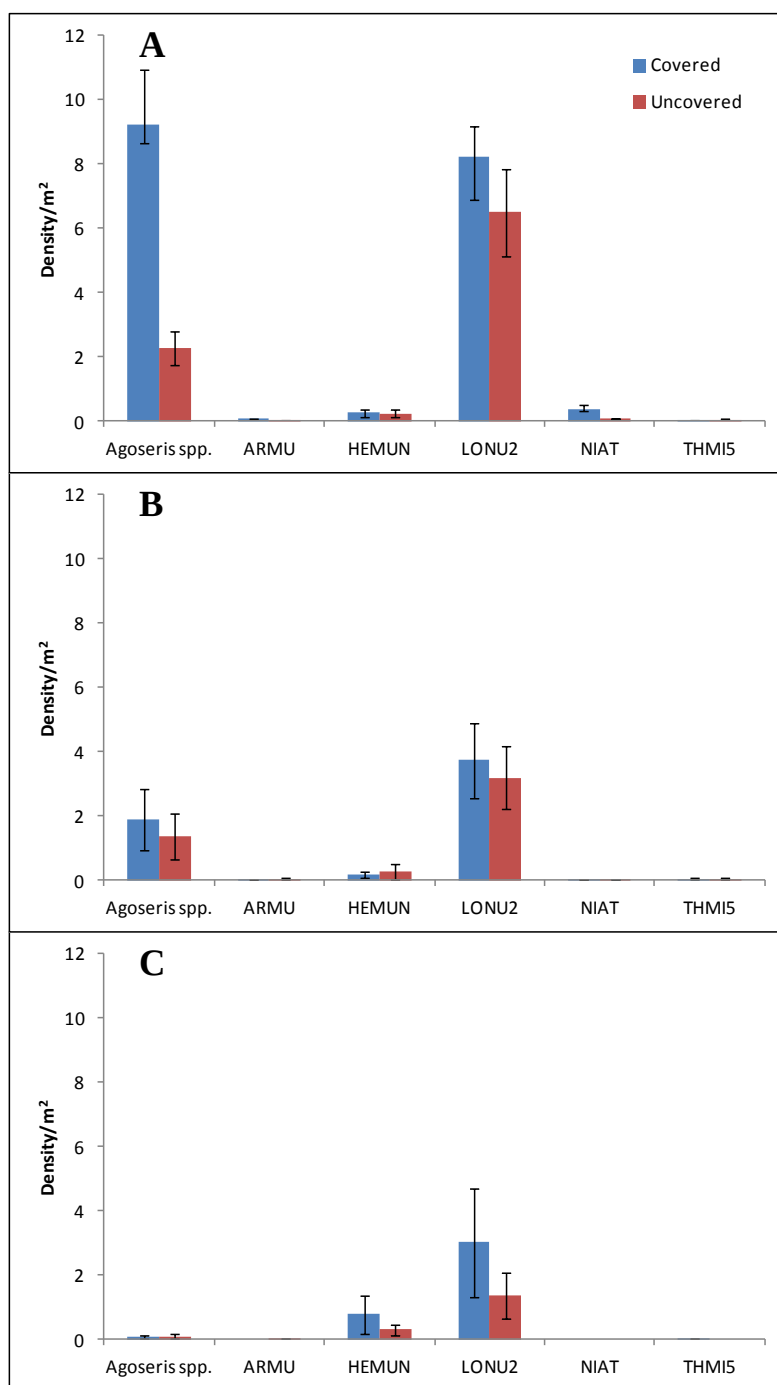


Figure 3. Mean density ($\pm$ SE) of mix 1 species for A) 1 year, B) 2 years, and C) 5 years post seeding.

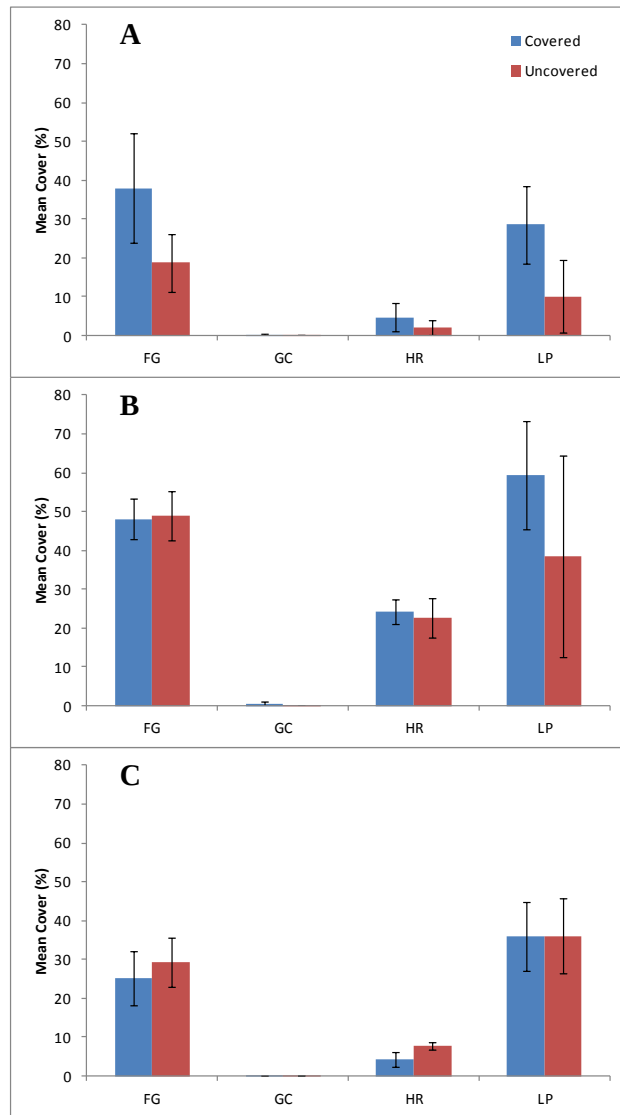


Figure 4. Mean density ($\pm$ SE) of mix 2 species for: A) 1 year, B) 2 years, and C) 5 years post seeding.

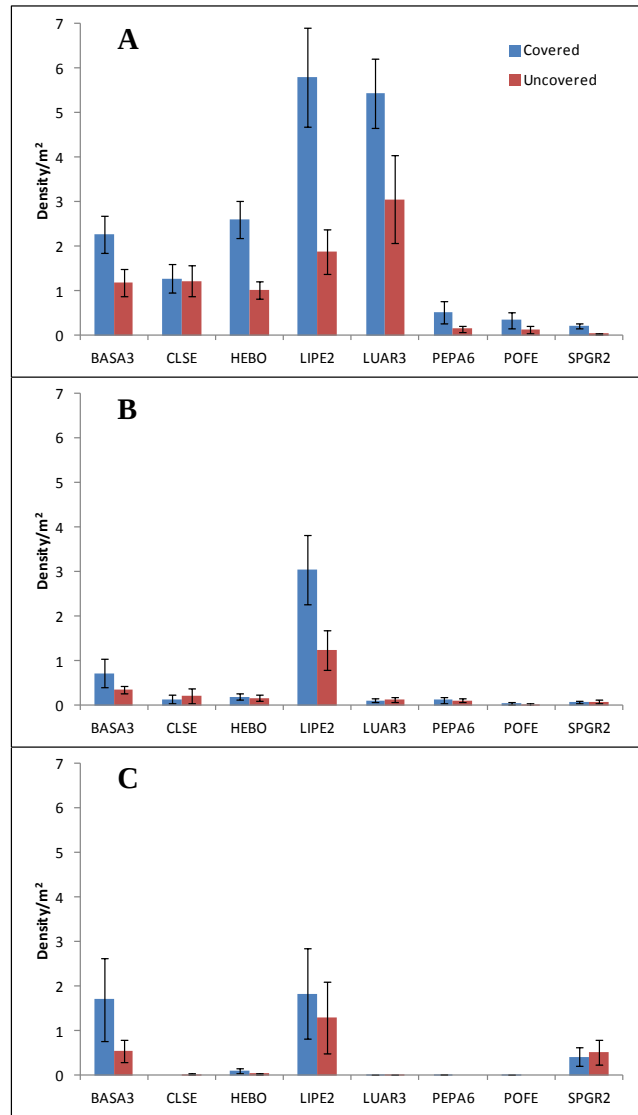


Figure 5. Mean density ($\pm$ SE) of seeded species by site for: A) 1 year, B) 2 years, and C) 5 years post seeding.

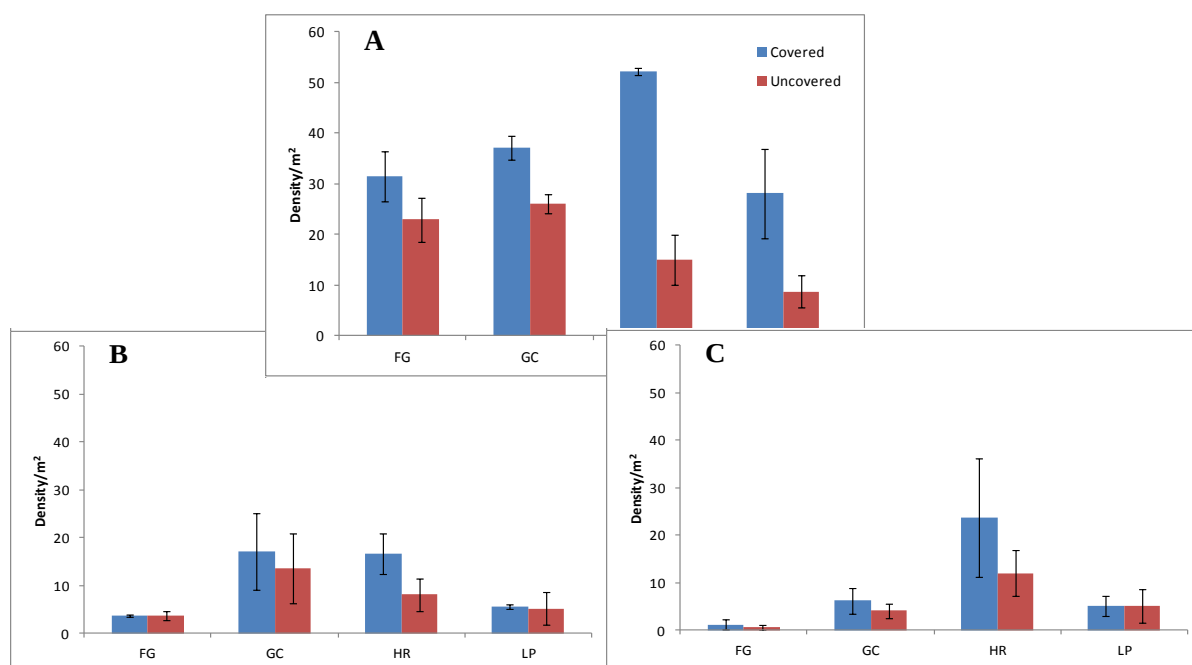


Figure 6. Mean cover of cheatgrass (*Bromus tectorum*) by site for: A) 1 year, B) 2 years, and C) 5 years post seeding.

Wildland Forb Seeding Methods

Currently, seed mixes used for restoration generally do not include native forb species, primarily due to their high cost. Because these species have not been included in past restoration efforts there is a lack of information about planting and establishing native forb species in wildland settings. As these native forbs become more available on the market, the lower costs should facilitate land manager's ability to include these species in seed mixes used for restoration. This creates a need to determine the best methods of establishing native forb species in wildland settings.

Objectives

1. Evaluate native forb establishment in Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) using four different mechanical planting methods; broadcast seeding followed by a Lawson aerator, Dixie harrow or Ely chain, and drill seeding.
2. Evaluate impact of treatments on other components of the community.

Methods

The study was established on two sites (referred to as North and South) in Tooele County, Utah. Annual precipitation at both sites is 330 mm (13 in) (PRISM Climate Group 2015). Five treatments were done in 30.5 x 45 m (100.1 x 147.6 ft) plots in a randomized block design with two blocks at each site. The study was replicated in 2008 and 2009 at each site. The five treatments include an untreated control, broadcast seeding followed by either a Lawson aerator, Dixie harrow or Ely chain, and drill seeding using a Truax Rough Rider no-till drill. Nine forb species were seeded (Table 3) on each treatment except the control. Density of perennial species, cover of all species, and basic ground cover was sampled in 100 random 0.25 m quadrats in each plot. Data was sampled 1 year, 2 years, and 6 years post treatment.

Table 3. Seed mix and seeding rate for the wildland forb seeding methods study.

Species Code	Scientific Name	Common Name	PLS m ⁻²
ASUT	<i>Astragalus utahensis</i>	Utah milkvetch	21.85
BASA3	<i>Balsamorhiza sagittata</i>	arrowleaf balsamroot	24.54
CRAC2	<i>Crepis acuminata</i>	tapertip hawksbeard	5.17
HEBO	<i>Hedysarum boreale</i>	northern sweetvetch	6.46
LIPE2	<i>Linum perenne</i>	blue flax 'Appar'	65.01
LUAR3	<i>Lupinus argenteus</i>	silvery lupine	2.91
PEPA8	<i>Penstemon palmeri</i>	palmer penstemon	52.31
PEEA	<i>Penstemon eatonii</i>	firecracker penstemon	34.23
SPMU2	<i>Sphaeralcea munroana</i>	munro globemallow	46.50

Final Results and Discussion

Because of different sowing rates, results for seeded species are presented in percentages of sampled density to seeded density for each species. Munro's globemallow (*Sphaeralcea munroana*) was excluded from results because it was present prior to seeding and we were unable to differentiate seeded plants from naturally occurring plants. Total survival of all seeded species was less than 6% on all treatments. The harrow and chain treatments had the highest survival in the first and second years following treatment, but long term persistence was higher on the aerator treatment six years after treatment. The drill treatment had the lowest survival in all sample years (Figure 7). Site also influenced survival of species with the total survival of seeded species much higher in all sample years on the north site (Figure 8).

The effect of the mechanical treatments on individual species survival varied. Blue flax (*Linum perenne*) had the highest survival of any species on all four treatment types in all sample years. Utah milkvetch (*Astragalus utahensis*) had the highest emergence on the harrow treatments one year after treatment, but survival was similar to the chain treatment two years after treatment and both the chain and aerator treatment six years after treatment. Northern sweetvetch (*Hedysarum boreale*) had the highest germination on the chain treatment one year after treatment, but survival declined in subsequent years. Arrowleaf balsamroot (*Balsamorhiza sagittata*) had limited survival the first year, but survival increased and was similar on all treatments by the sixth year after treatment. Silvery lupine (*Lupinus argenteus*) had good survival on all treatments in the initial year following treatment, but was not sampled six years after treatment on any treatment plot. Palmer penstemon (*Penstemon palmeri*) and firecracker penstemon (*P. eatonii*) had very low survival on all treatments, but survival was lowest on the drill treatment and similar on all other treatments. Tapertip hawksbeard (*Crepis acuminata*) had almost no survival on any treatment (Figure 7).

The effect of the mechanical treatments on other components in the community is an important consideration. Wyoming big sagebrush cover was affected differently by each of the treatments. The Dixie harrow treatment had the highest reduction in sagebrush cover followed by the Lawson aerator, Ely chain, while the Truax drill had limited reduction on sagebrush cover the first year after treatment. Sagebrush cover increased in each subsequent sample year on all treatments including the control, but the effect of treatment remained the same in all sample years (Figure 9). The treatments with the highest disturbance (i.e., harrow, drill, and aerator) also

exhibited higher cover of cheatgrass (*Bromus tectorum*) than the drill treatment and control plots in all sample years (Figure 10).

The results from the study show that survival of seeded forb species can be improved in a Wyoming big sagebrush community with the appropriate seeding methodology. However, selection of the best methodology is contingent on a number of factors including: species to be seeded, objectives in sagebrush reduction, and weedy species that may be released.

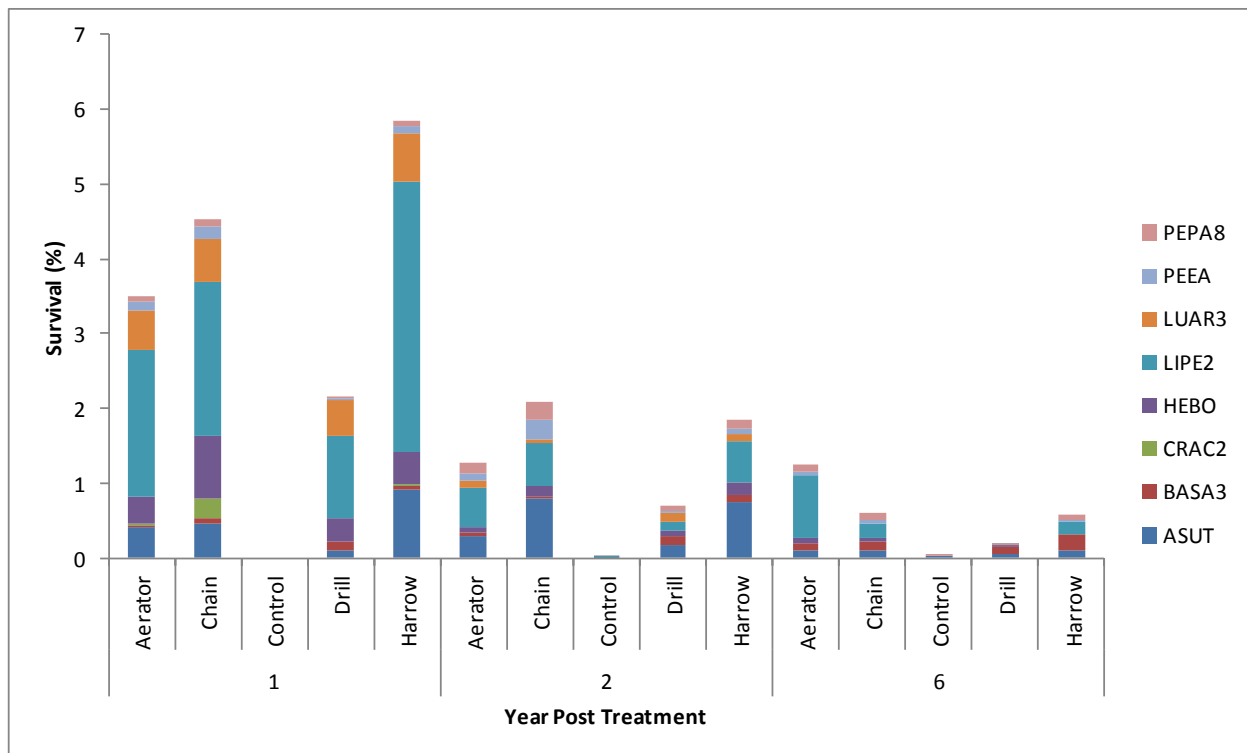


Figure 7. Mean survival of seeded forb species by treatment and year post treatment.

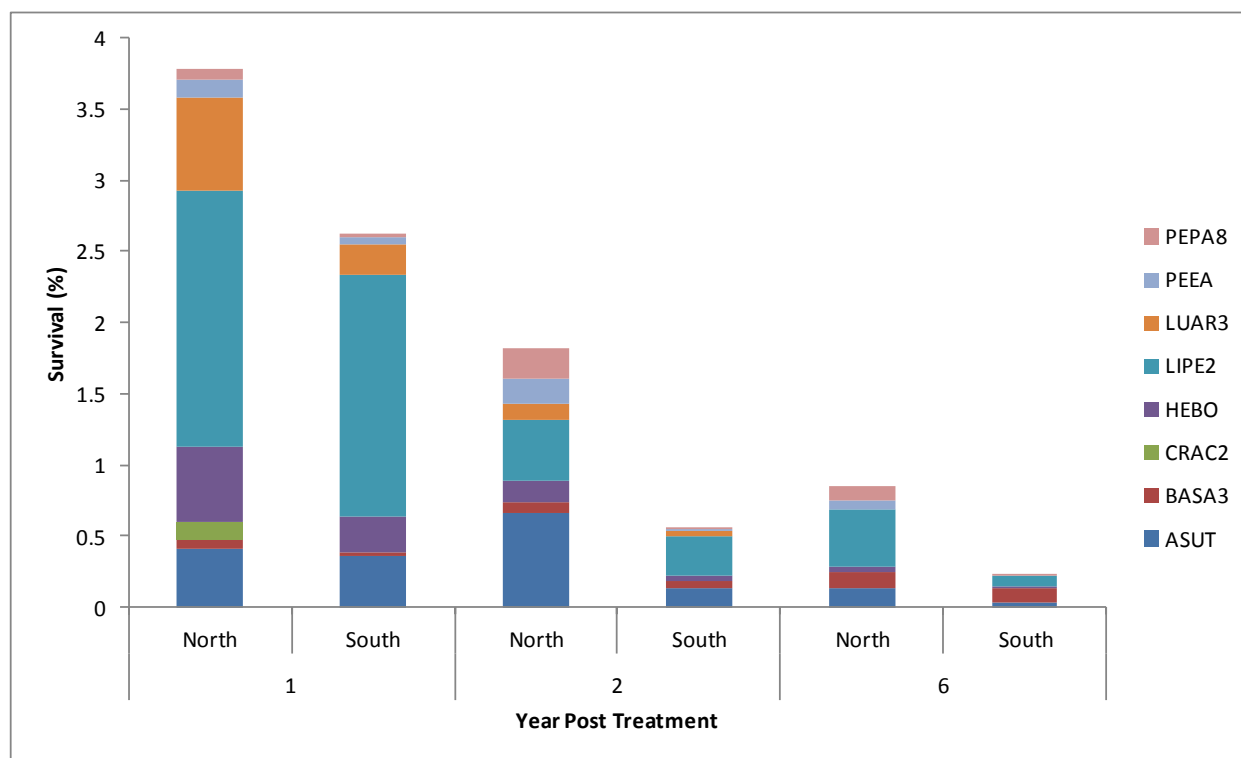


Figure 8. Mean survival of seeded species for all treatments by site and year post treatment.

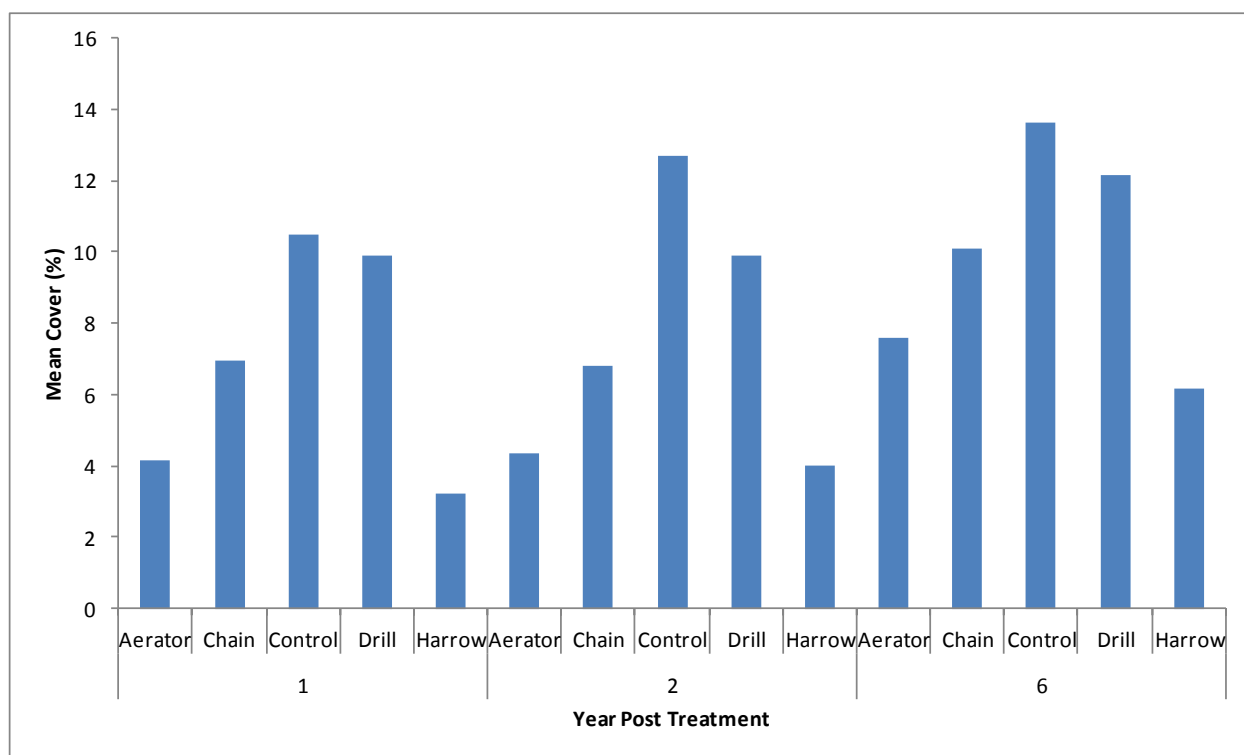


Figure 9. Mean cover of Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) by treatment and year post treatment.

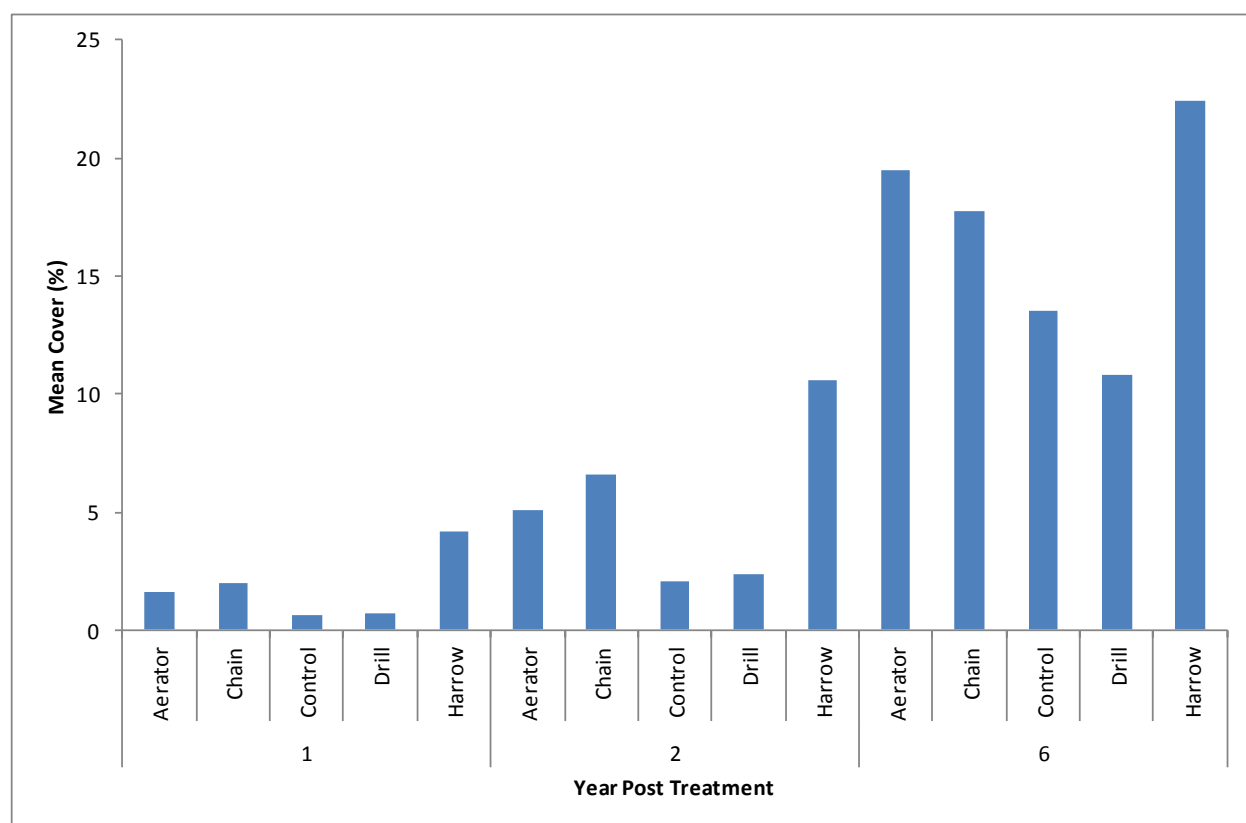


Figure 10. Mean cover of cheatgrass (*Bromus tectorum*) by treatment and year post treatment.

Native Seed Increase

Objectives

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

Methods

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

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

Results

Seed from 11 species with 57 accessions were harvested in 2015 (Table 4). Four species with 33 different accessions was seeded or transplanted into increase beds in the spring or fall of 2015

(Table 5). The foundation field of UDWR Tetra Great Basin wildrye was expanded by clonally splitting mature plants and transplanting rootstock into randomized plots.

Table 4. Native species harvested in 2015.

Code	Species	# of Accessions	Location
ASFI	<i>Astragalus filipes</i>	1	Ephraim
ARMAF	<i>Arenaria macradenia ferrisea</i>	1	Ft. Green
ASTER	<i>Aster sp.</i>	1	Ft. Green
CRAC2	<i>Crepis acuminata</i>	3	Ft. Green
CRYPT	<i>Cryptantha sp.</i>	1	Ft. Green
DAOR2	<i>Dalea ornata</i>	1	Ephraim
ENNUN	<i>Enceliopsis nudicaulis</i>	3	Ft. Green
HEMUN	<i>Heliomeris multiflora nevadensis</i>	5	Ft. Green
LECI4	<i>Leymus cinereus</i>	30*	Ephraim
HECO26	<i>Hesperostipa comata</i>	7	Ft. Green
PEPA6	<i>Penstemon pachyphyllus</i>	4	Ft. Green

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

Table 5. Native species sown in 2015.

Code	Species	# of Accessions	Location
HEMUN	<i>Heliomeris multiflora nevadensis</i>	5	Ft. Green
PEPA6	<i>Penstemon pachyphyllus</i>	17	Ft. Green`
LILEL2	<i>Linum lewisii lewisii</i>	10	Ft. Green
IPAG	<i>Ipomopsis aggregata</i>	1	Ft. Green

Presentations

Gunnell, Kevin L. 2015. Update of native plant research and activities at the Great Basin Research Center, Ephraim, UT. Great Basin Native Plant Project Annual Meeting; 2015 February 17-19; Boise, ID.

References

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Project Title Plant Material Work at the Shrub Science Lab

Project Agreement No. 13-IA-11221632-161

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Project Description

Wildland Seed Collection

Seed collection efforts in 2015 (Table 1) were focused on harvesting specific populations of thistleleaf penstemon (*Penstemon pachyphyllus*), Nevada showy goldeneye (*Heliomeris multiflora* var. *nevadensis*), skyrocket gilia (*Ipomopsis aggregata*) and basin wildrye (*Leymus cinereus*) where additional seed is needed for current increase projects.

Table 1. Species and number of sources collected in 2015.

Family	Common Name	# Collections
Asteraceae	Nevada showy goldeneye	7
Polemoniaceae	skyrocket gilia	5
Scrophulariaceae	thistleleaf penstemon	7
Poaceae	Basin wildrye	6

The Effect of Sowing Depth on Establishment of 20 Forbs Native to the Great Basin

Objectives

Evaluate the effect of field planting depth in loam textured soils on seedling emergence for 20 forbs native to the Great Basin.

Results and Discussion

This study was initially implemented in 2013 and fully replicated in fall 2014. In 2015, persistence data has been collected on the 2013 plantings and emergence data has been collected on the 2014 planting. Data collection is complete for this study. Analysis is ongoing.

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

Objectives

In section one of this study we evaluate a leading surrogate, provisional seed zones (PSZ) (Bower et al. 2014, Kramer et al. 2015) as a method for matching basin wildrye source populations to representative restoration sites.

As the locally adapted model of matching seed supplies to restoration sites is relatively new in large scale restoration efforts and in direct competition with the agricultural cultivar model (Jones 2009), common basin wildrye cultivars are included in the trial. In section two of this study we compare establishment success between pooled local populations and commercially available basin wildrye cultivars.

The cultivars Magnar and Trailhead (USDA 2012a, b) originate from regions outside the Great Basin but have historically been seeded extensively in the intermountain west. To our knowledge Great Basin populations have not been extensively evaluated for cultivar potential. In section three of this study we use a ‘pick the winner’ approach, emphasizing establishment ability to evaluate whether any individual regional source shows merit following the cultivar model of sourcing plant materials.

In section four of this study we evaluate how the population level characteristics of ploidy, seed weight, clean-out percentage, and viability relate to establishment.

This study was initially implemented in 2013 and fully replicated in fall 2014. In 2015, persistence data was collected on the 2013 plantings and emergence data collected on 2014 plantings. Establishment data will be collected in the spring of 2016, wrapping up this phase of the study.

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

This is a multiagency cooperative study assessing seed and ground treatments to improve forb establishment. Rocky Mountain Research Station involvement in this study includes locating, preparing and maintaining the Spanish Fork test site, selection and preparation of 10 native forb species and associated seed treatments totaling 33 combinations, weather station acquisition and deployment, and supplying tractor and seeder to install the study. The study was installed at three sites in Utah and Idaho. For complete details see Douglas A. Johnson’s write up in this report.

Presentations

Jensen, S. L. 2015. Field testing generalized seed zones with basin wildrye (*Leymus cinereus*). Great Basin Consortium Conference; 2015 February 17-19; Boise, Idaho.

Jensen, S. L. 2015. Field testing generalized seed zones with basin wildrye (*Leymus cinereus*). National Native Seed Conference 2015; Native Plant Materials Development, Production & Use in Habitat Restoration; 2015 April 13-16; Santa Fe, New Mexico.

Jensen, S. L. 2015. Native forbs for restoration: the utility of provisional seed zones. Field testing generalized seed zones with basin wildrye (*Leymus cinereus*). Utah Chapter of the Society for Range Management; 2015 November 5-6; Moab, Utah.

Additional Products

- In cooperation with the Utah Division of Wildlife Resources, Great Basin Research Center (GBRC) greenhouse grown plugs of: 12 sources of thickleaf penstemon from seed zone (15 - 20 Deg. F. / 3 – 6); two sources of Nevada showy goldeneye from seed zone (15 - 20 Deg. F. / 6 – 12); and three sources of Lewis flax (*Linum lewisii*) from zone (15 - 20 Deg. F. / 6 – 12) were transplanted into increase beds at the Fountain Green farm facility. Future seed harvests from these beds will serve as stock seed for these species/zone combinations for distribution to commercial producers.
- Additional seed from 2015 or prior year wildland collections for 16 sources was provided to UDWR to grow additional plugs to augment increase beds.
- Two species, thickleaf penstemon and yellow beeplant (*Cleome lutea*) were provided to Utah State University extension specialist Kevin Heaton in Garfield County, UT for seed increase. We anticipate expanding this relationship with additional seed increase efforts in future years.
- Seed of two species, skyrocket gilia and cleftleaf wildheliotrope (*Phacelia crenulata* var. *corrugata*) were provided to Malheur Experiment Station for cultural practice studies.
- Seed of 40 species was provide to USDA FS Region 4 to initiate a pollinator display garden at the Ruby Mountains and Jarbidge Ranger Station in Wells, NV.
- 10 bulk pounds of Blue penstemon (*Penstemon cyaneus*) was sent to L&H seed to establish increase fields.
- 110 bulk pounds of gooseberry leaf globemallow (*Sphaeralcea grossulariifolia*) was scarified for Jerry Erstrom of Quarter Circle J Seeds to increase the size of an existing production field.

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USDA- Natural Resource Conservation Service. 2012b. Trailhead Basin Wildrye Release Brochure. Aberdeen, ID: U.S. Department of Agriculture, Natural Resources Conservation Service, Aberdeen Plant Materials Center. 2 p.

Project Title Native Plant Selection, Release Development, and Information Transfer

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

Principal Investigators and Contact Information

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Project Description

The Aberdeen Plant Materials Center (PMC) was involved with the testing and selecting of accessions of native forbs for commercial release, and with developing protocols for plant and seed production. The PMC also developed NRCS Plant Guides for select species.

Hoary Tansyaster

Nine accessions of hoary tansyaster (*Machaeranthera canescens*) were evaluated from 2009 through 2011 for establishment, plant growth and seed production. Accession 9076670 had the best establishment and stands for 2009 and 2010. It also had the best rated vigor in 2010. This accession also had the tallest plants in the study. The population for 9076670 is located near the St. Anthony Sand Dunes in Fremont County, Idaho at 1,524 m (5,000 ft) elevation. The site has sandy soils and supports a bitterbrush (*Purshia tridentata*), Indian ricegrass (*Achnatherum hymenoides*), rabbitbrush (*Ericameria nauseosa*), and scurfpea (*Psoralidium* sp.) plant community. The location receives between 250 and 380 mm (10 to 15 in) of mean annual precipitation. In 2014, accession 9076670 was officially released as Amethyst Germplasm hoary tansyaster.

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

Wyeth or Whorled Buckwheat

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

Initial seed increase of accession 9076546 is ongoing. Release documentation is being developed, and official release will occur once the PMC has produced a sufficient amount of early generation seed. This year, the PMC produced a good quantity of seed which should be enough to supply initial demand.

Douglas Dustymaiden

Fifteen accessions of Douglas' dustymaiden (*Chaenactis douglasii*) were evaluated at Aberdeen PMC from 2009 to 2010 for establishment, growth and seed production. Following evaluation, accession 9076577 was chosen for further production and possible release. Accession 9076577 was originally collected in Boise County, Idaho near Arrow Rock and Lucky Peak Reservoirs. The site is a mountain big sagebrush/bitterbrush community in coarse granitic soils at 960 m (3,150 ft) elevation. Accession 9076577 ranked at or near the top in percent establishment, plant vigor, height, flower production and seed yield.

Seed increase plots of accession 9076577 were established at the PMC for early generation certified seed production in 2011, 2012 and 2013 with the intent to make a selected class germplasm release once the PMC had produced a sufficient amount of early generation seed. Due to repeated low establishment in seed production plantings the Douglas dustymaiden project was discontinued.

Flail-Vac Modifications

We have examined several techniques for harvesting light airborne seed such as that of hoary tansyaster. Direct combining takes relatively little time in the field, however this method yields correspondingly less seed due to the limitation of only getting a single harvest. Additionally it requires significantly more time to clean the seed compared to other methods because of the large amounts of inert matter collected.

In 2013 we harvested hoary tansyaster using a standard Woodward Flail-Vac seed stripper. The Flail-Vac was set to harvest approximately the top 20 to 30 cm (8 to 12 in) of the plants. We got two harvests using the Flail-Vac which yielded a total of 3.3 kg (7.3 lb), equivalent to 13.7 kg/ha (12.2 lb/ac). Only two harvests were possible because of the destructive nature of the Flail-Vac brush on the plants.

In 2015 we experimented with two modifications to the standard Flail-Vac harvester in an attempt to increase seed yields. We compared rigid pipes mounted to the Flail-Vac hood which penetrated into the plant canopy, to loops of chain that could be dragged through the plants. The Flail-Vac head itself was elevated above the plants so the brush did not come in contact with the flowers. The pipes or chains agitated the plants causing the release of seed into the air, while the airflow created by the Flail-Vac brushes sucked the light seed through and into the collection bin.

There were significant differences in performance of the two methods, though both were more effective than the standard Flail-Vac. Rigid pipes were more damaging to the plants than desirable. Plants got hung up on the pipes and pulled until they were uprooted or broken. We had to stop the tractor regularly to lift the arms and remove broken stems and plants from the front of the Flail-Vac; however, the seed yields were promising. The pipes effectively agitated the plant canopy and shook loose, ripe seed from the flowers and left non-ripe flowers and vegetation intact. The chain had enough weight to fall into the canopy and displace seed, but was less rigid

and caused very little, if any, damage. We experienced no broken stems or uprooted plants using the chain method.

Best results for hoary tansyaster occurred driving the tractor very slowly, between 0.87 and 1.1 km/h (1.4 and 1.8 mph) with the Flail-Vac set at 400 rpm. Lower brush speeds resulted in insufficient air flow, while higher speeds caused increasing amounts of seed to be sucked completely through the Flail-Vac and blown out the exhaust opening.

We were able to run the chain-modified Flail-Vac eight times through a 0.4 ha (1 ac) hoary tansyaster field. Each harvest was run in the opposite direction as the previous. Immediately after a Flail-Vac pass the plants were left leaning over from the weight of the heavy chain, but after a day or two they had regained their upright attitude. From our eight harvests we collected a total of 29 kg (64 lb) of clean seed, a 500% increase compared to the non-modified Flail-Vac.

Plant Guides

NRCS Plant Guides have been developed for 21 species of forbs and grasses native to the Intermountain West. Plant Guides offer the most recent information on plant establishment, management, and seed and plant production information. General information for the species can also be found in our Plant Guides including: information on potential uses, ethnobotanical significance, adaptation, pests, and potential problems. Plant guides are available at the PLANTS database, www.plants.usda.gov, and at the Aberdeen Plant Materials Center website: www.id.nrcs.usda.gov/programs/plant.html.

Propagation Protocols

Seed production information obtained during collection evaluation and seed increase of native forb species was used to develop propagation protocols for Douglas' dustymaiden, hoary tansyaster, nineleaf biscuitroot, fernleaf biscuitroot and Gray's biscuitroot and Searls' prairie clover. These protocols provide information on seed collection, planting, management, harvest, and cleaning. Propagation protocols are available at <http://www.nativeplantnetwork.org>.

Publications

Ogle, Dan; Peterson, Scott; St. John, Loren. 2014. Plant guide for Rocky Mountain penstemon, *Penstemon strictus* Benth. Aberdeen, ID: U.S. Department of Agriculture, Natural Resources Conservation Service, Aberdeen Plant Materials Center. 4 p.

Tilley, Derek. 2014. Release brochure for Amethyst germplasm hoary tansyaster, *Machaeranthera canescens* (Pursh) A. Gray. Aberdeen, ID: U.S. Department of Agriculture, Natural Resources Conservation Service, Aberdeen Plant Materials Center. 2 p.

Tilley, Derek. 2015. Seed production and field establishment of hoary tansyaster (*Machaeranthera canescens*). *Native Plants Journal* 16(1): 61-66.

Tilley, Derek. 2015. Notice of release of Amethyst Germplasm hoary tansyaster: selected class of natural germplasm. *Native Plants Journal* 16(1): 55-60.

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

Additional Products

- Early generation certified seed of Amethyst Germplasm hoary tansyaster is in production, and allocations have been made to Utah Crop Improvement and Idaho Foundation Seed Program.
- Early generation certified seed of Wyeth buckwheat is being produced and will be available through Utah Crop Improvement and University of Idaho Foundation Seed Program when release is approved.

Project Title 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:

1. Irrigation Requirements for Native Buckwheat Seed Production in a Semi-arid Environment
2. Irrigation Requirements for Seed Production of Five *Lomatium* Species in a Semi-Arid Environment
3. Irrigation Requirements for Seed Production of Five Native *Penstemon* Species in a Semi-Arid Environment
4. Prairie Clover and Basalt Milkvetch Seed Production in Response to Irrigation
5. Native Beeplant (*Cleome* spp.) Seed Production in Response to Irrigation in a Semi-Arid Environment
6. Irrigation Requirements for Seed Production of Various Native Wildflower Species started in the Fall of 2012
7. Direct Surface Seeding Systems for the Establishment of Native Plants in 2015

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

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 Malheur Experiment Station
 Oregon State University, Ontario, OR 2015

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Summary

Native buckwheats (*Eriogonum* spp.) are important perennials in the Intermountain West. Buckwheat seed are desired for rangeland restoration activities, but little cultural practice information is available for seed production of native buckwheat. The seed yield of *Eriogonum umbellatum* and *E. heracleoides* were evaluated over multiple years in response to four biweekly irrigations applying either 0, 1 inch of water, or 2 inches of water (total of 0, 4 inches, or 8 inches/season). *Eriogonum umbellatum* seed yield was maximized by 5 to 8 inches of water applied per season in warmer, drier years and no irrigation was needed in cooler, wetter years. Averaged over ten years, seed yield of *Eriogonum umbellatum* was maximized by 6.5 inches of water applied per season. Over five seasons, seed yield of *Eriogonum heracleoides* was only responsive to irrigation in 2013, a dry year when seed yield was maximized by 4.9 inches of applied water.

Introduction

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

is stable and consistent seed productivity over years. In native rangelands, the natural variations in spring rainfall and soil moisture result in highly unpredictable water stress at flowering, seed set, and seed development, which for other seed crops is known to compromise seed yield and quality. Native wildflower plants are not well adapted to croplands. They often are not competitive with crop weeds in cultivated fields. Poor competitiveness with weeds could also limit wildflower seed production. Both sprinkler and furrow irrigation could provide supplemental water for seed production, but these irrigation systems risk further encouraging weeds. Also, sprinkler and furrow irrigation can lead to the loss of plant stand and seed production due to fungal pathogens. By burying drip tapes at 12-inch depth and avoiding wetting the soil surface, 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 *Eriogonum umbellatum* (Sulphur-flower buckwheat) and *Eriogonum heracleoides* (Parsnipflower buckwheat).

Materials and Methods

Plant Establishment

Seed of *Eriogonum umbellatum* was received in late November in 2004 from the Rocky Mountain Research Station (Boise, ID). The plan was to plant the seed in the fall of 2004, but due to excessive rainfall in October, the ground preparation was not completed and planting was postponed to early 2005. To try to ensure germination, the seed was submitted to cold stratification. The seed was soaked overnight in distilled water on January 26, 2005, after which the water was drained and the seed soaked for 20 minutes 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, 2005, seed of *Eriogonum umbellatum* was planted in 30-inch rows using a custom-made small plot grain drill with disc openers. All seed was planted at 20-30 seeds/ft of row at 0.25-inch depth. The trial was irrigated with a minisprinkler system from March 4 to April 29 (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 0.10 inch/hour. A total of 1.72 inches of water was applied with the mini sprinkler system. *Eriogonum umbellatum* 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 *Eriogonum umbellatum* were uneven. *Eriogonum umbellatum* did not flower in 2005. In early October, 2005 more seed was received from the Rocky Mountain Research Station for replanting. The empty lengths of row were replanted by hand. 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 *Eriogonum heracleoides*. On November 25, 2009 seed of *Eriogonum heracleoides* was planted in 30-inch rows using a custom-made plot grain drill with disk openers. All seed was planted on the soil surface at 20-30 seeds/ft of row. After planting, sawdust was applied in a narrow band over the seed row at 0.26 oz/ft of row (558 lb/acre). Following planting and sawdust application, the beds were covered with row cover. The row cover (N-sulate, DeWitt Co., Inc., Sikeston, MO) covered four rows (two beds) and was applied with a mechanical plastic mulch layer. The field was irrigated for 24 hours on December 2, 2009 due to very dry soil conditions.

After *Eriogonum heracleoides* had emerged, the row cover was removed in April, 2010. The irrigation treatments were not applied to *Eriogonum heracleoides* in 2010. Stands of *Eriogonum heracleoides* 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 percent sawdust and 50 percent hydro seeding mulch (Hydrostraw LLC, Manteno, IL) by volume. The mulch mixture was sprayed with water using a backpack sprayer.

Irrigation for Seed Production

The planted strips were divided into plots 30 ft long (*Eriogonum umbellatum* in April 2006 and *Eriogonum heracleoides* 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 4 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. Irrigation dates are found in Table 1.

Flowering, Harvesting, and Seed Cleaning

Flowering dates for each species were recorded (Table 1). The *Eriogonum umbellatum* plots produced seed in 2006, in part because they had emerged in the spring of 2005. *Eriogonum heracleoides* 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. *Eriogonum umbellatum* and *Eriogonum heracleoides* seeds did not separate from the flowering structures in the combine. In 2006, the unthreshed seed of *Eriogonum umbellatum* was taken to the U.S. Forest Service Lucky Peak Nursery (Boise, ID) and run through a dewinger to separate seed. The seed was further cleaned in a small clipper seed cleaner. 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.

Cultural Practices

On October 27, 2006, 50 lb phosphorus (P)/acre and 2 lb zinc (Zn)/acre were injected through the drip tape to all plots of *Eriogonum umbellatum*. On November 17, 2006, November 9, 2007, and April 15, 2008, all plots of *Eriogonum umbellatum* had Prowl® at 1 lb ai/acre broadcast on the soil surface for weed control. On March 18, 2009, Prowl at 1 lb ai/acre and Volunteer® at 8 oz/acre were broadcast on all *Eriogonum umbellatum* plots for weed control. On December 4, 2009 and November 17, 2010, Prowl at 1 lb ai/acre was broadcast on all plots of *Eriogonum umbellatum*. On November 9, 2011 and November 7, 2012 Prowl at 1 lb ai/acre was broadcast

on all plots of both species. On April 3, 2013, Select Max at 32 oz/acre was broadcast for grass weed control on all plots of *Eriogonum umbellatum*. On February 26, 2014, Prowl at 1 lb ai/acre and Select Max at 32 oz/acre were broadcast on all plots of both species. On March 13, 2015, Prowl at 1 lb ai/acre was broadcast on all plots of both species. In addition to herbicides, weeds were controlled with hand weeding as necessary.

Table 1. *Eriogonum umbellatum* and *Eriogonum heracleoides* flowering, irrigation, and seed harvest dates by species in 2006-2015. Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	Year	Flowering dates			Irrigation dates		Harvest
		Start	Peak	End	Start	End	
<i>Eriogonum umbellatum</i>	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
<i>Eriogonum heracleoides</i>	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

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 of 5.8 inches. Precipitation from January through June in 2007, 2008, 2013, and 2015 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, and 2015 were higher than average (Table 2). Both buckwheats flowered and were harvested earlier in 2013-2015 than in 2011-2012 (Table 1), consistent with more early season growing degree days (Table 2).

Seed Yields

Eriogonum umbellatum, Sulfur-flower Buckwheat

In 2006, seed yield of *Eriogonum umbellatum* increased with increasing water application, up to 8 inches, the highest amount tested (Tables 3 and 4). In 2007-2009 seed yield showed a quadratic response to irrigation rate. Seed yields were maximized by 8.1 inches, 7.2 inches, and 6.9 inches of water applied in 2007, 2008, and 2009, respectively. In 2010, there was no significant difference in yield between the irrigation treatments. In 2011, seed yield was highest with no irrigation. The 2010 and 2011 seasons had unusually cool (Table 2, Fig. 2) and wet weather (Fig. 2). The 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 *E. umbellatum* in the non-irrigated treatment in 2010 and 2011 seemed to be related to the high spring precipitation. The negative effect of irrigation on seed yield in 2011 might have been related to the presence of rust. Irrigation could have exacerbated the rust and resulted in lower yields. In 2012, seed yield of *Eriogonum umbellatum* increased with increasing water application, up to 8 inches, the highest amount tested. In 2013 and 2014, seed yields showed quadratic responses to irrigation rate. Seed yield was maximized by 5.7 inches and by 5.3 inches of water applied in 2013 and 2014, respectively. In 2015, seed yields were not responsive to irrigation. Averaged over 10 years, seed yield of *E. umbellatum* showed a quadratic response to irrigation rate with the highest yield achieved with 6.5 inches of water applied.

Eriogonum heracleoides, Parsnip-flower Buckwheat

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, and 2015 (Tables 3 and 4). Averaged over 5 years, seed yield of *E. heracleoides* showed a quadratic response to irrigation rate with the highest yield achieved with 5.2 inches of water applied. Seed yields peaked in 2013 and have declined over the last two years, possibly due to loss of stand.

Conclusions

The total irrigation requirements for these arid-land species were low and varied by species. *Eriogonum heracleoides* only responded to irrigation 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 *E. umbellatum* responded to irrigation in 7 of the 10 years, with quadratic responses to irrigation rate varying from 0 to 8 inches, depending on year. Buckwheat flowering and harvests have been earlier in 2013-2015, probably due to warmer weather.

Table 2. Early season precipitation and growing degree-days at the Malheur Experiment Station, Ontario, OR, 2006-2015.

Year	Precipitation (inches)		Growing degree-days (50-86°F)
	Jan-June	April-June	Jan-June
2006	9	3.1	1273
2007	3.1	1.9	1406
2008	2.9	1.2	1087
2009	5.8	3.9	1207
2010	8.3	4.3	971
2011	8.3	3.9	856
2012	5.8	2.3	1228
2013	2.6	1.4	1319
2014	5.1	1.6	1333
2015	4.8	2.7	1575
72-year average	5.8	2.7	1178 ^a

^a22-year average.

Table 3. *Eriogonum umbellatum* and *Eriogonum heracleoides* seed yield in response to irrigation rate (inches/season) in 2006 through 2015. Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	Year	Irrigation rate			LSD (0.05)
		0 inches	4 inches	8 inches	
		----- lb/acre -----			
<i>Eriogonum umbellatum</i>	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
	Average	158.8	217.4	224.1	28.5
<i>Eriogonum heracleoides</i>	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
	Average	169.3	275.8	247.8	58.9

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

Table 4. Regression analysis for *Eriogonum umbellatum* and *Eriogonum heracleoides* 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: $-b/2c$, where b is the linear parameter and c is the quadratic parameter. Malheur Experiment Station, Oregon State University, Ontario, OR.

<i>Eriogonum umbellatum</i>							Maximum seed yield	Water applied for maximum yield
Year	intercept	linear	quadratic	R ²	P		lb/acre	inches/season
2006	137.9	27.8		0.68	0.01		360	8
2007	79.6	28.3	-1.8	0.69	0.05		194	8.1
2008	121.3	34.6	-2.4	0.73	0.01		246	7.2
2009	132.3	31.9	-2.3	0.6	0.05		243	6.9
2010	252.9	9.2	-1.8	0.08	NS ^a			
2011	232.7	-16		0.58	0.01		233	0
2012	61.2	30.5	-1.9	0.65	0.01		185	8.1
2013	113.2	45.2	-4	0.62	0.05		241	5.7
2014	257	74.2	-7	0.76	0.01		454	5.3
2015	140.0	-5.7		0.11	NS			
Average	158.8	21.2	-1.6	0.75	0.01		228	6.5

<i>Eriogonum heracleoides</i>							Maximum seed yield	Water applied for maximum yield
Year	intercept	linear	quadratic	R ²	P		lb/acre	inches/season
2011	61.7	-0.8		0.01	NS			
2012	271.5	1.8		0.01	NS			
2013	287.4	96.7	-9.8	0.64	0.05	525		4.9
2014	297.6	27.2	-3.8	0.08	NS			
2015	83.6	27.5	-2.8	0.29	NS			
Average	169.3	43.4	-4.2	0.71	0.01	282		5.2

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

Acknowledgements

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

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Summary

Lomatium species are important 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 inch of water, or 2 inches of water (total of 0, 4 inches, or 8 inches/season) was evaluated for four *Lomatium* species over multiple years starting in 2007. Over seven seed production seasons, *Lomatium dissectum* (fernleaf biscuitroot) seed yield was maximized by 5 to 6 inches of water applied per season in cooler, wetter years and by 8 inches of water applied per season in warmer, drier years. Over nine seed production seasons, *Lomatium grayi* (Gray's biscuitroot) seed yield was maximized by 0 to 5 inches of water applied per season in cooler, wetter years and by 5 to 8 inches of water applied per season in warmer, drier years. Over nine seed production seasons, *Lomatium triternatum* (Nineleaf biscuitroot) seed yield was maximized by 4 to 8 inches of water applied per season in cooler, wetter years and by 8 inches of water applied per season in warmer, drier years. Over four seed production seasons, *Lomatium nudicaule* (barestem biscuitroot) seed yield did not respond to irrigation. In the two seed production seasons observed, seed yield of *Lomatium suksdorfii* (Suksdorf's desert parsley) responded to irrigation in 2015.

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

Native wildflower plants are not well adapted to croplands. They often are not competitive with crop weeds in cultivated fields. Poor competitiveness with weeds could also limit wildflower seed production. 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, Oregon State University, 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 desert parsley

Materials and Methods

Plant Establishment

Seed of *Lomatium dissectum*, *L. grayi* and *L. triternatum* was received in late November in 2004 from the Rocky Mountain Research Station (Boise, ID). The plan was to plant the seed in the fall of 2004, but due to excessive rainfall in October, 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 *Lomatium grayi* and *L. triternatum* had started to sprout.

In late February 2005, drip tape (T-Tape TSX 515-16-340) was buried at 12-inch depth between two 30-inch rows of a Nyssa silt loam with a pH of 8.3 and 1.1% 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 in Table 1 was planted in 30-inch rows using a custom-made plot grain drill with disc openers. All seed was planted at 20-30 seeds/ft of row. The seed was planted 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 0.10 inch/hour. A total of 1.72 inches of water was applied with the minisprinkler system. *Lomatium triternatum*, and *L. grayi* 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 *Lomatium triternatum*, and *L. grayi* were uneven. *Lomatium dissectum* did not emerge. None of the species flowered in 2005. In early October, 2005 more seed was received from the Rocky Mountain Research Station for replanting. The plots had the entire row lengths replanted using the planter on October 26, 2005. In the spring of 2006, the plant stands of the replanted species were excellent.

On November 25, 2009 seed of *L. nudicaule*, *L. suksdorfii*, and three selections of *L. dissectum* (LODI 38, LODI 41, and seed from near Riggins, ID) was planted in 30-inch rows using a custom-made plot grain drill with disk openers. All seed was planted on the soil surface at 20-30 seeds/ft of row. After planting, sawdust was applied in a narrow band over the seed row at 0.26 oz/ft of row (558 lb/acre). Following planting and sawdust application, the beds were covered with row cover. The row cover (N-sulate, DeWitt Co., Inc., Sikeston, MO) covered four rows (two beds) and was applied with a mechanical plastic mulch layer. The field was irrigated for 24 hours on December 2, 2009 due to very dry soil conditions.

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 4 irrigations that were 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 lb phosphorus (P)/acre and 2 lb zinc (Zn)/acre were injected through the drip tape to all plots. On November 11, 100 lb 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 8 oz/acre were broadcast on all plots for weed control. On April 9, 50 lb N/acre and 10 lb P/acre were applied through the drip irrigation system to the three *Lomatium* spp.

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 lb 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 lb N/acre, 10 lb 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 lb N/acre, 25 lb 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 lb N/acre, 25 lb 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 lb N/acre, 25 lb 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.

Table 2. *Lomatium* flowering, irrigation, and seed harvest dates by species in 2006-2015. Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	Year	Flowering			Irrigation		Harvest
		Start	Peak	End	Start	End	
<i>Lomatium dissectum</i>	2006				19-May	30-Jun	
	2007				5-Apr	24-Jun	
	2008				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)
<i>Lomatium grayi</i>	2006				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
<i>Lomatium triternatum</i>	2006				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)
<i>Lomatium nudicaule</i>	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
<i>Lomatium suksdorfii</i>	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

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 of 5.8 inches. Precipitation from January through June in 2007, 2008, 2013, and 2015 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, and 2015 were higher than average (Table 2). The high accumulated growing degree days in 2015 probably caused early harvest dates (Table 2).

Table 3. Early season precipitation and growing degree-days at the Malheur Experiment Station, Ontario, OR, 2006-2015.

Year	Precipitation (inches)		Growing degree-days (50-86°F)
	Jan-June	April-June	Jan-June
2006	9	3.1	1273
2007	3.1	1.9	1406
2008	2.9	1.2	1087
2009	5.8	3.9	1207
2010	8.3	4.3	971
2011	8.3	3.9	856
2012	5.8	2.3	1228
2013	2.6	1.4	1319
2014	5.1	1.6	1333
2015	4.8	2.7	1575
72-year average	5.8	2.7	1178 ^a

^a22-year average.

Flowering and Seed Set

Lomatium grayi and *L. triternatum* started flowering and producing seed in 2007 (2nd year after fall planting in 2005, Tables 2 and 4). *Lomatium dissectum* started flowering and producing seed in 2009 (4th year after fall planting in 2005). *Lomatium nudicaule* started flowering and produced seed in 2012 (3rd year after fall planting in 2009). *Lomatium suksdorfii* started flowering and produced seed in 2013 (4th year after fall planting in 2009).

Seed Yields

Lomatium dissectum, Fernleaf Biscuit Root

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

Seed yield of *L. dissectum* had linear responses to irrigation rate in 2009 (Tables 4 and 6). Seed yield with the 4-inch irrigation rate was significantly higher than with the non-irrigated check, but the 8-inch irrigation rate did not result in a significant increase above the 4-inch rate. In 2010 and 2011, seed yields of *L. dissectum* showed a quadratic response to irrigation rate. Seed yields were estimated to be maximized by 5.4 and 5.1 inches of applied water in 2010 and 2011, respectively. In 2012, seed yields of *L. dissectum* were not responsive to irrigation. In 2013, 2014, and 2015 seed yield increased linearly with increasing irrigation rate up to 8 inches, the

highest amount applied. Averaged over the 7 years, seed yield showed a quadratic response to irrigation rate and was estimated to be maximized at 930 lb/acre/year by applying 6.5 inches of applied water.

Lomatium dissectum Riggins Selection

The Riggins selection *L. dissectum* started flowering in 2013, but only in small amounts. Seed yields of Riggins selection *L. dissectum* showed a quadratic response to irrigation rate in 2014 (Tables 5 and 7). Seed yields were estimated to be maximized by 4.8 inches of applied water in 2014. Seed was inadvertently not harvested in 2015.

Lomatium dissectum Selections 38 and 41

L. dissectum 38 and 41 started flowering in 2013, but only in small amounts. Seed yields of *L. dissectum* 38 were not responsive to irrigation in 2014 and 2015 (Tables 5 and 7). Seed yields of *L. dissectum* 41 were not responsive to irrigation in 2014. In 2015, seed yields of *L. dissectum* 41 showed a quadratic response to irrigation rate (Tables 5 and 7). Seed yields of *L. dissectum* 41 were estimated to be maximized by 4.9 inches of applied water in 2015.

Lomatium grayi, Gray's Biscuitroot

Lomatium grayi showed a trend for increasing seed yield with increasing irrigation rate most years (Tables 4 and 6). The highest irrigation rate resulted in significantly higher seed yield than the non-irrigated check in six of the last eight years. Seed yields of *L. grayi* were substantially higher in 2008 and 2009.

In 2008, seed yields of *L. grayi* showed a quadratic response to irrigation rate. Seed yields were estimated to be maximized by 6.9 inches of water applied in 2008. In 2009, seed yield showed a linear response to irrigation rate. Seed yield with the 4-inch irrigation rate was significantly higher than in the non-irrigated check, but the 8-inch irrigation rate did not result in a significant increase above the 4-inch rate.

In 2010, seed yield was not responsive to irrigation, possibly caused by the unusually wet spring of 2010. Rodent damage was a further complicating factor in 2010 that compromised seed yields. Extensive rodent (vole) damage occurred over the 2009-2010 winter. The affected areas were transplanted with 3-year-old *L. grayi* plants from an adjacent area in the spring of 2010. To reduce their attractiveness to voles, the plants were mowed after becoming dormant in early fall of 2010 and in each subsequent year.

In 2011, seed yield again did not respond to irrigation. The spring of 2011 was unusually cool and wet.

In 2012, seed yields of *L. grayi* showed a quadratic response to irrigation rate, with a maximum seed yield at 5.5 inches of applied water.

In 2013, seed yield increased linearly with increasing water application, up to 8 inches, the highest amount applied.

In 2014, seed yields of *L. grayi* showed a quadratic response to irrigation rate, with a calculated maximum seed yield of 1477 lb/acre at 5.3 inches of applied water.

In 2015, seed yields of *L. grayi* showed a quadratic response to irrigation rate, with a calculated maximum seed yield of 579 lb/acre at 4.3 inches of applied water.

Over 9 years, seed yield of *L. grayi* was estimated to be maximized at 797 lb/acre/year by 5.2 inches of applied water. Most appropriately, irrigation probably should be variable according to precipitation.

Lomatium nudicaule, Barestem Biscuitroot

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

Lomatium triternatum, Nineleaf Biscuitroot

Lomatium triternatum showed a trend for increasing seed yield with increasing irrigation rate most years (Tables 4 and 6). The highest irrigation rate resulted in significantly higher seed yield than the non-irrigated check in seven of the last eight years. Seed yields of *L. triternatum* were substantially higher in 2008-2011.

In 2008–2011 seed yields of *L. triternatum* showed a quadratic response to irrigation rate. Seed yields were estimated to be maximized by 8.4, 5.4, 7.8, and 4.1 inches of water applied in 2008, 2009, 2010, and 2011, respectively.

Each year from 2012 through 2015 seed yield increased linearly with increasing water applied up to the highest amount of water applied, 8 inches.

Over 9 years, seed yield of *L. triternatum* was estimated to be maximized at 1273 lb/acre/year at 7.7 inches of applied water.

Lomatium suksdorfii, Suksdorfii Desert Parsley

Lomatium suksdorfii started flowering in 2013, but only in small amounts. Seed yields of *L. suksdorfii* were not responsive to irrigation in 2014 (Tables 5 and 7). In 2015, seed yield increased linearly with increasing water applied up to the highest amount of water applied, 8 inches.

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. *Lomatium grayi* and *L. triternatum* had reasonable seed yields starting in the second year. *L. dissectum* and *L. nudicaule* were productive in their fourth year, while *L. suksdorfii* 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). *Lomatium nudicaule* did not respond to irrigation in these trials. Natural rainfall was sufficient to

maximize seed production for *L. nudicaule* in the absence of weed competition. *Lomatium dissectum* required approximately 6 inches of irrigation. *Lomatium grayi* and *L. triternatum* responded quadratically to irrigation with the optimum varying by year.

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Table 4. Seed yield response to irrigation rate (inches/season) for four *Lomatium* species in 2006 through 2015. Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	Year	Irrigation rate				Species	Year	Irrigation rate			
		0 inches	4 inches	8 inches	LSD (0.05)			0 inches	4 inches	8 inches	LSD (0.05)
<i>Lomatium dissectum</i>		----- lb/acre -----				<i>Lomatium grayi</i>		----- 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
7-year average		392.0	851.3	899.5	95.1	9-year average		445.1	778.2	696.5	227.2

Species	Year	Irrigation rate				Species	Year	Irrigation rate			
		0 inches	4 inches	8 inches	LSD (0.05)			0 inches	4 inches	8 inches	LSD (0.05)
<i>Lomatium nudicaule</i>		----- lb/acre -----				<i>Lomatium triternatum</i>		----- lb/acre -----			
	2010	---- no flowering ----					2006	---- no flowering ----			
	2011	---- no flowering ----					2007	2.3	17.5	26.7	16.9 ^b
	2012	53.8	123.8	61.1	NS		2008	195.3	1060.9	1386.9	410
	2013	357.6	499.1	544	NS		2009	181.6	780.1	676.1	177
	2014	701.3	655.6	590.9	NS		2010	1637.2	2829.6	3194.6	309.4
	2015	430.6	406.1	309.3	NS		2011	1982.9	2624.5	2028.1	502.3 ^b
4-year average		376.3	421.1	385.8	NS		2012	238.7	603	733.2	323.9
							2013	153.7	734.4	1050.9	425
							2014	240.6	897.1	1496.7	157
							2015	403.2	440.8	954.9	446.6
						9-year average		559.5	1109.8	1271.0	156.7

^bLSD (0.10)

Table 5. Seed yield response to irrigation rate (inches/season) for two *Lomatium* species in 2014 and 2015. Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	Year	Irrigation rate			LSD (0.05)
		0 inches	4 inches	8 inches	
<i>Lomatium dissectum</i> Riggins selection	2014	276.8	497.7	398.4	163
<i>Lomatium dissectum</i> selection 38					
	2014	281.9	356.4	227.1	NS
	2015	865.1	820.9	774.6	NS
	2-year average	573.5	588.6	432.9	NS
<i>Lomatium dissectum</i> selection 41					
	2014	222.2	262.4	149.8	NS
	2015	152.2	561.9	407.4	181.4
	2-year average	187.2	412.1	278.6	167.4
<i>Lomatium suksdorfii</i>					
	2014	162.6	180.0	139.8	NS
	2015	829.6	1103.9	1832.0	750.2
	2-year average	496.1	642.0	1208.6	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 - 2015, and 2- to 9-year averages. For the quadratic equations, the amount of irrigation that resulted in maximum yield was calculated using the formula: $-b/2c$, where b is the linear parameter and c is the quadratic parameter. Malheur Experiment Station, Oregon State University, Ontario, OR.

<i>Lomatium dissectum</i>							
Year	intercept	linear	quadratic	R ²	P	Maximum seed yield	Water applied for maximum yield
						lb/acre	inches/season
2009	86.4	34.6		0.31	0.10	363	8.0
2010	265.8	109.8	-10.1	0.68	0.01	564	5.4
2011	567.5	319.3	-31.4	0.86	0.001	1379	5.1
2012	402.7	7.0		0.04	NS		
2013	565.3	79.9		0.65	0.01	1204	8.0
2014	392.7	126.9		0.82	0.001	1408	8.0
2015	628.2	98.1		0.76	0.001	1413	8.0
Average	392.0	166.2	-12.8	0.94	0.001	930	6.5
<i>Lomatium grayi</i>							
Year	intercept	linear	quadratic	R ²	P	Maximum seed yield	Water applied for maximum yield
						lb/acre	inches/season
2007	37.5	12.0		0.26	0.10	134	8.0
2008	393.3	315.4	-23.0	0.93	0.001	1475	6.9
2009	378.7	40.8		0.38	0.05	705	8.0
2010	1035.7	95.3	-17.1	0.22	NS		
2011	608.2	-27.8		0.07	NS		
2012	231.9	68.1	-6.2	0.66	0.01	419	5.5
2013	635.6	55.0		0.25	0.10	1075	8.0
2014	533.1	354.0	-33.2	0.64	0.05	1477	5.3
2015	186.4	181.3	-20.9	0.71	0.01	579	4.3
Average	445.1	135.1	-13.0	0.59	0.05	797	5.2
<i>Lomatium nudicaule</i>							
Year	intercept	linear	quadratic	R ²	P	Maximum seed yield	Water applied for maximum yield
						lb/acre	inches/season
2012	75.9	0.9		0.01	NS		
2013	373.7	23.3		0.1	NS		
2014	704.5	-13.8		0.08	NS		
2015	442.7	-15.2		0.15	NS		
Average	399.2	-1.2		0.01	NS		
<i>Lomatium triternatum</i>							
Year	intercept	linear	quadratic	R ²	P	Maximum seed yield	Water applied for maximum yield
						lb/acre	inches/season
2007	3.3	3.1		0.52	0.01	28	8.0
2008	195.3	283.9	-16.9	0.77	0.01	1388	8.4
2009	181.6	237.4	-22.0	0.83	0.001	822	5.4
2010	1637.2	401.5	-25.9	0.83	0.001	3193	7.8
2011	1982.9	315.1	-38.7	0.45	0.10	2624	4.1
2012	277.8	61.8		0.49	0.05	772	8.0
2013	197.7	112.2		0.66	0.01	1095	8.0
2014	249.6	157.4		0.97	0.001	1509	8.0
2015	323.8	69.0		0.51	0.01	875	8.0
Average	559.5	186.2	-12.2	0.85	0.001	1272	7.7

^a Not 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 2014 and 2015 for *Lomatium suksdorfii* and three selections of *L. dissectum* 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, Oregon State University, Ontario, OR.

<i>Lomatium suksdorfii</i>							
Year	intercept	linear	quadratic	R ²	P	Maximum seed 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	1756.4	8.0
Average	171.7	-2.5		0.01	NS		
<i>Lomatium dissectum</i> 'Riggins'							
Year	intercept	linear	quadratic	R ²	P	Maximum seed yield lb/acre	Water applied for maximum yield inches/season
2014	276.8	95.2	-10	0.57	0.05	503.5	4.8
<i>Lomatium dissectum</i> '38'							
Year	intercept	linear	quadratic	R ²	P	Maximum seed yield lb/acre	Water applied for maximum yield inches/season
2014	281.9	44.1	-6.4	0.11	NS		
2015	865.4	-11.3		0.01	NS		
Average	573.5	25.1	-5.3381	0.11	NS		
<i>Lomatium dissectum</i> '41'							
Year	intercept	linear	quadratic	R ²	P	Maximum seed yield lb/acre	Water applied for maximum yield inches/season
2014	222.2	29.1	-4.8	0.13	NS		
2015	152.2	172.9	-17.6291	0.67	0.01	576.3	4.9
Average	187.2	101.0	-11.2012	0.43	0.1	415.1	4.5

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

Species	Optimum amount of irrigation	Years to first	
		seed set	Life span
	inches/season	from fall planting	years
<i>Lomatium dissectum</i>	5 in wet years, 8 in dry years	4	9+
<i>Lomatium grayi</i>	0 in wet years, 5 to 8 in dry years	2	9+
<i>Lomatium nudicaule</i>	no response	3	4+
<i>Lomatium triternatum</i>	average of 6.9 inches over 8 years	2	9+
<i>Lomatium suksdorfii</i>	8 inches (2015)	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. *Penstemon acuminatus* (sharp-leaf penstemon), *Penstemon speciosus* (royal penstemon), and *Penstemon cyaneus* (blue penstemon) seed yields were maximized by 4 to 8 inches of water applied per season in warmer, drier years and were not responsive to irrigation in cooler, wetter years. *Penstemon pachyphyllus* (thick-leaf beard-tongue) seed yields were maximized by 8 inches of water applied per season in warmer, drier years and were not responsive to irrigation in cooler, wetter years. In 6 years of testing, seed yields of *Penstemon deustus* (scabland penstemon) only responded to irrigation in 2015, with 5.4 inches of water applied resulting in the highest yields.

Introduction

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

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

Native wildflower plants are not well adapted to croplands. They often are not competitive with crop weeds in cultivated fields. Poor competitiveness with weeds could also limit wildflower seed production. Both sprinkler and furrow irrigation could provide supplemental water for seed production, but these irrigation systems risk further encouraging weeds. Also, sprinkler and furrow irrigation can lead to the loss of plant stand and seed production due to fungal pathogens. By burying drip tapes at 12-inch depth and avoiding wetting the soil surface, 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 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, 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: *Penstemon acuminatus*, *P. deustus*, and *P. speciosus*

Seed of *Penstemon acuminatus*, *P. deustus*, and *P. speciosus* was received in late November in 2004 from the Rocky Mountain Research Station (Boise, ID). The plan was to plant the seed in the fall of 2004, but due to excessive rainfall in October, the ground preparation was not completed and planting was postponed to early 2005. To try to ensure germination, the seed was submitted to cold stratification. The seed was soaked overnight in distilled water on January 26, 2005, after which the water was drained and the seed soaked for 20 min in a 10% 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 percent organic matter. The drip tape was buried in alternating inter-row spaces (5 ft apart). The flow rate for the drip tape was 0.34 gal/min/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 Rocky Mountain Research Station 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 *P. deustus*. On November 11, 2006, the *Penstemon deustus* plots were replanted again at 30 seeds/ft of row.

Cultural Practices in 2006

On October 27, 2006, 50 lb phosphorus (P)/acre and 2 lb zinc (Zn)/acre were injected through the drip tape to all plots of 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

Penstemon acuminatus and *P. speciosus* were sprayed with Aza-Direct® at 0.0062 lb ai/acre on May 14 and 29 for lygus bug control. Irrigations for each species were initiated and terminated on different dates (Table 2).

Cultural Practices in 2008

On November 9, 2007 and on April 15, 2008, Prowl at 1 lb ai/acre was broadcast on all plots for weed control. Capture® 2EC at 0.1 lb ai/acre was sprayed on all plots of *Penstemon acuminatus* and *P. speciosus* on May 20 for lygus bug control. Irrigations for each species were initiated and terminated on different dates (Table 2). Due to substantial stand loss, all plots of *P. deustus* 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. The flowering, irrigation timing, and harvest timing were recorded for each species (Table 2). On December 4, 2009, Prowl at 1 lb ai/acre was broadcast for weed control on all plots.

Cultural Practices in 2010

The flowering, irrigation, and harvest timing of the established wildflowers were recorded for each species (Table 2). 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 *P. acuminatus* were disked out.

Cultural Practices in 2011

The timing of flowering, irrigations, and harvests varied by species (Table 2). 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 *Penstemon speciosus*.

Cultural Practices in 2014

On April 18, Orthene at 8 oz/acre was broadcast to all plots of *Penstemon speciosus* for lygus bug control. On April 29, 5 lb Fe/acre was applied through the drip tape to all plots of *Penstemon speciosus*.

Cultural Practices in 2015

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

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 *P. speciosus* 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 makeup of the stand over time.

Plant Establishment: *Penstemon cyaneus*, *P. deustus*, and *P. pachyphyllus*

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

Cultural Practices in 2010

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

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

Cultural Practices in 2011

Seed from the middle 2 rows in each plot of *Penstemon deustus* 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, 2012, 50 lb nitrogen/acre, 10 lb phosphorus/acre, and 0.3 lb iron (Fe)/acre was applied to all plots as liquid fertilizer injected through the drip tape. On April 23, 2012, 0.3 lb Fe/acre was applied to all plots of as liquid fertilizer injected through the drip tape.

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

Cultural Practices in 2013

Seed of *Penstemon cyaneus* and *P. pachyphyllus* was harvested manually. The replanted *P. deustus* did not flower in 2013. Weeds were controlled by hand weeding 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 *Penstemon deustus* was harvested with a small plot combine. Seed of the other species was harvested manually.

Cultural Practices in 2015

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

Stands of *P. cyaneus* and *P. pachyphyllus* 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 makeup of the stand over time. Weeds were controlled each year by hand weeding.

Irrigation for Seed Production

In April, 2006 each planted strip of *Penstemon acuminatus*, *P. deustus*, and *P. speciosus* was divided into plots 30 ft long. Each plot contained four rows of each species. The experimental designs were randomized complete blocks with four replicates. The three treatments were a non-irrigated check, 1 inch of water applied per irrigation, and 2 inches of water applied per irrigation. Each treatment received 4 irrigations that were applied approximately every 2 weeks starting with 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. *Penstemon deustus* and *P. speciosus* were irrigated together, but separately from *Penstemon acuminatus*.

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.

Penstemon cyaneus, *P. deustus* (2nd planting), and *P. pachyphyllus* 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 *P. deustus* was too poor to result in reliable seed yield estimates. Replanting of *P. deustus* 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. *Penstemon deustus* seed pods were too hard to be opened in the combine; the unthreshed seed was precleaned in a small clipper seed cleaner and then seed pods were broken manually by rubbing the pods on a ribbed rubber mat. The seed was then cleaned again in the small clipper seed cleaner. The other species were threshed in the combine and the seed was further cleaned using a small clipper seed cleaner. Seed of *P.*

cyaneus, *P. pachyphyllus*, and *P. speciosus* were harvested by hand when stands became too poor for combining.

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 of 5.8 inches. Precipitation from January through June in 2007, 2008, 2013, and 2015 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, and 2015 were higher than average (Table 3).

Flowering and Seed Set

Penstemon acuminatus and *P. speciosus* had poor seed set in 2007, partly due to a heavy lygus bug infestation that was not adequately controlled by the applied insecticides. In the Treasure Valley, the first hatch of lygus bugs occurs when 250 degree-days (52°F base) are accumulated. Data collected by an AgriMet weather station adjacent to the field indicated that the first lygus bug hatch occurred on May 14, 2006; May 1, 2007; May 18, 2008; May 19, 2009; and May 29, 2010. The average (1995-2010) lygus bug hatch date was May 18.

Penstemon acuminatus and *P. speciosus* start flowering in early May (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 *P. acuminatus* and *P. speciosus* in 2007 also was related to poor vegetative growth compared to 2006 and 2008.

In 2009, all plots of *P. acuminatus* and *P. speciosus* again showed poor vegetative growth and seed set. Root rot affected all plots of *P. acuminatus* in 2009, killing all plants in two of the four plots of the wettest treatment (2 inches per irrigation). Root rot affected the wetter plots of *P. speciosus* in 2009, but the stand partially recovered due to natural reseeding.

Seed Yields

Penstemon acuminatus, Sharpleaf Penstemon

There was no significant difference in seed yield between irrigation treatments for *P. acuminatus* 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 4.0 inches of water applied in 2007.

In 2008, seed yield showed a linear response to applied water.

In 2009, there was no significant difference in seed yield between treatments. 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

Table 2. *Penstemon* flowering, irrigation, and seed harvest dates by species in 2006-2015. Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	Year	Flowering dates			Irrigation dates		Harvest
		Start	Peak	End	Start	End	
<i>Penstemon acuminatus</i>	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
<i>Penstemon cyaneus</i>	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
<i>Penstemon deustus</i> ^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			
	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
<i>Penstemon pachyphyllus</i>	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
<i>Penstemon speciosus</i>	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

^aSecond planting in the fall of 2009.

88.5 percent for the 0-, 4-, and 8-inch irrigation treatments, respectively. The trial area was disked out in 2010.

Following the 2005 planting, seed yields were substantial in 2006 and moderate in 2008. *P. acuminatus* performed as a short-lived perennial.

Penstemon cyaneus, 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 and 2014.

Penstemon deustus, 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 showed a quadratic response to irrigation with a maximum seed yield at 5.4 inches of water applied.

Penstemon pachyphyllus, Thicketleaf Beardtongue

Seed yields did not respond to irrigation in 2011, 2012, 2014, and 2015 (Tables 4 and 5).

In 2013, seed yields increased with increasing irrigation up to the highest tested of 8 inches.

Penstemon speciosus, Royal Penstemon

In 2006-2009 and 2014 and 2015, seed yield of *P. speciosus* showed a quadratic response to irrigation rate (Tables 4 and 5). Seed yields were maximized by 4.3, 4.2, 5.0, 4.3, 5.2, and 5 inches of water applied in 2006, 2007, 2008, 2009, 2014, and 2015, respectively. In 2010, 2011, and 2012 there was no difference in seed yield between treatments.

Seed yield was low in 2007 due to lygus bug damage, as discussed previously. Seed yield in 2009 was low due to stand loss from root rot. The plant stand recovered somewhat in 2010 and 2011, due in part to natural reseeding, especially in the non-irrigated plots. In 2013, seed yield increased with increasing water application, up to 8 inches, the highest amount tested. Averaged over 9 years, seed yield was maximized by 5.0 inches of water applied.

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). *Penstemon acuminatus* did not respond to irrigation in these trials. In 6 years of testing, seed yields of *P. deustus* only responded to irrigation in 2015. Natural rainfall was sufficient to maximize seed production in the absence of weed competition.

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Table 3. Early season precipitation and growing degree-days at the Malheur Experiment Station, Ontario, OR, 2006-2015.

Year	Precipitation (inches)		Growing degree-days (50-86°F)
	Jan-June	April-June	Jan-June
2006	9	3.1	1273
2007	3.1	1.9	1406
2008	2.9	1.2	1087
2009	5.8	3.9	1207
2010	8.3	4.3	971
2011	8.3	3.9	856
2012	5.8	2.3	1228
2013	2.6	1.4	1319
2014	5.1	1.6	1333
2015	4.8	2.7	1575
72-year average	5.8	2.7	1178 ^a

^a22-year average.

Table 4. Native wildflower seed yield in response to irrigation rate (inches/season) in 2006 through 2015. Malheur Experiment Station, Oregon State University, 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			
<i>Penstemon acuminatus</i> ^a	2006	538.4	611.1	544	NS	<i>Penstemon pachyphyllus</i>	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
							Average	278.2	212.3	272.2	NS
<i>Penstemon cyaneus</i>	2011	857.2	821.4	909.4	NS	<i>Penstemon speciosus</i> ^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
	Average	366.2	405.1	452.4	NS		2011	371.1	328.2	348.6	NS
<i>Penstemon deustus</i> ^c	2006	1246.4	1200.8	1068.6	NS		2012	103.8	141.1	99.1	NS
	2007	120.3	187.7	148.3	NS		2013	8.7	80.7	138.6	63.7
	2008	-- Stand disked out --					2014	76.9	265.6	215.1	76.7
	2011	637.6	477.8	452.6	NS		2015	105.4	207.3	173.7	50.3
	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.^b LSD (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. (Continued on next page.) 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- 2015, and 4 to 10-year averages. For the quadratic equations, the amount of irrigation that resulted in maximum yield was calculated using the formula: $-b/2c$, where b is the linear parameter and c is the quadratic parameter. Malheur Experiment Station, Oregon State University, Ontario, OR.

<i>Penstemon acuminatus</i>							
Year	Intercept	linear	quadratic	R ²	P	Maximum seed 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	4
2008	56.2	30.9	-1.8	0.63	0.05	188	8.5
2009	19.5	-1.1		0.23	NS		
Average	165.6	17.1	-1.8	0.1	NS		

<i>Penstemon cyaneus</i>							
Year	intercept	linear	quadratic	R ²	P	Maximum seed 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	1094	8
2013	221.7	87.9	-10.9	0.63	0.05	399	4
2014	214.2	0.1		0.01	NS		
2015	113.2	16.6		0.32	NS		
Average	360.6	9.2		0.24	NS		

<i>Penstemon deustus</i>							
Year	intercept	linear	quadratic	R ²	P	Maximum seed 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	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	5.4
Average	333.0	4.9	-0.79	0.03	NS		

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

Table 5. (Continued from previous page.) Regression analysis for native wildflower seed yield in response to irrigation rate (inches/season) in 2006 - 2014, and 4 to 10-year averages. Malheur Experiment Station, Oregon State University, Ontario, OR.

<i>Penstemon pachyphyllus</i>							
Year	intercept	linear	quadratic	R ²	P	Maximum seed yield	Water applied for maximum yield
						lb/acre	inches/season
2011	507.1	-11		0.04	NS		
2012	263.1	-3.3		0.01	NS		
2013	156.8	11.3		0.33	0.1	247	8
2014	275.6	-1.2		0.01	NS		
2015	89.5	-8.5	1.1	0.06	NS		
Average	278.2	-32.2	3.9	0.21	NS		

<i>Penstemon speciosus</i>							
Year	intercept	linear	quadratic	R ²	P	Maximum seed yield	Water applied for maximum yield
						lb/acre	inches/season
2006	163.5	85.1	-9.9	0.66	0.05	346	4.3
2007	2.5	3.2	-0.4	0.48	0.1	9	4.2
2008	94.1	113.7	-11.4	0.56	0.05	378	5
2009	6.8	4.4	-0.5	0.54	0.05	16	4.2
2010	147.2	29.8	-2.1	0.35	NS ^a		
2011	360.6	-2.8		0.01	NS		
2012	103.8	19.3	-2.5	0.3	NS		
2013	11	16.2		0.77	0.001	141	8
2014	76.9	77.1	-7.5	0.62	0.05	276	5.2
2015	105.4	42.4	-4.2	0.64	0.05	212	5.0
Average	108.3	29.1	-2.9	0.58	0.05	181	5.0

^a Not 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, Oregon State University, Ontario, OR.

Species	Optimum amount of irrigation for seed production	Year of first seed set	Approximate life span
	inches/season	from fall planting	years
<i>Penstemon acuminatus</i>	0 in wetter years, 4 in warm, dry years	1	3
<i>Penstemon cyaneus</i>	0 in wetter years, 4 to 8 in drier years	1	3
<i>Penstemon deustus</i>	response to irrigation in one out of 6 years	2	3
<i>Penstemon pachyphyllus</i>	no response in 2011, 2012, 2014, 2015, 8 inches in 2013 (drier year)	1-2	3
<i>Penstemon speciosus</i>	0 in cool, wet years, 4 to 8 in warm, dry years	1	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 inches, or 8 inches/season) were tested.

Over the five year period of study, *Dalea searlsiae* (Searl's prairie clover) seed yield was maximized by 6 - 9 inches of water applied per season in warmer, drier years and by 0 inches of water applied per season in cooler, wetter years. *Dalea ornata* (western prairie clover) seed yield was maximized by 4 - 8 inches of water applied per season in warmer, drier years and by 0 inches of water applied per season in cooler, wetter years. *Astragalus filipes* (basalt milkvetch) seed yield was not responsive 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 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. Native plants are often not competitive with crop weeds in cultivated fields. Poor competitiveness with weeds could also 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, 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 three native wildflower legume species (Table 1) planted in 2009.

Table 1. Wildflower species planted in the fall of 2009 at the Malheur Experiment Station, Oregon State University, 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-foot-wide strip about 450 feet long on Nyssa silt loam at the OSU Malheur Experiment Station, Ontario, Oregon. The soil had a pH of 8.3 and 1.1% organic matter. In October 2009, two drip tapes 5 feet apart (T-Tape TSX 515-16-340) were buried at 12-inch depth to irrigate the four rows in the plot. Each drip tape irrigated two rows of plants. The flow rate for the drip tape was 0.34 gal/min/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 disk openers. All seed was planted on the soil surface at 20-30 seeds/ft of row. After planting, sawdust was applied in a narrow band over the seed row at 0.26 oz/ft of row (558 lb/acre). Following planting and sawdust application, the beds were covered with row cover. The row cover (N-sulate, DeWitt Co., Inc., Sikeston, MO) covered four rows (two beds) and was applied with a mechanical plastic mulch layer. The field was irrigated for 24 hours on December 2, 2009 due to very dry soil conditions.

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

Each year, weeds were controlled by hand weeding as necessary. Seed from the middle 2 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 twelve 30-ft plots. Each plot contained four rows of each species. The experimental design for each species was a randomized complete block with four replicates. The three treatments were a non-irrigated check, 1 inch of water applied per irrigation, and 2 inches of water applied per irrigation. Each treatment received 4 irrigations 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 *Astragalus filipes* was irrigated separately. Flowering, irrigation, and harvest dates were recorded (Table 2).

Seed Beetle Control

Harvested seed pods of *Dalea ornata*, *D. searlsiae*, and *Astragalus filipes* had extensive damage from feeding by seed beetles in 2013 and 2014; indicating that control measures during and following flowering 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, Rimon at 12 oz/acre was broadcast in the evening to minimize harm to pollinators.

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

Species	Year	Flowering			Irrigation		Harvest
		Start	Peak	End	Start	End	
<i>Dalea searlsiae</i>							
	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
<i>Dalea ornata</i>							
	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
<i>Astragalus filipes</i>							
	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

Results and Discussion

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

Dalea searlsiae, Searl's Prairie Clover

In 2012, 2014, and 2015 seed yields showed a quadratic response to irrigation (Tables 4 and 5). Maximum seed yields were achieved with 6.6, 8.9, and 6.6 inches of water applied in 2012,

2014, and 2015, respectively. In 2013, seed yields increased with increasing irrigation rate up to the highest tested of 8 inches. In 2011, seed yields were highest with no irrigation. Averaged over the 5 years, seed yield showed a quadratic response to irrigation with a maximum seed yield at 6.8 inches of water applied.

Dalea ornata, Western Prairie Clover

Seed yields showed a quadratic response to irrigation in 2012, 2013, 2014, and 2015 with a maximum seed yield at 7.7, 8.1, 6.9, and 4.3 inches of water applied, respectively (Tables 4 and 5). Seed yields did not respond to irrigation in 2011. Averaged over the 5 years, seed yield showed a quadratic response to irrigation with a maximum seed yield at 5.4 inches of water applied.

Astragalus filipes, Basalt Milkvetch

Seed yields only responded to irrigation 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 3. Early season precipitation and growing degree-days at the Malheur Experiment Station, Ontario, OR, 2006-2015.

Year	Precipitation (inches)		Growing degree-days (50-86°F)
	Jan-June	April-June	Jan-June
2006	9	3.1	1273
2007	3.1	1.9	1406
2008	2.9	1.2	1087
2009	5.8	3.9	1207
2010	8.3	4.3	971
2011	8.3	3.9	856
2012	5.8	2.3	1228
2013	2.6	1.4	1319
2014	5.1	1.6	1333
2015	4.8	2.7	1575
72-year average	5.8	2.7	1178 ^a

^a22-year average.

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

Species	Year	0 inches	4 inches	8 inches	LSD (0.05)
----- lb/acre -----					
<i>Dalea searlsiae</i>					
	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
	Average	146.9	212.7	224.0	36.8
<i>Dalea ornata</i>					
	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	117.0 ^b
	Average	185.6	344.1	317.2	57.9
<i>Astragalus filipes</i>					
	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 $y = a + bx + cx^2$. For the quadratic equations, the amount of irrigation that resulted in maximum yield was calculated using the formula: $-b/2c$, where b is the linear parameter and c is the quadratic parameter. Malheur Experiment Station, Oregon State University, Ontario, OR.

Dalea searlsiae

Year	intercept	linear	quadratic	R ²	P	Maximum seed yield	Water applied for maximum yield
						lb/acre	inches/season
2011	263.3	-8.3		0.49	0.05	263	0
2012	175.5	40.7	-3.1	0.62	0.05	309	6.6
2013	15.5	3.7		0.54	0.01	45	8
2014	60.0	39.1	-2.2	0.79	0.001	234	8.9
2015	221.2	39.4	-3.0	0.56	0.05	350	6.6
Average	146.9	23.3	-1.7	0.64	0.01	226	6.8

Dalea ornata

Year	intercept	linear	quadratic	R ²	P	Maximum seed yield	Water applied for maximum yield
2011	454.9	-12.5		0.11	NS ^a		
2012	145.1	74.2	-4.8	0.65	0.01	432	7.7
2013	28.6	25.3	-1.6	0.88	0.001	130	8.1
2014	119.4	107.1	-7.8	0.87	0.001	487	6.9
2015	212.9	85.1	-9.8	0.69	0.05	398	4.3
Average	185.6	62.8	-5.8	0.83	0.01	356	5.4

Astragalus filipes

Year	intercept	linear	quadratic	R ²	P	Maximum seed yield	Water applied for maximum yield
						lb/acre	inches/season
2011	90.6	-1.6		0.01	NS		
2012	19.7	-0.8		0.04	NS		
2013	8.5	0.9	-0.2	0.25	NS		
2014	56.6	9.4	-0.9	0.08	NS		
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 (*Cleome* spp.) Seed Production in Response to Irrigation in a Semi-Arid Environment

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Summary

Beeplant (*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 their seed production. The seed yield response of *Cleome serrulata* (Rocky Mountain beeplant) and *Cleome lutea* (yellow spiderflower or yellow beeplant) to four biweekly irrigations applying either 0, 1 inch of water, or 2 inches of water (total of 0, 4 inches, or 8 inches/season) was evaluated over multiple years. *Cleome serrulata* 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. *Cleome* 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 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. Native plants are often not competitive with crop weeds in cultivated fields. Poor competitiveness with weeds could also limit wildflower seed production. Both sprinkler and furrow irrigation could provide supplemental water for seed production, but these irrigation systems risk further encouraging weeds. Also, sprinkler and furrow irrigation can lead to the loss of plant stand and seed production due to fungal pathogens.

By burying drip tapes at 12-inch depth and avoiding wetting the soil surface, 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 *Cleome serrulata* (Rocky Mountain beeplant) and *Cleome lutea* (Yellow beeplant).

Materials and Methods

Plant Establishment

Each species was planted in separate strips containing four rows, 30 inches apart (a 10-foot-wide strip), and about 450 feet long on Nyssa silt loam at the OSU Malheur Experiment Station, Ontario, Oregon. The soil had a pH of 8.3 and 1.1% organic matter. In October 2010, two drip tapes five feet apart (T-Tape TSX 515-16-340) were buried at 12-inch depth to irrigate the four rows in the plot. Each drip tape irrigated two rows of plants. The flow rate for the drip tape was 0.34 gal/min/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 *Cleome serrulata* was planted each year in 30-inch rows using a custom-made plot grain drill with disk openers in mid-November each year. 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 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. Starting in 2011 seed of *C. lutea* 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 *Cleome serrulata* and *Cleome lutea* 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 *Cleome serrulata* and *C. lutea* in April of 2012. On April 29, 2012, all plots of *C. serrulata* and *C. lutea* were sprayed with Capture® at 5 oz/acre to control flea beetles. On June 11, 2012, *C. serrulata* was again sprayed with Capture at 5 oz/acre to control a re-infestation 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 resulting 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 *C. serrulata* and *C. lutea* were sprayed with Capture® at 5 oz/acre to control flea beetles. On April 3, 2015, all plots of *C. serrulata* and *C. lutea* were sprayed with Entrust at 2 oz/acre (0.03 lb ai/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 twelve 30-ft plots. Each plot contained four rows of each species. The experimental design for each species was a randomized complete block with four replicates. The three treatments were a non-irrigated check, 1 inch of water applied per irrigation, and 2 inches of water applied per irrigation. Each

treatment received 4 irrigations that were applied approximately every 2 weeks starting with 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.

Table 1. *Cleome serrulata* and *Cleome lutea* flowering, irrigation, and seed harvest dates by species. Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	Year	Flowering dates			Irrigation dates		Harvest
		Start	Peak	End	Start	End	
<i>Cleome serrulata</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	Full stand loss					
	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
<i>Cleome lutea</i>	2012	16-May	15-Jun	30-Jul	2-May	13-Jun	12-Jul to 30-Aug
	2013	Full stand loss, fleabeetle damage					
	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

Table 2. Early season precipitation and growing degree-days at the Malheur Experiment Station, Ontario, OR, 2006-2015.

Year	Precipitation (inches)		Growing degree-days (50-86°F)
	Jan-June	April-June	Jan-June
2011	8.3	3.9	856
2012	5.8	2.3	1228
2013	2.6	1.4	1319
2014	5.1	1.6	1333
2015	4.8	2.7	1575
72-year average	5.8	2.7	1178 ^a

^a22-year average.

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 2). In 2014, after the 4 bi-weekly irrigations ended, *Cleome serrulata* and *Cleome lutea* 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 lb N/acre, 30 lb P/acre, and 0.2 lb Fe/acre were applied through the drip tape to all plots of *Cleome serrulata* and *Cleome lutea*.

Flowering and Harvest

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

Table 3. *Cleome serrulata* and *Cleome lutea* seed yield in response to irrigation rate (inches/season). Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	Year	Irrigation rate			LSD (0.05)
		0 inches	4 inches	8 inches	
		----- lb/acre -----			
<i>Cleome serrulata</i>	2011	446.5	499.3	593.6	100.9 ^b
	2012	184.3	162.9	194.7	NS ^a
	2013	No stand, flea beetle damage			
	2014	66.3	80	91.3	NS
	2015	54.0	41.0	37.9	NS
	Average	150.8	157.1	183.7	NS
<i>Cleome lutea</i>	2012	111.7	83.7	111.4	NS
	2013	No stand, flea beetle damage			
	2014	207.1	221.7	181.7	NS
	2015	136.9	80.5	113.0	NS
	Average	151.9	128.6	135.4	NS

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

^b LSD (0.10)

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 and 2015 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, 2014, and 2015 were higher than average (Table 2) and was associated with early flowering and seed harvest.

Cleome serrulata, 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, or 2015. There was no plant stand in 2013 due to early, severe flea beetle damage. The additional irrigations applied starting on August 12 in 2014 did result in an extension/resumption of flowering, but seed harvested in mid-October was not mature.

The winter and spring of 2011 were wetter and this annual plant developed well, responded to later irrigation, and had higher seed yield. The pattern of results over years suggests that *Cleome*

spp. may need early irrigation in drier years in addition to irrigation during flowering and seed set.

Cleome lutea, Yellow Spiderflower or Yellow Beeplant

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

Table 4. Regression analysis for *Cleome serrulata* and *Cleome lutea* seed yield (y) in response to irrigation (x) (inches/season) using the equation $y = a + bx + cx^2$. Malheur Experiment Station, Oregon State University, Ontario, OR.

<i>Cleome serrulata</i>						Maximum seed yield	Water applied for maximum yield
Year	intercept	linear	quadratic	R ²	P	lb/acre	inches/season
2011	439.6	18.4		0.35	0.05	587	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		
Average	206	6.5		0.33	NS		

<i>Cleome lutea</i>						Maximum seed yield	Water applied for maximum yield
Year	intercept	linear	quadratic	R ²	P	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		
Average	159.3	-1.6		0.04	NS		

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6. Irrigation Requirements for Seed Production of Various Native Wildflower Species Started 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. 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 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 (Table 1).

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

Species	Common name	Longevity	Row spacing (inches)
<i>Chaenactis douglasii</i>	Douglas' dustymaiden	perennial	30
<i>Crepis intermedia</i> ^b	Limestone hawksbeard	perennial	30
<i>Cymopterus bipinnatus</i> ^a	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 thelypod	biennial	30

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

^b Planted in the fall of 2011.

Materials and Methods

Plant Establishment

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

On October 30, 2012 seed of 11 species (Table 1) was planted in either 15-inch or 30-inch rows using a custom-made plot grain drill with disk openers. All seed was planted on the soil surface at 20-30 seeds/ft of row. After planting, sawdust was applied in a narrow band over the seed row at 0.26 oz/ft of row (558 lb/acre). Following planting and sawdust application, the beds were covered with row cover. The row cover (N-sulate, DeWitt Co., Inc., Sikeston, MO) covered four rows (two beds) and was applied with a mechanical plastic mulch layer. *Cymopterus bipinnatus* was planted on November 25, 2009, and *Crepis intermedia* was planted on November 28, 2011 as previously described.

Weeds were controlled by hand weeding as necessary.

Cultural Practices for Cymopterus bipinnatus and Crepis intermedia

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 to prevent bird feeding on young seedlings and new shoots. The bird netting was placed over No. 9 galvanized wire hoops. During seedling emergence, wild bird seed was placed several hundred feet from the trial to attract quail away from the trials. Bird netting was removed in early May. Bird netting was applied and removed each spring. On April 13, 2012, 50 lb nitrogen/acre, 10 lb phosphorus/acre, and 0.3 lb iron (Fe)/acre was applied to all plots of *Cymopterus bipinnatus* as liquid fertilizer injected through the drip tape.

Cultural Practices in 2013

Starting on March 29, 2013, the row cover was removed and bird netting applied for the species planted in the fall of 2012. Bird netting was removed in early May. On July 26, all plots of *Machaeranthera canescens* were sprayed with Capture at 19 oz/acre (0.3 lb ai/acre) for aphid control. On October 31, seed of *Phacelia linearis* was planted as previously described.

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

Cultural Practices in 2014

Starting in late March, 2014, the row cover was removed and bird netting applied. Bird netting was removed in early May. Stand of *Chaenactis douglasii*, which was replanted in the fall of 2013, was poor and did not allow evaluation of irrigation responses.

On November 11, *Phacelia linearis*, *Nicotiana attenuata*, and *Thelypodium milleflorum* were replanted as previously described.

Cultural Practices in 2015

Starting in late March 2015, the row cover was removed and bird netting applied. Bird netting was removed in early May.

Irrigation for Seed Production

In March of 2010 for *Cymopterus bipinnatus*, and March of 2013 for the other species, the strip of each wildflower species was divided into twelve 30-ft long plots. Each plot contained four rows of each species. The experimental design for each species was a randomized complete block with four replicates. The three treatments were a non-irrigated check, 1 inch of water per irrigation, and 2 inches of water per irrigation. Each treatment received four irrigations that were applied approximately every 2 weeks starting 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 *Nicotiana attenuata* which did not germinate in 2014 and the *Ligusticum* spp. which did not flower.

All species were harvested manually, except *Phacelia hastata*. *Phacelia hastata* was harvested with a small plot combine. *Chaenactis douglasii* and *Crepis intermedia* were harvested once a week with a leaf blower in vacuum mode. *Machaeranthera canescens* seed was harvested by cutting and windrowing the plants. After drying for 2 days the *Machaeranthera canescens* plants were beaten on plastic tubs to separate the seed heads from the stalks. Seed of all species was cleaned manually.

Results and Discussion

Precipitation from January through July in 2013 (2.6 inches) was below and in 2014 (5.1 inches) and 2015 (5.3) was close to the 72-year average of 6.0 inches (Table 3). The accumulation of growing degree days (50 to 86° F) was higher than average in 2013, 2014, and 2015 (Table 3).

Stands of *Ligusticum porteri* and *Ligusticum canbyi* were poor and uneven not permitting evaluation of irrigation responses.

Stands of *Chaenactis douglasii* were poor in 2013 and 2014, not permitting evaluation of irrigation responses. After replanting in the fall of 2013 and 2014, adequate stand was established allowing evaluations of irrigation responses in 2015.

Stand of *Nicotiana attenuata* was uneven and did not permit evaluation of irrigation responses in 2015.

Ipomopsis aggregata had very little flowering in 2013, then flowered and set seed in 2014. The existing stand of *Ipomopsis aggregata* died over the winter of 2014/2015 indicating a biennial growth habit.

Cymopterus bipinnatus did not flower in either 2010 or 2011, and had very little flowering in 2012.

Stand of replanted *Phacelia linearis* was very poor, but was replaced by an excellent volunteer stand of *Phacelia hastata* originating from unharvested seed of the adjacent *Phacelia hastata* stand. Irrigation responses for *Phacelia hastata* were evaluated for the new stand and for the 3 year-old stand.

Crepis intermedia flowered and produced seed for the first time in 2015, the third year since fall planting in 2011.

Extensive die-off of *Enceliopsis nudicaulis* occurred over the winter of 2014/2015. The die-off was more severe in the plots receiving the highest amount of irrigation.

Seed Yield Responses (Tables 4 and 5)

Chaenactis douglasii (Douglas' dustymaiden) seed yields did not respond to irrigation in 2015.

Crepis intermedia (limestone hawkbeard) seed yields increased with increasing irrigation rate up to the highest tested of 8 inches in 2015.

Cymopterus bipinnatus (Hayden's cymopterus) seed yields did not respond to irrigation in 2013. In 2014, seed yields increased with increasing irrigation rate up to the highest tested of 8 inches. In 2015, seed yields showed a quadratic response to irrigation with a maximum seed yield at 4.2 inches of water applied.

Enceliopsis nudicaulis (nakedstem sunray) seed yield was very low and was not responsive 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 *E. nudicaulis* were substantially reduced in 2015 and were highest without irrigation. Seed yields have been very low each year due at least in part to very low plant stands.

Heliomeris multiflora (showy goldeneye) seed yield increased with increasing irrigation rate up to the highest tested of 8 inches in 2013, 2014, and 2015.

Ipomopsis aggregata (scarlet gilia) seed yields were highest with 4 inches of applied water in 2014.

Machaeranthera canescens (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 *M. canescens* were not responsive to irrigation.

Phacelia hastata (silverleaf phacelia) (planted in the fall of 2012) seed yields, showed a quadratic response to irrigation with a maximum seed yield at 5.4 and 7.5 inches of water applied in 2013 and 2014, respectively. In 2015, seed yield of *P. hastata* was not responsive to irrigation, possibly due to loss of stand in this weak perennial.

Seed yields of *Phacelia hastata*, planted in the fall of 2014, increased with increasing irrigation rate up to the highest tested of 8 inches.

Seed yields of *Phacelia linearis* (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 *P. linearis* were not responsive to irrigation.

The establishment of *Thelypodium milleflorum* (manyflower thelypody) has been difficult and plant stands have been poor. Seed yield of *T. milleflorum* 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, Oregon State University, Ontario, OR.

Experiment station, Oregon State University, Corvallis, OR.						
Year	Flowering dates			Irrigation dates		Harvest
	Start	Peak	End	Start	End	
<i>Chaenactis douglasii</i> , 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	6-8 to 7-15
<i>Machaeranthera canescens</i> , 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
<i>Phacelia hastata</i> , 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)
<i>Phacelia linearis</i> , 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					
<i>Enceliopsis nudicaulis</i> , nakedstem sunray						
2013	30-Jun		15-Sep	3-Jul	14-Aug	8-Aug to 30-Aug
2014	5-May	1-Jul	30-Jul	6-May	17-Jun	14-Jul to 30-Aug
2015	28-Apr	13-May	5-Aug	29-Apr	10-Jun	2-Jun to 15-Aug
<i>Heliomeris multiflora</i> , showy goldeneye						
2013						
2014	15-Jul		30-Aug	5-Jun	17-Jun	8-Aug, 15-Aug, 28-Aug
2015	20-May	20-Jun	30-Aug	13-May	24-Jun	15-Jul to 15-Aug
<i>Cymopterus bipinnatus</i> , 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-May		24-Apr	1-Apr	13-May	8-Jun
<i>Ipomopsis aggregate</i> , 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					
<i>Thelypodium milleflorum</i> , manyflower thelypody						
2013	no flowering					
2014	22-Apr	5-May	10-Jun	23-Apr	3-Jun	2-Jul
2015	no flowering					
<i>Crepis intermedia</i> , Limestone hawksbeard						
2015	28-Apr	5-May	1-Jun	21-Apr	3-Jun	6-1 to 7-2

Table 3. Early season precipitation and growing degree-days at the Malheur Experiment Station, Ontario, OR, 2013-2015.

Year	Precipitation (inches)		Growing degree-days (50-86°F)
	Jan-June	April-June	Jan-June
2013	2.6	1.4	1319
2014	5.1	1.6	1333
2015	4.8	2.7	1575
72-year average	5.8	2.7	1178 ^a

^a22-year average.**Table 4.** Native wildflower seed yield in response to season long irrigation rate (inches). Malheur Experiment Station, Oregon State University, Ontario, OR.

		Irrigation rate			LSD (0.05)
Species	Year	0 inches	4 inches	8 inches	
----- lb/acre -----					
<i>Chaenactis douglasii</i>	2015	132.1	137.6	183.3	NS ^a
<i>Crepis intermedia</i>	2015	75.5	75.8	153.7	58.1
<i>Cymopterus bipinnatus</i>	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
	Average	580.9	1078.8	968.7	325 ^b
<i>Enceliopsis nudicaulis</i>	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
	Average	6.5	16.6	13.1	NS
<i>Helioomeris multiflora</i>	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
	Average	88.3	124.7	185.6	46.8
<i>Ipomopsis aggregata</i>	2014	47.1	60.9	63.6	9
<i>Machaeranthera canescens</i>	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
<i>Phacelia hastata</i> (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
<i>Phacelia hastata</i> (planted fall 2014)	2015	0.0	21.4	50.4	13.7
<i>Phacelia linearis</i>	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
<i>Thelypodium milleflorum</i>	2014	200.5	246.2	205.6	NS

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: $-b/2c$, where b is the linear parameter and c is the quadratic parameter. Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	Year	intercept	linear	quadratic	R ²	P	Maximum seed yield lb/acre	Water applied for maximum yield inches/season
<i>Chaenactis douglasii</i>	2015	125.4	6.4		0.08	NS		
<i>Crepis intermedia</i>	2015	58.6	12.7		0.32	0.1	160	8
<i>Cymopterus bipinnatus</i>	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
	Average	580.9	200.5	-19.0	0.24	NS		
<i>Enceliopsis nudicaulis</i>	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	0.1	13	0.0
	Average	6.5	4.2	-0.4	0.27	NS		
<i>Heliomeris multiflora</i>	2013	27	8.5		0.38	0.05	95	8
	2014	150.5	14.6		0.27	0.1	268	8
	2015	75.2	13.3		0.48	0.05	182	8
	Average	84.2	12.2		0.55	0.01	181	9
<i>Ipomopsis aggregata</i>	2014	48.5	2.1		0.23	NS		
<i>Machaeranthera canescens</i>	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		
<i>Phacelia hastata</i> (planted fall 2012)	2013	35.3	26.7	-2.5	0.66	0.01	108	5.4
	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	0.001	180	6.6
(planted fall 2014)	2015	-1.3	6.3		0.88	0.001	49	8
<i>Phacelia linearis</i>	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

^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 2015

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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 generally problematic, especially for certain species. Fall planting is important for many species because their seed requires a period of cold to break dormancy (vernalization). Fall planting of native seed has resulted in poor stands in some years at the Malheur Experiment Station. Loss of soil moisture, soil crusting, and bird damage are some detrimental factors hindering emergence of fall planted seed. Previous trials at the Malheur Experiment Station have examined seed pelleting, planting depth, and soil anti-crustants with a group of species that have problematic establishment (Shock et al. 2010). Planting at depth with soil anti-crustant improved emergence compared to surface planting. Seed pelleting did not improve emergence. Despite these positive results, emergence was extremely poor for all species tested due in part to soil crusting and bird damage.

In established native perennial fields at the Malheur Experiment Station, and in rangelands, we have observed prolific natural emergence from seed that falls on the soil surface and is covered by thin layers of organic debris. In 2011, 2012, and 2013, trials tested the effect of seven planting systems on surface planted seed (Table 1; Shock et al. 2012, 2013, 2014). Row cover can be a protective barrier against soil desiccation and bird damage. Sawdust might mimic the protective effect of organic debris, while 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. The treatments did not test all possible combinations of factors, but tested combinations that might be likely to result in adequate stand establishment based on previous observations. In 2015, the seven planting systems were tested for emergence of 11 important species, most of which are problematic to establish. Seven of these species are native to Malheur County and surrounding rangelands and forests.

Materials and Methods

Ten species for which stand establishment has been problematic were chosen. An eighth species (*Penstemon speciosus*) was chosen as a check, because it has reliably produced good stands at the Malheur Experiment Station in Ontario, OR. Seed weights for all species were determined. A portion of the seed was treated with a liquid mix of the fungicides Thiram® and Captan (10g Thiram, 10g Captan in 0.5 liter of water). Seed weights of the treated seeds were determined after treatment. The seed weights of untreated and treated seed were used to make seed packets

containing approximately 300 seeds each. The seed packets were then assigned to one of six treatments (Table 1). The planned planting time of November was postponed to January due to unusually high precipitation and cold weather in November and December. The trial was planted manually on January 7, 8, and 9, 2015. The experimental design was a randomized complete block with six replicates. Plots were one 30-inch-wide by 5-ft-long bed. Two seed rows were planted within each bed.

After planting, the sawdust was applied in a narrow band over the seed row at 0.26 oz/ft of row (558 lb/acre). For the treatments receiving both sawdust and sand, the sand was applied at 0.65 oz/ft of row (1,404 lb/acre) as a narrow band over the sawdust. Following planting 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). Since the soil was frozen, preventing the use of the mechanical plastic mulch applicator, the row cover was applied manually. Clamps were used to fasten the row cover. The hydroseed mulch treatment was not applied due to the low air temperature. On April 15, 2015, the row cover was removed and emergence counts were made in every plot.

Tetrazolium tests were conducted to determine seed viability of each species (Table 2). The tetrazolium results were used to correct the emergence data to emergence of viable seed. Data were analyzed using analysis of variance (General Linear Models Procedure, NCSS, Kaysville, UT). Means separation was determined using a protected Fisher's least significant difference test at the 5 percent probability level, LSD (0.05).

Results and Discussion

Overall, emergence in the trial in 2015 was poor. The late planting and dry spring probably contributed to the poor emergence. Emergence and stand of *Phacelia hastata*, *Ligusticum porteri*, *Ligusticum canbyi*, *Nicotiana attenuata*, *Thelypodium milleflorum*, and *Ipomopsis aggregata* was 10% or less (Table 3). There was no significant difference in stand between planting systems for *Phacelia hastata*, *Ligusticum porteri*, *Ligusticum canbyi*, *Thelypodium milleflorum*, and *Ipomopsis aggregata*.

There were statistically significant differences in stand between planting systems for five 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 *Machaeranthera canescens*, *Phacelia linearis*, and *Heliomeris multiflora* (Table 3). Sawdust added to the row cover plus seed treatment only improved stands of *Phacelia linearis*.

Adding seed treatment to sawdust plus row cover improved stands of *Phacelia linearis* and reduced stands of *Chaenactis douglasii* and *Heliomeris multiflora*. Adding sand to sawdust, seed treatment, plus row cover increased stand for *Penstemon speciosus*.

In 2013 (Shock et al. 2014), the same establishment systems were tested with 15 species, including all of the species in the 2015 trial. In 2013, systems including row cover improved stand of 6 of the species including *Chaenactis douglasii*, *Machaeranthera canescens*, *Thelypodium milleflorum*, and *Penstemon speciosus*. The combined planting system that included seed treatment improved the stand of *Penstemon speciosus* and reduced the stand of

Phacelia hastata and *Ipomopsis aggregata*. The treatment combination that included seed covering with sand improved stand of *Chaenactis douglasii* and *Heliomeris multiflora*.

In 2014, the same establishment systems were tested with 8 of the species in the 2015 trial (Shock et al. 2015). Overall, emergence in 2014 was poor. December of 2013 and January of 2014 precipitation was about 50% lower than normal and could have contributed to the poor emergence. There was no significant difference in stand between treatments for *Phacelia linearis*, *Phacelia hastata*, *Heliomeris multiflora*, or *Ligusticum canbyi*.

In 2014, systems including row cover improved stand of *Machaeranthera canescens* and *Ligusticum porteri*. Sawdust added to the row cover plus seed treatment only improved stands of *Ligusticum porteri*. Adding seed treatment to sawdust plus row cover did not improve stands of any species. Adding sand to sawdust, seed treatment, plus row cover increased the stand of *Penstemon speciosus*.

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 (Shock et al. 2011, 2012, 2013, 2014). 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.

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Table 1. Planting systems evaluated for emergence of eight native plant species. Mouse bait packs were scattered over the trial area. Malheur Experiment Station, Oregon State University, Ontario, OR, 2015.

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

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

^bHydroseed mulch was not tested in 2015 due to January planting, and unlike previous years, only the seed treatment for system No. 6.

Table 2. Seed weights and tetrazolium test (seed viability) results for seed used for the planting systems treatments in the fall of 2014 and evaluated in the spring of 2015. Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	Common name	Pre-plant untreated seed weight	Tetrazolium test
		seeds/g	%
<i>Chaenactis douglasii</i>	Douglas' dustymaiden	600	69
<i>Machaeranthera canescens</i>	hoary tansyaster	1,020	78
<i>Phacelia hastata</i>	silverleaf phacelia	996	96
<i>Phacelia linearis</i>	threadleaf phacelia	3,213	98
<i>Helioomeris multiflora</i>	showy goldeneye	1,600	94
<i>Ligusticum porteri</i>	Porter's licorice-root	206	28
<i>Ligusticum canbyi</i>	Canby's licorice-root	256	17
<i>Nicotiana attenuata</i>	showy penstemon	7,823	81
<i>Thelypodium milleflorum</i>	manyflower thelypody	5,482	93
<i>Ipomopsis aggregata</i>	scarlet gilia	693	40
<i>Penstemon speciosus</i>	showy penstemon	608	86

Table 3. Plant stands of eleven native plant species on April 15, 2015 in response to seven planting systems used in January of 2015. Emergence for each species was corrected to the percent emergence of viable seed. Oregon State University, Malheur Experiment Station, Ontario, OR.

Species	Row cover, Seed treatment, Sawdust	Row cover, Seed treatment	Row cover, Sawdust	Seed treatment, Sawdust	Row cover, Seed treatment, Sawdust, Sand	Seed treatment	Untreated check	LSD (0.05)
	----- % establishment -----							
<i>Chaenactis douglasii</i>	3.9	2.9	14.8	2.6	4.3	1.1	7.3	3.9
<i>Machaeranthera canescens</i>	35.4	30.7	30.5	17.7	27.4	8.3	17.4	12.8
<i>Phacelia hastata</i>	0.9	2.5	1.8	2.2	2.4	2.3	1.3	NS
<i>Phacelia linearis</i>	9.0	4.0	3.1	5.0	11.6	4.4	1.8	3.0
<i>Heliomeris multiflora</i>	27.5	27.1	44.4	9.1	31.6	6.0	9.9	7.1
<i>Ligusticum porteri</i>	3.4	1.8	2.4	3.6	3.6	0.2	0.6	NS
<i>Ligusticum canbyi</i>	0.3	0.7	1.6	5.6	7.5	0.3	0.7	NS
<i>Nicotiana attenuata</i>	1.2	0.8	1.8	0.2	1.3	0.0	0.3	1.1
<i>Thelypodium milleflorum</i>	1.4	2.1	2.1	1.2	2.2	1.6	1.6	NS
<i>Ipomopsis aggregata</i>	0.3	1.7	2.5	0.7	2.2	0.6	0.3	NS
<i>Penstemon speciosus</i>	4.7	1.6	2.1	1.3	10.2	0.6	1.6	4.6

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Management Applications and/or Seed Production Guidelines**Irrigation water requirements for native wildflower seed production****Clint Shock and Erik Feibert, 15 January 2016**

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

Species	Common names	Flowering dates*	Irrigation water needs inches/year	Years to first harvest	Stand life years	Seed yield lb/ac per harvest
<i>Eriogonum umbellatum</i>	Sulphur-flower buckwheat	L. May to July	0-8	1	10+	100-350
<i>Eriogonum heracleoides</i>	Parsnip-flowered buckwheat	May to June	0-4	2	5+	50-400
<i>Penstemon acuminatus</i>	Sharpleaf penstemon	L. April to E. June	<4	2	3	100-600
<i>Penstemon deustus</i>	Scabland penstemon	May to E. July	0-4	1	2	200-600
<i>Penstemon speciosus</i>	Royal penstemon	May to June	0-4	2	3	25-350
<i>Penstemon cyaneus</i>	Blue penstemon	May to June	0-8	1	3	200-800
<i>Penstemon pachyphyllus</i>	Thickleaf beardtongue	L. April to E. June	<4	2	3	200-500
<i>Lomatium dissectum</i>	Fernleaf biscuitroot	April to E. May	5-8	4	8+	300-1200
<i>Lomatium triternatum</i>	Nineleaf biscuitroot	April to E. June	4-8	2	9+	700-2000
<i>Lomatium grayi</i>	Gray's biscuitroot	L. March to E. May	0-5	2	9+	300-1200
<i>Lomatium nudicaule</i>	Bare-stem desert parsley	April to May	0-8	3	4+	500-600
<i>Cymopterus bipinnatus</i>	Hayden's cymopterus	April to May		3	4+	300-2500
<i>Sphaeralcea parvifolia</i>	Smallflower globemallow	May to June	<4	1	4-5	100-500
<i>Sphaeralcea grossulariifolia</i>	Gooseberryleaf globemallow	May to June	<4	1	4-5	150-400
<i>Sphaeralcea coccinea</i>	Scarlet globemallow	May to June	<4	1	4-5	100-300
<i>Dalea searlsiae</i>	Searls' prairie clover	May to June	0-8	2	5+	150-300
<i>Dalea ornata</i>	Western prairie clover	May to June	0-8	2	5+	150-450
<i>Astragalus filipes</i>	Basalt milkvetch	L. April to June	<4	2	4+	10-100
<i>Cleome serrulata</i>	Rocky mountain beeplant	June to August	0-8	1	1	100-500
<i>Cleome lutea</i>	Yellow beeplant	May to July	<4	1	1	100-200
<i>Machaeranthera canescens</i>	hoary tansyaster	Mid-Aug to L. Sept.	4	1	2+	200-400
<i>Phacelia hastata</i>	silverleaf phacelia	May to July	0-8	1	2+	100-300
<i>Phacelia linearis</i>	threadleaf phacelia	E. May to L. June	4	1	1	150-300
<i>Enceliopsis nudicaulis</i>	nakedstem sunray	May to August	4	1	2	10-35
<i>Heliomeris multiflora</i>	showy goldeneye	L. May to August	8	1	3+	50-250
<i>Ipomopsis aggregata</i>	scarlet gilia	L. April to July	4	2	2	50-60
<i>Thelypodium milleflorum</i>	manyflower thelypod	L. April-mid June	8	2	2	200-250

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

Management Applications

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

Additional Products

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

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Project Title Characterizing Germplasm Relationships and Maximizing Seedling Establishment of 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), and may not recover for decades (or longer) without human intervention. Many western rangelands also suffer from long-term reductions in biodiversity, altered nutrient and water cycling, diminished livestock and wildlife forage production, and increased wildfire frequency (Sheley et al. 2008). Concerns related to biodiversity as well as food and habitat resources for sage-grouse (*Centrocercus urophasianus*) and native pollinators are particularly important for sagebrush-steppe rangelands like the Great Basin (Rowland et al. 2008; Cane 2011; Cane et al. 2013). However, few North American forb species (including legumes) are available for use in restoration projects in the Great Basin. 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. We have developed a process that begins with collections, carries through evaluations and seed production practices, and ends with planting guidelines for rangeland restoration/revegetation (Bhattarai et al. 2008, 2010, 2011; Bushman et al. 2010; Johnson et al. 2008, 2011, 2012, 2013).

Utah trefoil (*Lotus utahensis* Ottley) naturally occurs in the southern Great Basin and the Mojave Basin and Range, a dry region with particular needs for restoration/revegetation. 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. These replicated plantings are under evaluation for plant development, phenology, morphology, seed production, and other physiological characteristics. These initial studies comprise important early stages in our germplasm release process and will provide a scientific basis for ensuring that locally adapted plant materials are characterized and released for use. To these initial studies, it is critical to add research that defines gene-flow and evolutionary patterns of Utah trefoil populations, develops seed germination and emergence protocols for commercial seed production, and identifies best planting practices for rangeland sites.

Methods

We are characterizing the type of differences among collections of Utah trefoil and nearly related taxa in common garden plots in northern Utah, measuring biomass, heading date, seed production, morphological measures, and forage quality/tannin contents. We are also using AFLP DNA-based markers to assess collection relationships and gene flow. We will use multivariate analyses of collection-site environmental data, molecular marker data, and common-garden measures to create appropriate germplasm release strategies.

Hard seededness is a common feature in legume species, which limits initial, uniform germination and subsequent establishment. Based on germplasm selected in the first portion of this research project, the effects of various seed treatments (scarifications, boiling water treatment, and control) and age of seed (newly harvested or one-year-old seed) will be investigated for Utah trefoil. All combinations of these treatments will be tested in a greenhouse to determine which combination of treatments yields the best germination and seedling establishment.

Given the data obtained from first and second portions of this research project, the best treatment combination will be used in field plantings. Seeds from the most promising collections will be planted in replicated 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.

Anticipated Results and Discussion

From the characterization of gene-flow and population relationships, we will be able to identify populations of Utah trefoil and understand how the different seed transfer zones and populations relate to each other. From the greenhouse and field experiments, we will be able to identify the best seed treatments and seeding depths for Utah trefoil. The field experiments will allow us to determine if fall-dormant or spring plantings are the best for establishing Utah trefoil. This information will be published in peer-reviewed journal articles. We will work closely with seed growers and agency personnel to coordinate project activities, and actively participate in technology transfer opportunities. The ultimate outcome of this project will be the establishment of diverse forb species in sagebrush-steppe communities to enhance the food and habitat resources for sage-grouse and native pollinators in the face of global climate change.

Management Applications

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

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SEED INCREASE



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

Project Agreement No. 12-JV-11221632-044

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Project Description

Introduction

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

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

Objectives

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

Methods

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

Many of the test sites had sagebrush removed and were then tilled as part of seed bed preparation. Bluebunch wheatgrass plugs were planted into numerically identified study blocks consisting of several seed zones in all 16 sites, September through December, 2014 (Figures 2, 3, 4, 5 and 6). Two bluebunch cultivars, Anatone and Goldar, were also planted at select study locations. Two rows of

boundary plants were planted as protective borders for the bluebunch plugs at each site. After planting, plugs were watered (Figure 7) and plant identification numbers were recorded for future data collection (Figure 8).

Results

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



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

Table 1. EOSS Assistance – Planting Sites.

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



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



Figure 3. Francis Kilkenny sorting bluebunch plugs for planting.



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



Figure 5. Berta planting bluebunch wheatgrass plugs.



Figure 6. Crew planting plugs in the Steens Mountains.



Figure 7. Watering plugs after planting.



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

Management Applications and/or Seed Production Guidelines

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

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Project Title Seed Increase of Great Basin Native Forbs and Grasses for Restoration Research Projects

Project No. 14-JV-11221632-135

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Project Description

Seed was to be increased of selected Great Basin native forbs and grasses for restoration research projects. During the last year seed was increased for bluebunch wheatgrass (*Pseudoroegneria spicata*) and winterfat (*Krascheninnikovia lanata*).

Introduction

Bluebunch wheatgrass (*Pseudoroegneria spicata*) and winterfat (*Krascheninnikovia lanata*) are important forage species for both livestock and wildlife in the intermountain West. Commercial releases of bluebunch wheatgrass have not proven to be adapted to all Great Basin environments. The use of specifically adapted ecotypes could be an important advance to ensure successful range restorations. The current project efforts seek to increase seed of different ecotypes of bluebunch wheatgrass selected by the U.S. Forest Service in the Great Basin and to increase seed of winterfat for the BLM from Snake River Birds of Prey National Conservation Area in Idaho.



Figure 1. Harvested seed stalks of bluebunch wheatgrass. Malheur Experiment Station, Oregon State University, Ontario, OR.

Materials and Methods

Selections of bluebunch wheatgrass from eight seed zones in the southern sagebrush steppe Great Basin region were planted at the Malheur Experiment Station in Ontario, OR on June 4, 2014. The selections from each seed zone were planted in individual plots with four 30-inch rows which were 20 feet long. Seedlings were planted 12 inches apart in the rows. The plots were located 200 feet apart. Each row was irrigated with one drip tape laid on the soil surface. On March 6, 2015, 50 lb N/acre and 50 lb of P/acre were broadcast on the soil surface. The timing of seed maturity varied between individual plants within each plot. At each harvest, seed from all plants with mature seed within a plot was harvested (Figure 1, Table 1). Seed from each harvest from each plot was kept separate. On October 23, 2015 an additional eight selections from 8 additional seed zones were planted. These selections were from seed zones in the northern part of the Great Basin. Plots for this planting were smaller, having 2 rows 10 to 20 feet long. The selections planted were: N1, N3a, N4, N5, N6a, N6b, N7a, and N7b. The selections were watered manually twice after planting. On January 13, 2016, 50 lb N/acre was broadcast on the soil surface. On January 13, 2016, 50 lb N/acre was broadcast on the soil surface.

Winterfat seeds were received in March 2014 and planted into cell trays in a greenhouse. The seedlings were planted with 12-inch spacing in 30-inch rows on April 29, 2014. Four rows approximately 300 feet long were planted. Each row was irrigated with one drip tape laid on the soil surface. Seed was harvested in the fall of 2014 and given to the BLM at the Snake River Birds of Prey National Conservation Area. A few grams of seed from 2014 was retained and was sown in the greenhouse in the winter of 2014/2015 to provide seedlings for expanding the planting to four 400 feet long rows. The seedlings were transplanted in March of 2015. Seed was again harvested in the fall of 2015.

Results

The amounts of bluebunch wheatgrass seed harvested from each selection for each harvest date are listed in Table 1.

Table 1. Amount of raw uncleaned seed harvested from bluebunch wheatgrass in 2015 from each seed zone selection by harvest date. Malheur Experiment Station, Oregon State University, Ontario, OR.

Selection	Harvest date	Uncleaned seed weight, g
S2A	11-Jun	85.6
	26-Jun	900.0
	14-Jul	152.3
total		1137.8
S3A	12-Jun	34.4
	26-Jun	2131.5
total		2165.9
S4	26-Feb	320.9
	26-Jun	602.6
	14-Jul	53.4
total		976.9
S5	26-Jun	1034.4
	14-Jul	58.4
total		1092.8
S6A	26-Jun	784.6
	14-Jul	31.7
total		816.4
S6B		348.9
	26-Jun	1058.9
	14-Jul	336.7
total		1744.4
S7B	23-Jun	203.9
	26-Jun	1286.4
	14-Jul	13.6
total		1504.0



SPECIES INTERACTIONS



Project Title Drought Effects on the Symbiosis Between Wyoming Big Sagebrush Seedlings and Arbuscular Mycorrhizal Fungi

Project Agreement No. 14-JV-11221632-014

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Project Description

Introduction

Arbuscular mycorrhizal fungi (AMF) are obligate biotrophs that facilitate nutrient uptake in exchange for organic carbon (Smith et al. 2010). Traditionally, the plant-AMF symbiosis has been considered mutualistic (Finlay 2008). However, various results indicate that the symbiosis can range from mutualistic to parasitic depending on the plant-fungus genotype involved in the association and environmental conditions (Klironomos 2003, Jones and Smith 2004). During severe drought, plants close their stomata, which limits carbon uptake. Under these conditions, AMF could become parasitic if the host plant cannot exclude the fungus (Augé 2004, Augé et al. 2014). We investigated this possibility in *Artemisia tridentata* spp. *wyomingensis* (Wyoming big sagebrush) seedlings inoculated with AMF spores of *Rhizophagus irregularis*.

Objectives

- 1) Determine total AMF colonization and the abundance of different mycorrhizal structures after drought-induced stomatal closure.
- 2) Analyze whether drought affects the type of symbiosis that develops between Wyoming big sagebrush seedlings and *R. irregularis*.

Methods

The above objectives were investigated by conducting a completely randomized mesocosm experiment consisting of two inoculation treatments (non-inoculated and inoculated seedlings) and two watering regimens (well-watered and water-stressed seedlings). Initially, Wyoming big sagebrush seeds were germinated in rockwool cubes soaked in a hydroponic solution. After roots emerged from the cubes, seedlings were transplanted to 2 L cone-tainers filled with 1:1 sand:vermiculite mix. At this time, the roots were treated with water for the non-inoculated treatment or a suspension containing 200 spores of *R. irregularis* for the inoculated treatment. These spores were obtained from *in vitro* cultures of this fungus growing in Ri T-DNA transformed carrot roots (Becard and Fortin 1988). After transplanting to the cone-tainers, seedlings were grown in a greenhouse under a 15 h photoperiod and day/night conditions of 20/15 $\pm$ 3 °C. The soil was maintained at field capacity for four weeks

following transplanting. Subsequently some seedlings were kept well-watered, while others experienced a gradual and terminal drought imposed by withholding water from the pots. The effects of drought on the seedlings were monitored weekly by measuring stomatal conductance and photosynthetic electron transport (ETR) with a leaf porometer and a modulated chlorophyll fluorometer, respectively. When water-stressed plants showed negligible stomatal conductance and electron transport, water-stressed and well-watered plants were sampled and analyzed for the presence of different mycorrhizal structures and overall AMF colonization. AMF colonization was determined by the intersection method after staining with Chlorazol black E (McGonigle et al. 1990). For water-stressed seedlings, survival curves were also constructed based on the time at which the seedlings showed ETR values below $5 \mu\text{mol m}^{-2} \text{s}^{-1}$. At this time, leaves were still green, but the seedlings did not recover photosynthetic capacity after rewatering indicating hydraulic failure and death. Statistical differences were evaluated based on a lorank test.

Results and Discussion

After 5 weeks of withholding water, stomatal conductance began to decline in water-stressed plants and after 15 weeks of this treatment, stomatal conductance was negligible (Fig. 1). No differences in stomatal conductance were detected between control and AMF-inoculated plants. Independent of the watering regimen, no colonization was observed in non-inoculated seedlings (data not shown). In contrast, inoculated seedlings had total colonization values above 50% (Fig. 3A). This was observed at the time at which withholding watering was initiated (initial) and at the time when seedlings were harvested for final measurement of colonization. At this time, no differences in total and arbuscular colonization were apparent between well-watered and water-stressed seedlings (Fig. 3A and B). In contrast, vesicles were more abundant in well-watered than in water-stressed seedlings (Fig. 3C). Few spores were detected within the roots and their presence was not affected by the watering regimen (Fig. 3D). Although the percent of root length occupied by hyphae and arbuscules were similar in well-watered and water-stressed seedlings, root growth was higher in well-watered plants (Fig. 4A). Thus, water stress reduced AMF growth within the roots, but just in proportion to the reduction in root growth.

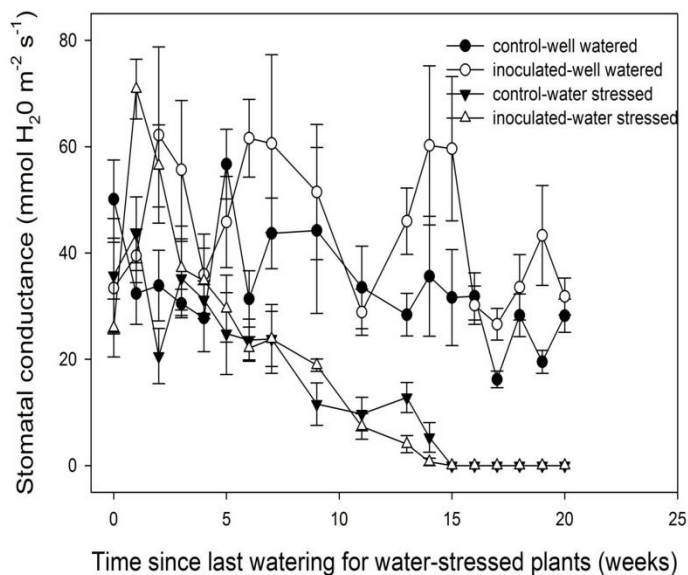


Figure 1. Changes in stomatal conductance of non-inoculated (control) and AMF-inoculated seedlings. Symbols represent means ($\pm$ standard errors) of 5 measurements for the well-watered seedlings and 20 measurements for the water-stressed ones. Water stress also decreased ETR (Fig. 2A). However, ETR was not affected by the inoculation treatment. Under water stress, ETR tended to be lower in inoculated than control seedlings; but for most of the days measured, the differences were not significant (Fig. 2A). As water stress continued, individual seedlings showed a rapid decline in ETR to zero (Fig. 2B), which was irreversible.

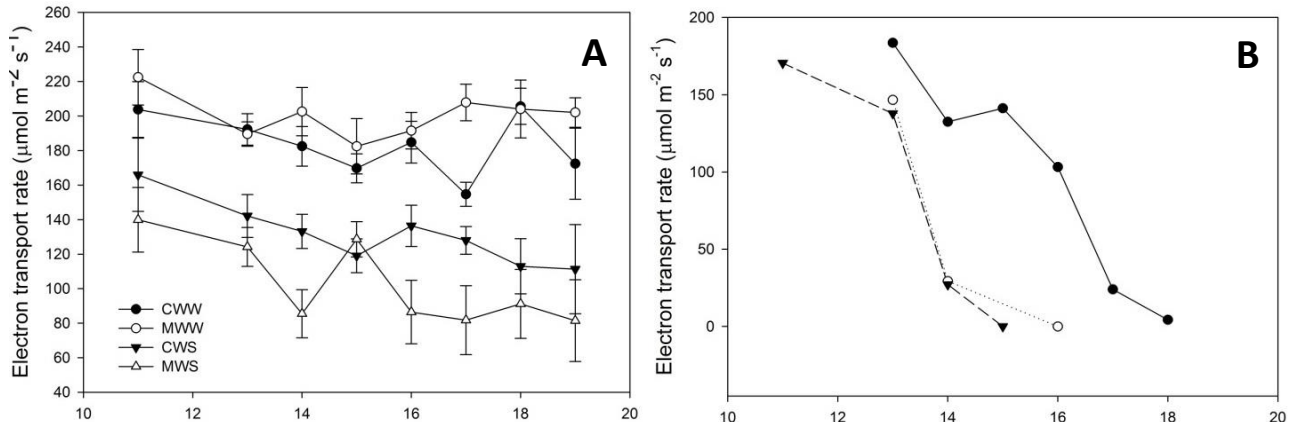


Figure 2. **A**, Average values of electron transport rates (ETR) for control well-watered (CWW), inoculated well-watered (MWW), control water-stressed (CWS), and inoculated water-stressed (MWS) sagebrush seedlings. **B**, Representative curves showing the rapid and final declined in ETR in three individual seedlings. Symbols in **A** represent means ($\pm$ SE) of 5 measurements for the well-watered seedlings and 20 measurements for the water-stressed ones.

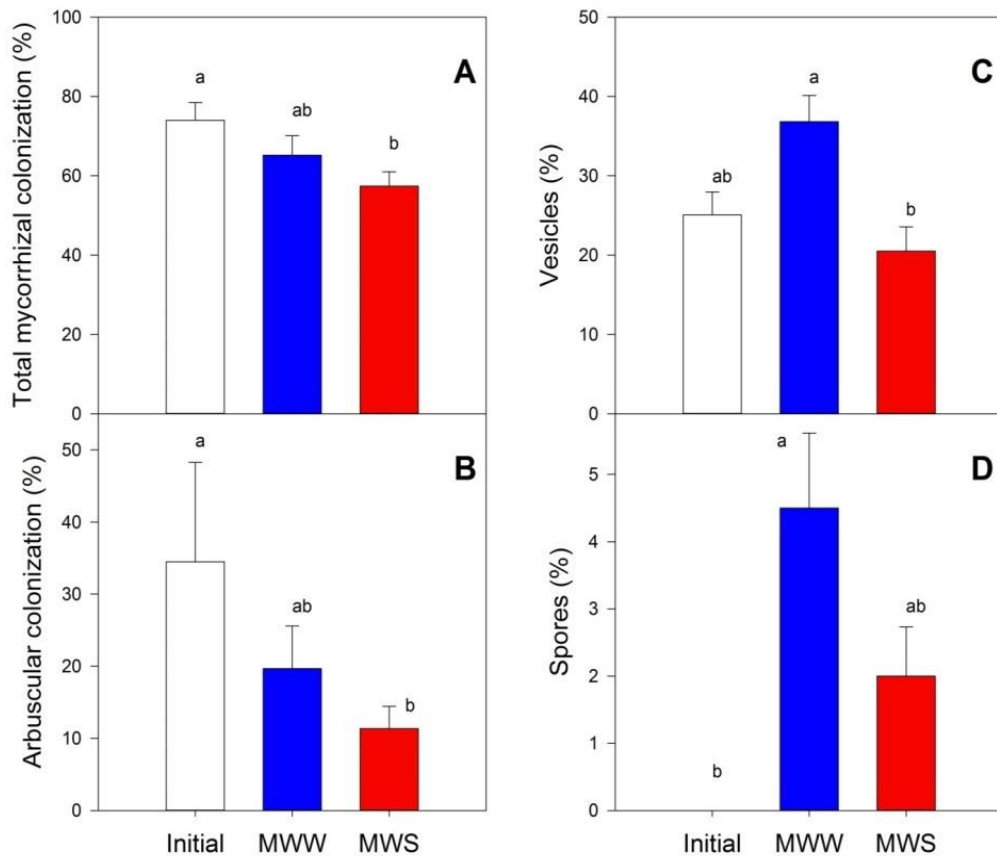


Figure 3. Mycorrhizal colonization of inoculated seedlings at the time of the last watering in water stressed plants (Initial), 20 weeks after this time in well-watered seedlings (MWW), and when electron transport was negligible in water-stressed seedlings (MWS). Bars represent means ($\pm$ SE) of 6 to 10 seedlings. Means not labeled by the same letter are significantly different ($p < 0.05$).

Overall, the results indicate that after closing their stomata due to severe drought, Wyoming big sagebrush seedlings remained colonized by AMF. Under these conditions, the seedlings were presumably not gaining carbon, while some carbon was likely needed to maintain the AMF. The presence of arbuscules, in particular, suggests that some exchange of nutrients occurred after stomatal closure. Arbuscules have rapid turnover and consequently it is unlikely that they represented non-active structures remaining from earlier colonization (Alexander et al. 1989, Vierheilig et al. 2005). Transfer of carbon to the fungus without a carbon gain by the plant would have led to a parasitic symbiosis (Jones and Smith 2004). This notion found support in the results from the survival analysis. After 91 days without watering survival was higher in inoculated than non-inoculated seedlings ($p = 0.004$, Fig. 4B). However, this trend was reversed as the period without watering lengthened. When only the survival that occurred after 91 days was considered, survival was higher in non-inoculated than inoculated seedlings ($p = 0.005$). As result of these two opposite trends, no significant differences in survival were detected between non-inoculated and inoculated seedlings at the end of the experiment ($p = 0.4$). The results from the survival analysis are, however, preliminary. This analysis was based on only 20 seedlings per treatment; experiments with a larger number of seedlings are needed to ascertain the survival patterns observed.

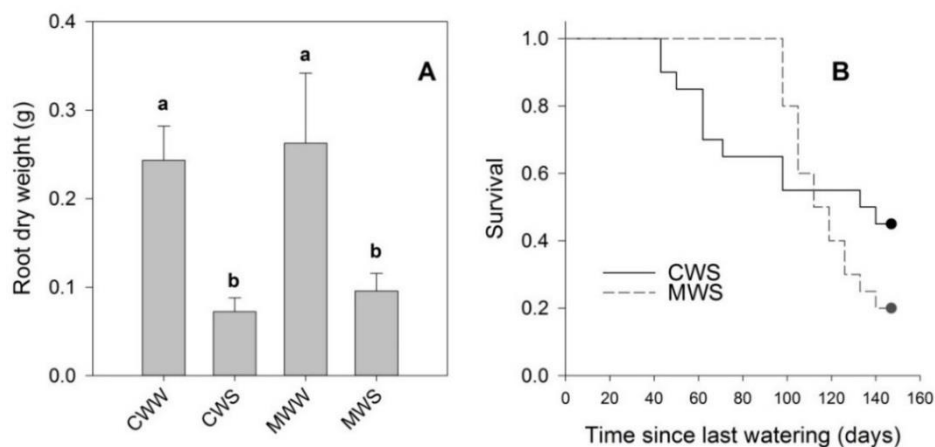


Figure 4. Effects of AMF colonization on root growth (**A**) and survival (**B**) of Wyoming big sagebrush seedlings. In **A**, bars represent means ($\pm$ SE) of 5 seedlings for the well-watered treatments (CWW and MWW) and 20 seedlings for the water-stressed ones (CWS and MWS). Means not labeled by the same letter are significantly different ($p < 0.05$).

Management Applications

Inoculation of seedlings with AMF is a common practice aimed at improving seedling establishment (Allen 1989, Turnau and Haselwandter 2002, Navarro Garcia et al. 2011). The success of this practice depends on the formation of a mutualistic symbiosis between the plant and the fungus. However, several factors can affect the nature of this symbiosis. Our preliminary data suggests that under severe water stress, the association of Wyoming big sagebrush seedlings with *R. irregularis* became parasitic. To alleviate this problem, additional management practices may be needed. In this regard, a possibility would be to utilize nurse plants (Padilla and Pugnaire 2006). Through a common mycorrhizal network, the larger, nurse plant would provide an alternative source of carbon to the AMF reducing their dependence on the young seedlings (Selosse et al. 2006). In addition, it is

plausible that the ability of sagebrush to exclude AMF under drought depends on the particular AMF involved in the association (Klironomos 2000; Finlay 2008). Although *R. irregularis* is common in sagebrush ecosystems (Carter et al. 2014), the particular strain that we used is not native to sagebrush habitats. The use of a native inoculum may result in a different response than the one observed, where the seedlings are able to exclude the fungus under severe water deficits. Current work is aimed at testing this notion.

Presentations

Velasco, J.; Smith, J. F.; Serpe, M. D. 2015. Drought effects on colonization of *Artemisia tridentata* seedlings by arbuscular mycorrhizal fungi. Botanical Society of America annual meeting; 25-29 July; Edmonton, Alberta.

Abstract: Arbuscular mycorrhizal fungi (AMF) are obligate biotrophs that facilitate nutrient uptake in exchange for organic carbon. Traditionally, the plant-AMF symbiosis has been considered mutualistic. However, various results indicate that the symbiosis can range from mutualistic to parasitic depending on the plant-fungus genotype involved in the association and environmental conditions. During severe drought, plants close their stomata, which limits carbon uptake. Under these conditions, AMF could become parasitic if the host plant cannot exclude the fungus. We investigated this possibility in *Artemisia tridentata* seedlings inoculated with AMF spores of *Rhizophagus irregularis*. Seedlings were initially grown under well-watered conditions. Subsequently some seedlings were kept well-watered, while others experienced a gradual and terminal drought. The effects of drought on the seedlings were monitored weekly by measuring stomatal conductance and photosynthetic electron transport. When water-stressed plants showed negligible stomatal conductance and electron transport, water-stressed and well-watered plants were sampled and analyzed for AMF colonization. Total AMF colonization was 62 (± 13) and 67 (± 17) % for well-watered and water stressed plants, respectively. Similarly, arbuscular colonization was 27 (± 4) and 27 (± 11) % for well-watered and water-stressed plants. The lack of significant differences in total and arbuscular colonization between well-watered and water stressed plants indicates that *A. tridentata* seedlings did not exclude *R. irregularis* under drought. This may lead to a parasitic symbiosis under severe water stress.

Davidson, B. E.; Smith, J. F.; Serpe, M. D. 2015. Community structure of arbuscular mycorrhizal fungi colonizing *Artemisia tridentata* seedlings following inoculation and transplanting. Botanical Society of America annual meeting; 25-29 July; Edmonton, Alberta. [Poster]

Abstract: Inoculation of seedlings with arbuscular mycorrhizal fungi (AMF) can alter the AMF taxa present in the roots after transplanting. This may occur even when native AMF is used as the inoculum because the environmental conditions and hosts that are used for AMF multiplication are different from those in natural habitats. The effect of inoculation on AMF composition was investigated in seedlings of *Artemisia tridentata* ssp. *wyomingensis* inoculated with native AMF. Seedlings were first grown in a greenhouse in sterilized soil (non-inoculated seedlings) or soil containing a mixture of native mycorrhizal species (inoculated seedlings). Three-month old seedlings were transplanted outdoors to 24 L pots filled with soil from a sagebrush habitat or to a recently burned sagebrush habitat. At the time of transplanting the percent colonization was negligible for non-inoculated seedlings and ranged between 24 to 81% for the inoculated ones. Three, 5, or 8 months after transplanting colonization was about twofold higher in inoculated than non-inoculated seedlings. To characterize the effect of inoculation on the AMF community, DNA was extracted from the roots and amplified with AMF specific primers. The AMF taxa were characterized based on sequences from the LSU-D2 rDNA region. A total of 6 phylotypes were

identified, two within the Claroideoglomeraceae and four within the Glomeraceae. In addition, sequences were grouped into operational taxonomic units (OTUs) with sequence similarities higher than 94%. This resulted in the identification of 29 OTUs. Ordination analyses, using non-parametric multidimensional scaling, indicated that inoculation did not alter the structure of the AMF community. Individual seedlings, regardless of inoculation treatment, were simultaneously colonized by AMF belonging to 3 to 6 OTUs. The lack of significant differences in AMF communities among inoculation treatments appeared to have been related to the predominance of certain OTUs. In all experiments and treatments, four OTUs were dominant. Overall, the results indicate that the inoculum generated from native AMF contributed to the colonization of roots that developed after transplanting, resulting in higher levels of colonization than those naturally occurring in the soil without altering the AMF community.

Serpe, M. D.; Davidson, B. E. 2015. Improvement in colonization and seedling survival of Wyoming big sagebrush seedlings following inoculation with native arbuscular mycorrhizae. National Native Seed Conference; 13-16 April; Santa Fe, New Mexico.

Davidson, B. E.; Serpe, M. D. 2015. Community structure of arbuscular mycorrhizal fungi colonizing Wyoming big sagebrush seedlings transplanted to the Snake River Birds of Prey, NCA. Great Basin Consortium Conference; 17-19 February; Boise, Idaho.

Publications

Davidson, B. E. 2015. Consequences of pre-inoculation with native arbuscular mycorrhizae on root colonization and survival of *Artemisia tridentata* ssp. *wyomingensis* (Wyoming big sagebrush) seedlings after transplanting. Boise, ID: Boise State University. 104 p. Thesis.

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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 seeding 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 will compile cover and density data and assess species establishment and persistence with respect to environmental parameters, restoration treatments, and seeding techniques. We will use effect-size analysis (e.g., log response ratio of pre/post species cover and density). 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 also will characterize soil properties (texture, pH, organic matter) using the USDA web soil survey (<http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm>), environmental parameters (precipitation and temperature variables, slope, aspect) using PRISM climate data (<http://www.prism.oregonstate.edu>), and wildlife/livestock impacts using information contained in WRI reports to assess their influence on seeding success (Obj. 1). We also will characterize species by the traits prioritized during development of plant materials as well as life form, growth form and phenological pattern, tolerance to grazing and drought, and seeding rate to decipher their association with seeding success (Obj. 2). Finally, we will calculate treatment and seeding costs from WRI reports and quantify the cost effectiveness and efficiency of each seeding project (Obj. 3).

Expected Results and Discussion

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.

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Project Title Impacts of Climate Change and Exotic Species to 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 increasingly difficult due to 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).

In addition to assisted migration of key native plants as part of restoration, simultaneous transfer of 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. 2011, Grady et al., in review). 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). One approach to study if plant interactions have evolved is to compare fitness of inter- and intraspecific competition pairs between plants that have either a sympatric (i.e., sourced from the same location/population) or allopatric neighbor (i.e., sourced from a different location). A fitness advantage from growing next to a sympatric neighbor indicates an evolved interaction, generally due to either evolved niche differentiation or facilitation.

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 micro-organisms) may increase restoration effectiveness. Understanding this community genetic “interactome” is critical for advancing restoration practice and theory during rapid environmental change.

Objectives

We propose to investigate the importance of maintaining community interactions for restoration using a common garden provenance approach. This research will build upon current research in which we are investigating the effectiveness of adding live and commercial soil microbial inoculum during revegetation of *Artemisia tridentata*, *Elymus elymoides*, and *Achnatherum hymenoides* with and without competition by *Bromus tectorum* at three common gardens (Mountain Home, Idaho; west Salt Lake, Nevada; Fredonia, Arizona). Our group includes experts in plant and microbial genomics and the application of genomic approaches for restoration.

We will expand one of the three common gardens that we have developed to include a plant genetic by community interaction experiment to test the following hypotheses: 1) Genetic variation across the thermal range of *A. tridentata* and *A. hymenoides* is correlated to past climate such that plants are locally adapted, 2) Competition with exotic species reduces plant fitness and exacerbates maladaptation due to climate change, 3) Inoculation with locally adapted soil microbes will decrease the negative impacts of competition with exotic species, 4) Both intra- and inter-specific plant interactions are less competitive when plants are grown with sympatric neighbors (i.e., sourced from the same location) compared to allopatric neighbors (i.e., sourced from different locations), especially in the presence of exotic species, and 5) Sympatric benefits are greatest when inoculated with soil microbes, together reducing negative impacts from maladaptation and exotic species. 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 one common garden at the core of the distribution of both *A. tridentata* and *A. hymenoides*. This common garden is located west of Salt Lake City on the Hill Airforce Base with a mean minimum January temperature of -7° C, a mean maximum July temperature of 32° C and annual precipitation of 165 mm. At the site, we have installed fencing to reduce browsing, a 4,000 gallon (15,141 L) water tank and irrigation lines, and a weather station. This infrastructure was established for ongoing research sponsored by a grant from the Department of Defense (DoD). This previously funded grant creates a synergy with GBNPP as we have established garden infrastructure, coordination with local groups that can help with planting and watering, we have already collected germplasm that can be used in this experiment, and we have analyzed DNA of soil microbes in the experimental garden and in the live soil inoculum. The DoD grant did not include a genetic component nor a native plant interaction experiment.

Experimental Design

From prior research, we have collected seeds from nine separate locations for *A. tridentata* and *A. hymenoides*. In each of three regions (southern Idaho, central Utah, and northern Arizona), we have collected seeds from three populations across an elevation gradient, with each population separated by approximately 300 meters in elevation. At the common garden, we will plant greenhouse-grown seedlings into three blocks of each of the following four treatments for a total of 12 blocks: 1) live soil inoculation, exotic species competition, 2) no inoculation, exotic species competition, 3) live soil inoculation, no exotic species competition, and 4) no inoculation, no competition. Each garden is located in a cheatgrass-infested field. The no competition treatment will be created by hand removal of *B. tectorum*. Soil inoculation treatments include collecting live soil inoculum from a local source

(within 1km from the garden) from the rhizosphere underneath either *A. tridentata* or *A. hymenoides*. We will evaluate population variation in response to climate, inoculation, and competition with *B. tectorum* by planting nine seedlings from each of nine populations for each species in each of 12 blocks for a garden total of 1,944 plants.

We will evaluate if plants benefit from sympatric neighbors (either intra- or interspecific), and if these benefits increase in the presence of exotic species and with microbial inoculation. In two blocks from each of the four treatments described above, we will plant six intra-specific sympatric pairs (12 plants) from three populations (one from each region: ID, UT, AZ) for each species; 12 intra-specific allopatric pairs (24 plants) for each species; six inter-specific sympatric pairs (12 plants) from each of three populations; 12 inter-specific allopatric pairs (24 plants).

Measurements

We will measure growth (height, canopy diameter, diameter at root collar, aboveground biomass), survival, plant physiological traits (specific leaf area, leaf nitrogen content), and determine fungal communities and infection rate using microscopy approaches.

Statistical Procedures

We will compare among treatments using a combination of analysis of variance and restricted maximum likelihood procedures at both the block level ($n=3$ for population variation among nine populations) and at the individual plant level ($n = 27$ per population); or for sympatric/allopatric comparison at the plant pair level ($n = 18$ allopatric pairs or 36 individuals and $n = 12$ sympatric pairs or 24 individuals).

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SCIENCE DELIVERY



Project Title Science Delivery for the Great Basin Native Plant Project

Project Agreement No. 14-JV-11221632-018

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Project Description

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

Objectives

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

Results and Discussion

Accomplishments related to the identification and sharing of GBNPP scientific developments include:

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

Project Title SeedZone Mapper Smartphone 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.

Objectives

Develop a smartphone (iOS and 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.

Methods

An ESRI/Leaflet browser app was developed as a prototype to test proof-of-concept for the smartphone app (http://fs.bioe.orst.edu/web_maps/Seed_Zones.html). Leaflet is a lightweight library that is responsive and is compatible for many devices from PC's to tablets to phones (iOS, Android). The simple interface allows the user to access their location and get a popup with the seed zone. This is where we want to go with the app, but need to configure it for off-line use. This product is being researched further and is a solution that remains on the table.

Development and programming of smartphone apps has become a competitive and expensive business. “Off –the-shelf” solutions are available, but often they do not meet all the needs of a specific project. We have researched a number of products, including Fulcrum, ESRI (Collector, Explorer) Avenza PDF maps, MapBox, and a few others. As expected, each application does well in some areas, but poorly in others.

We have contacted Digital Visions (a USFS enterprise team) who developed a proposal for app development, but it did not meet our objectives. We also have engaged with the CIO mobile apps group, but at this time they are working on infrastructure to brand and distribute mobile apps, not develop them.

A strong contender is the S1 Mobile App (<http://www.blm.gov/or/gis/mobile/s1mobile/>) developed jointly for the Bureau of Land Management/USFS Region 6 in Oregon. This powerful product may meet our needs with some modifications and we are currently exploring this as an avenue for a final product.

Expected Results and Discussion

A list of desired features for the smartphone app has been compiled, and includes:

1. Android and iOS usability.
2. Off-line functionality.
3. Pop-up with the seed zone parameters.
4. Ability to host locally on the device the CONUS seed zone layer.
5. Ability to host a variety of tiled basemaps – imagery, topos, agency-specific maps, roads.
6. Easy updating of the app (basemaps, etc.) when in a connected environment.
7. No USFS firewall issues, i.e. no datasets that are internal only.
8. Ability to collect geospatial data (i.e. contractor collects a point with quantity and species of seed collected, date, slope, aspect, etc.).

An app that includes these features will allow land managers and seed collectors (both agency and contractors) to easily access and use the provisional seed zones while in the field (in an off-line environment). This will improve efficiency and effectiveness of activities such as seed collection, seed movement decision-making, restoration planning, and project implementation.

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CRESTED WHEATGRASS DIVERSIFICATION



Project Title Presence of Native Vegetation in Crested Wheatgrass (*Agropyron cristatum*) Seedings and the Influence of Crested Wheatgrass on Native Vegetation

Project Agreement No. 11-IA-11221632-003

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Project Description

Objectives

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

Methods

We sampled 120 crested wheatgrass plant communities in southeastern Oregon between May and August 2012, and June and September 2013 to investigate which factors promote native plant recruitment in crested wheatgrass plant communities. At each plot slope, aspect, elevation and UTM location were recorded.

Sites were selected with input from Bureau of Land Management professionals to represent a wide range of management practices such as: timing (spring or fall), intensity (distance to water/fence lines) of grazing, range of time since seeding, and other environmental factors (elevation, aspect and slope, and proximity to untreated areas).

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

Soil samples were collected at three locations in each plot with a 61 cm (24 in) hole located at the center of the plot and at 15 m NW and SE of the center of the plot. From each of these holes soil samples were taken from 0-15 cm, from 0-20.3 cm (0-8 in), and from 20.3-61 cm (8-24 in). Depth to hardpan was recorded if it fell within the 61 cm (24 in). The values for each of the samples per plot were averaged into a single plot value. Soil texture for the 0-8 inch and 8-24 inch samples was measured using the hydrometer method. The 0-15 cm samples were used to obtain soil pH, nitrogen, carbon, and total organic matter for each site.

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

Results and Discussion

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

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

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

Environmental factors explained as little as 0% of the variability in annual grass density and as much as 56% of the variability of large bunchgrass density. Perennial forb basal cover, annual grass and Sandberg bluegrass (*Poa secunda*) basal cover and density variability were also well explained (43-46%) by environmental factors.

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

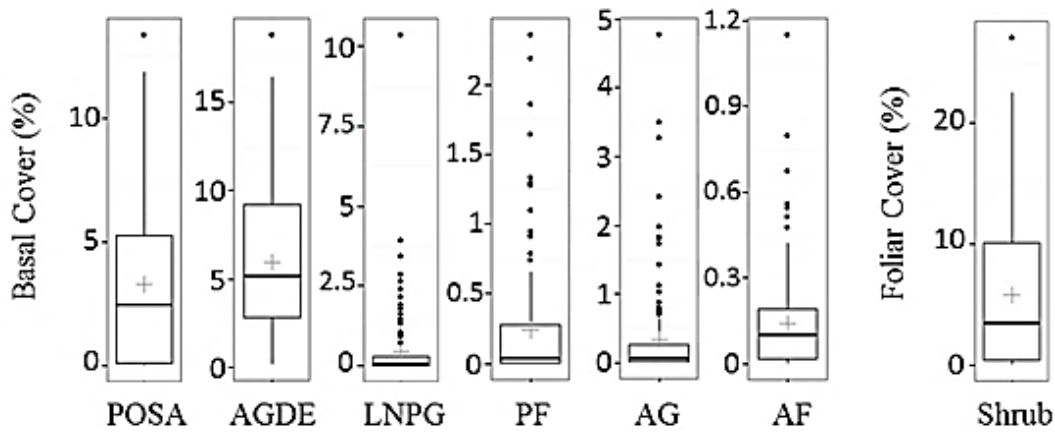


Figure 1. Boxplot showing the percent basal cover of Sandberg bluegrass (POSA), crested wheatgrass (AGDE), large native perennial bunchgrass (LNPG), perennial forbs (PF), annual grass (AG), annual forbs (AF) and foliar cover (%) of shrubs across 121 crested wheatgrass stands sampled in southeastern Oregon. The median is shown as the solid black line, the mean is depicted as a grey cross. The upper and lower ends of the box correspond to the first and third quartiles (the 25th and 75th percentiles). Whiskers extend from the 25th and 75th percentiles to the lowest or highest value that is within 1.5 * the inter-quartile range. Data beyond the end of the whiskers are outliers and plotted as points (as specified by Tukey).

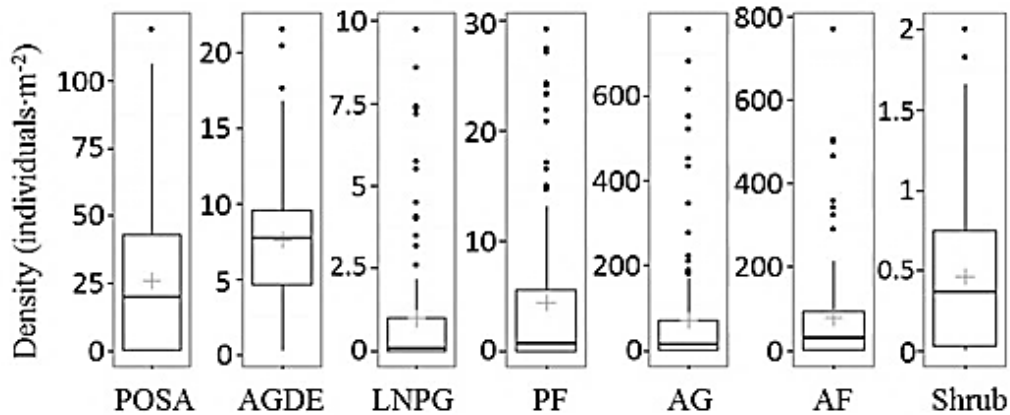


Figure 2. Boxplot showing density (plants·m⁻²) of Sandberg bluegrass (POSA), crested wheatgrass (AGDE), large native perennial bunchgrass (LNPG), perennial forbs (PF), annual grass (AG), annual forbs (AF) and shrubs across 121 crested wheatgrass stands sampled in southeastern Oregon. The median is shown as the solid black line, the mean is depicted as a grey cross. The upper and lower ends of the box correspond to the first and third quartiles (the 25th and 75th percentiles). Whiskers extend from the 25th and 75th percentiles to the lowest or highest value that is within 1.5 * the inter-quartile range. Data beyond the end of the whiskers are outliers and plotted as points (as specified by Tukey).

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

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

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

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

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

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

Sagebrush cover and density were negatively correlated with precipitation in the year after seeding and the interaction between precipitation and fire and was positively correlated with seeding age and

time since fire (adj. $R^2 = 0.34$ and 0.34 , $p < 0.001$). Sandberg bluegrass, perennial forb, and shrub density varied by pre-seeding treatment/disturbance. These results suggest that pre-seeding treatment/disturbance and precipitation following seeding significantly influence the plant community characteristics of crested wheatgrass stands.

Large native perennial bunchgrass density and basal cover (Fig. 3) were 20- to 30-times greater in grazed compared to ungrazed crested wheatgrass seedings ($p = 0.01$ and 0.01). Sagebrush density and cover (Fig. 3) was 16- and 14-fold greater in the grazed compared to ungrazed crested wheatgrass stands. Density and cover (Fig. 3) of other native plant groups were also greater in grazed compared to ungrazed crested wheatgrass plant seedings. Grazing appears to reduce the competitiveness of crested wheatgrass and thereby allows a greater expression on native vegetation in crested wheatgrass stands.

Future Plans

We will be preparing the final manuscript with plans to submit to Rangeland Ecology & Management. We also will be revising as needed the manuscript submitted to Journal of Arid Environments. We will be presenting some of our findings at the Society for Range Management Meetings in Texas in February 2016.

Management Applications

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

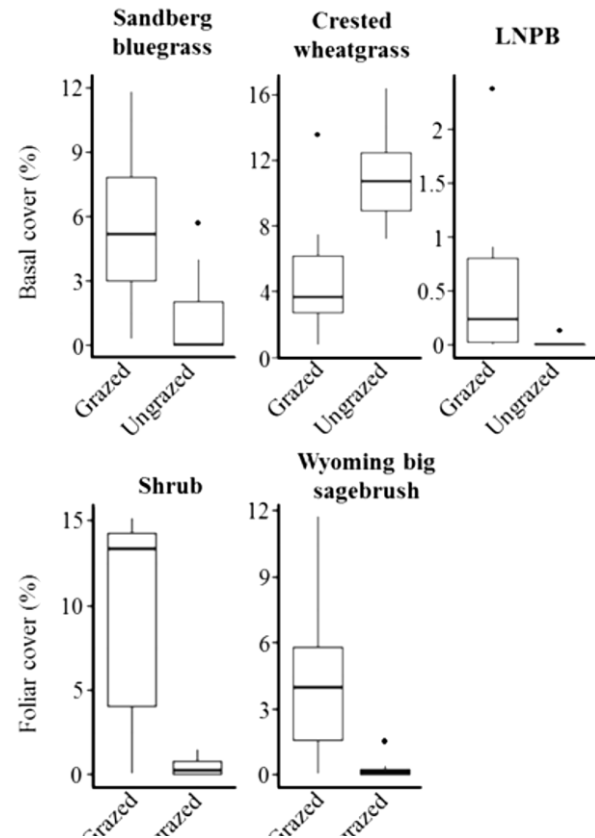


Figure 3. Basal cover (%) of Sandberg bluegrass, crested wheatgrass, and large native perennial bunchgrasses (LNPB) and foliar cover (%) of shrubs and Wyoming big sagebrush on crested wheatgrass seedings that were grazed ($n = 6$) or ungrazed ($n = 6$). Grazed and ungrazed sites had similar soil texture, location, seeding age, and time since fire. Functional groups and species were compared using Wilcoxon rank sums and were significantly different at $p < 0.05$.

Presentations

Davies, K. W.; Nafus, A. M.; Svejcar, T. J. 2015. Vegetation characteristics of crested wheatgrass stands vary by seeding year precipitation, disturbance history, and management. Society for Rangeland Management Meeting; 2015 February; Corpus Christi, TX.

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RESTORATION STRATEGIES



Project Title Herbicide Impacts on Forb Performance in Degraded Sagebrush Steppe Ecosystems

Project Agreement No. 14-CR-11221632-067

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Project description

Invasion of sagebrush ecosystems by cheatgrass (*Bromus tectorum*) leads to loss of ecosystem structure and function. Restoration efforts are required to re-attain an intact native plant community. Restoration treatments can include: mowing, herbicide applications, a combination of mowing and herbicide applications, and grazing; but if these treatments promote soil resource availability they may further reduce the resistance of the ecosystem to invasion. Further, herbicide applications may negatively impact native vegetation, with cascading effects on other native populations such as sage grouse (*Centrocercus urophasianus*).

This study aimed to:

1. Assess how mowing, grazing and herbicide treatments impact soil microbial activity and soil nitrogen (N) availability.
2. Evaluate the impact of imazapic on forbs native to the sagebrush steppe ecosystem by:
 - (a) Quantifying how different application rates (concentrations) affect forb performance.
 - (b) Determining how the timing of imazapic application relative to seeding of forbs impacts forb performance.
 - (c) Measuring whether a fire-induced change in soil microbial activity mediates the impact of imazapic on soils. Results indicated that mowing, herbicide applications, a combination of mowing and herbicide applications, and grazing do not impact soil microbial activity and alter soil nutrient availability if abiotic conditions, such as drought, limit biological processes in semi-arid ecosystems.

Imazapic applications significantly impacts performance of *B. tectorum*, as well as performance of native forbs (*A. filipes*, *A. millefolium*, and *S. grossularifolia*) regardless of concentration and timing of application. This suggests that imazapic is not specific to cheatgrass, and that the use of imazapic could negatively impact native vegetation that are essential to the survival of sage grouse. Although imazapic negatively impacted *A. filipes*, *A. millefolium*, and *S. grossularifolia* performance, the response of *A. filipes* to imazapic applications was significantly less negative than that of the other

species, indicating a need for additional studies to evaluate how plant functional types may mediate impacts of imazapic on their performance.

Introduction

Disturbance of native plant communities by invasive non-native plant species is a global problem, because invasion leads to reduced plant diversity, ecosystem function, and ecosystem services (Chapin et al. 2002). In the intermountain west of North America, invasion of the winter annual cheatgrass (*Bromus tectorum*) has significantly altered the native Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) ecosystem (e.g., Knapp 1996). Cheatgrass has invaded thousands of square kilometers, accounting for about 20 percent of the historic sagebrush-bunchgrass communities, and in those areas cheatgrass accounts for almost 100 percent coverage (Knapp 1996). The spread of cheatgrass has reduced the ecosystem's fire regime from 60-110 years (Whisenant 1990) to 3-5 years (D'Antonio and Vitousek 1992), thus exacerbating its impact on ecosystem structure and function. Wyoming big sagebrush is a shrub that was distributed on more than 60 million hectares in the western region of North America (West 1983) and as a foundation species (Prevey et al. 2010) it provides valuable habitat for other native plant and animal species, such as sage grouse (*Centrocercus urophasianus*) and pygmy rabbits (*Brachylagus idahoensis*) (Busby 2011). While cheatgrass is able to recover quickly after a fire, the short fire return interval prevents the recovery and re-establishment of native plant species. Consequently, restoration efforts are necessary to re-attain an intact native plant community.

Cheatgrass invasion may be suppressed with a suite of management tools including mowing, grazing and herbicide applications, but whether these treatments lead to the desired restoration outcomes remains questionable (Pyke et al. 2013). To improve our understanding of these types of management tools on ecosystems, restoration projects could benefit from an explicit recognition of treatment-induced changes in plant-soil feedbacks (Kardol and Wardle 2010). Namely, fuel reduction treatments – mowing and grazing in particular – can alter plant-soil feedbacks by increasing soil resources, thereby inadvertently promoting growth of the plant species that's most likely to invade (Prevey et al. 2010). Resource availability in soils is a key variable that can explain the potential success of restoration treatments because, according to ecological theory, native plants fare best when resources are adequately depleted (e.g., Tilman et al. 1997); and vice versa, increases in resource availability in space or time can reduce resistance to invasion by cheatgrass in native plant communities (Prevey et al. 2010). Thus quantifying impacts of restoration treatments on the processes that drive soil nutrient availability will improve our understanding of the effectiveness of restoration projects.

The pre-emergent herbicide imazapic, which kills plants by inhibiting the production of branched chain amino acids, can be an effective herbicide for cheatgrass control but it may negatively impact native species (Baker et al. 2009). To date, contrasting results have been generated about its impact on performance of non-target species, such as forbs native to the sagebrush steppe ecosystem that are essential for sage grouse survival (Shinn and Thill 2002, 2004; Kyser et al. 2007; Baker et al. 2009). The impact of imazapic on non-target species may hinge on the amount of imazapic applied to the system and on its persistence in the soil from where it can affect plant growth. Imazapic persistence in the soil depends on imazapic degradation rates which are primarily driven by the soil microbial community (Grymes et al. 1995). Imazapic has an average half-life in soil of 120 days (Grymes et al. 1995) but, in dry lands, such as a semi-arid desert, microbial activity is frequently limited by water availability, which may prolong the predicted half-life time of imazapic in soil. Further, these soils

are frequently subjected to fire, which can impact the soil microbial community and its activity (Hart et al. 2005), thus potentially changing the decay rate of imazapic.

Methods

Field Experiment

To evaluate how different restoration methods may impact soil microbial activity and N mineralization, a manipulative field experiment was conducted on a loam soil at the Morley Nelson Birds of Prey National Conservation Area (BOP-NCA) in southwestern Idaho (lat. 43°13'50"N, long. 116°19'20"W). The historical plant community was dominated by *A. tridentata* subsp. *wyomingensis* and secondarily by *A. tridentata* subsp. *tridentata*, but multiple fires (with the last fire occurrence in 1987) and past land use eliminated them from the study area and much of the surrounding landscape. Before the experimental treatments, the plant community was dominated by cheatgrass, a non-native tumble-mustard (*Sisymbrium altissimum* L), and Sandberg's bluegrass (*Poa secunda* J Presl, an early seral perennial). Experimental plots (1 ha) located within three large replicate blocks were treated with a full-factorial, completely randomized combination of fuel reduction/native plant restoration treatments: mowing, mowing + herbicide, herbicide application, and control (no treatment), with half of all plots grazed by sheep (12.8 ac/AUM) in 2013, while the other half was not grazed. Herbicide plots were prep-mowed in April 2012, and mowing-only and mowing + herbicide plots were mowed in May 2012. Mowing was to 10 cm stubble height using a tractor-pulled rotomower. Herbicide plots received 280 g ha⁻¹ of glyphosate with a boomless sprayer without surfactant in April 2012 following mowing, and then 280 g ha⁻¹ of imazapic with Hasten surfactant via a calibrated boom sprayer in October 2012 (for more site information see also: Brabec et al. 2015).

In June of 2014 (two years following initiation of the experiment), we collected soil samples from field plots that received the following treatments: (1) herbicide applications, (2) mowing, (3) a combination of mowing and herbicide applications, and (4) control (i.e., receiving no treatments). Each one of these plots was either grazed or not grazed, and these plots were not seeded. We collected ten subsamples of soil across each plot (5 cm depth) using an Edelman Combination Auger (<http://www.ams-samplers.com>). Following collection, subsamples were composited into one sample, such that we obtained one composite sample per treatment across the replicates (n=3). Immediately upon sampling the individual soil cores were composited, sieved to 2 mm, and visible roots >2 mm in length were removed. Soils were stored at 6°C for approximately 2 weeks.

We conducted a 60 day controlled laboratory incubation study with the soils to evaluate the impact of the treatments on potential C decomposition rates. The soil (40 g dry weight) was incubated for 90 days in 1 L Mason jars containing four 50 ml centrifuge tubes filled with 10 g soil each. Temperature was maintained at 20° C, and soil moisture was kept at 60% of water holding capacity. Soil water-holding capacity was determined by the difference in weight for soils at saturation and at oven dry (100° C), and water was added as needed during the experiment to maintain a soil moisture content of 60% saturation. Further, 5 mL of water was added to the bottom of each jar to prevent soil drying. The mason jars were tightly sealed, and a septum in the jar lid allowed gas samples to be removed from the headspace with a 10 mL syringe. Soil CO₂ evolution was measured on days 1, 3, 7, 15, 30, and 60 of the incubation. Following each gas sampling event, the caps were removed and the jars were flushed with air for 30 minutes. Respiration rates were analyzed on four sub-samples per replicate using a LI-7000 infrared gas analyzer (IRGA, LICOR Corp., Lincoln, NE). Nitrogen mineralization was measured using a potential N mineralization assay. Soils were extracted with 2M KCl on days 0, 7, 15, 30 and 60. We analyzed the concentration of NO₃ via manual vanadium (III) reduction, and the concentration of NH₄ using a Berthelot reaction (Forster, 1995).

Greenhouse Experiment

To assess how imazapic applications may affect the performance of native forb species: milkvetch (*Astragalus filipes*), common yarrow (*Achillea millefolium*), and Gooseberryleaf globemallow (*Sphaeralcea grossularifolia*), we conducted two greenhouse experiments in which we: (1) applied a gradient of imazapic concentrations (hereafter ‘the imazapic concentration experiment’), and (2) varied the timing of application (hereafter ‘the imazapic application timing experiment’) relative to seeding of the forbs (Fig. 1). Soils were collected in degraded recently burned and unburned sagebrush ecosystems (0-10 cm depth) at the Morley Nelson Birds of Prey National Conservation Area. The soil was air-dried for 7 days, litter and roots were removed by using a 2 mm sieve, and kept under dry conditions at 20-23°C until ready for planting. A fifteen day laboratory incubation with the soil was performed to confirm that the fire had altered microbial activity in the recently burned soil, compared to the unburned soil. Soils from each treatment were placed in 1 L mason jars, then incubated in the dark for 15 days under controlled soil moisture (60% WHC) and temperature (20° C) conditions. The mason jars were tightly sealed with a septum in the jar lid which allowed gas samples to be removed from the headspace with a 10 mL syringe. Soil CO₂ evolution was measured on days 1, 3, 7, and 15 of the incubation. Following each gas sampling event, the caps were removed and the jars were flushed with air for 30 minutes. Respiration rates were analyzed on four sub-samples per replicate using a LI-7000 infrared gas analyzer (IRGA, LICOR Corp., Lincoln, NE)



Figure 1. Greenhouse experiment.

The imazapic concentration experiment was set up as a complete randomized block design (n=10) (Fig. 3). Imazapic concentrations of 0 g ha⁻¹ a.i., 140 g ha⁻¹ a.i., 280 g ha⁻¹ a.i., and 560 g ha⁻¹ a.i. with 1% Hasten surfactant were applied evenly to pots two weeks prior to planting forbs. Pots (6.4 cm diameter and 12.7 cm depth) were lined with a nylon sack (Fig. 2) filled with cleaned rocks and covered with 250 g of the burned and unburned soil. Soil was watered evenly to 60% water holding capacity. Forbs were planted after the seeds were germinated according to their specific germination requirements (Table 1). The seeds were planted with equal spacing (Fig. 3) and the pots were randomized every three weeks. Plants were grown at 15° C-25° C for 41 days.



Figure 2. Pot preparation.

For reparation of the imazapic application timing experiment, burned and unburned soils were composited and transferred to pots in a similar fashion as described above. Imazapic (280 g ha⁻¹ a.i. plus 1% Hasten surfactant), or water containing 1% Hasten surfactant, but no imazapic, was added by spray to all of the pots. *A. millefolium*, *A. filipes*, *S. grossularifolia*, and *Bromus tectorum* (n=10) were planted after 2, 4, 8, or 16 weeks. The plants were watered daily and kept at optimal conditions in the greenhouse. Soils waiting to be planted were maintained under the same conditions and watered 3 times weekly. After the plants grew for 41 days, height was recorded and the foliage was harvested. Plants were dried at 40° C for 24 hours, and weighed for aboveground biomass quantification. The soils were frozen at -20° C until belowground biomass could be processed. Live roots were removed from the soil, washed and dried in the oven for 40° C for 24 hours, after which they were weighed.

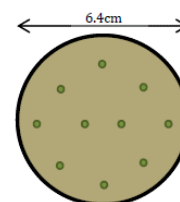


Figure 3. Seed Spacing.

Table 1. Germination protocol.

Forb	Scarify	Stratify	Surface Sterilize	Plant depth
<i>Astragalus filipes</i>	220 grit sandpaper for 3 minutes (50 seeds X 8)	NO	NO	3.5 mm
<i>Achillia millefolium</i>	NO	NO	NO	0 mm
<i>Sphaeralcea grossularifolia</i>	18 M H ₂ SO ₄ for 10 min (200 seeds X 4)	3/15/13- 4/29 Refrigerated (~5°C) in petri dishes on moist filter paper for 7 weeks	NO	6.5 mm
<i>Bromus Tectorum</i>	NO	NO	NO	Light dusting

Statistical Analyses

To evaluate how fuel reduction treatments in the field impacted CO₂ respiration and N mineralization rates, two-way ANOVA's were conducted with treatments (i.e., grazing and fuel reduction treatments) as fixed effects, using the Univariate GLM in SPSS Statistics 17.0. We conducted three-way ANOVA's using the Univariate GLM in SPSS Statistics 17.0 for the imazapic concentration experiment using burning, plant species, and imazapic concentration treatments as fixed effects. We used two way ANOVA's with imazapic application timing experiment. For all ANOVAs, means were compared by the Tukey test, after confirmation that the ANOVA was significant. The level of significance was $P < 0.05$.

Results and discussion

Field Experiment

Mowing, herbicide applications, a combination of both treatments, and grazing had no effect on soil microbial CO₂ respiration (Fig. 4) or N mineralization (Figs. 5a and b). These data contradict observations showing positive effects of similar management activities on soil resource availability (Chambers and Wisdom 2009). However, effects of mowing and grazing both are mediated by abiotic conditions (Wardle et al. 2004), and our study site was subjected to considerable drought conditions while management activities were ongoing (Brabec et al. 2015). These conditions likely contributed to the limited the response of the soil microbial community to the fuel reduction treatments.

Greenhouse Experiment

Burning significantly affected soil microbial activity ($p < 0.05$); recently burned soils had a greater content of labile C leading to greater resource availability for soil microbes and greater CO_2 respiration rates compared to soils that were not burned (Fig. 6). These data indicate that changes in the soil microbial community occurred following a fire and these changes may impact decay rates of imazapic and hence its impact on forb performance. However, although we found that imazapic application significantly suppressed biomass production for each of the forb species ($p < 0.05$, $n=10$; Fig. 7 and Fig. 8a-c), burning did not mediate the response of forbs to imazapic applications. These data either indicate that burning did not lead to a change in microbial activity that was sufficiently large to impact imazapic degradation, or that fire may impact soil microbial strains that are not actively involved in the degradation of imazapic. In agricultural settings it has been observed that degradation of herbicides is controlled only by specific microbial strains, thus herbicide application itself rather than fire induced changes in the microbial community, may impact herbicide degradation rates in soil (Huang et al., 2009).

The magnitude of the response to imazapic application differed among species. We calculated the response as the percent change in biomass production relative to the control (i.e., no imazapic application), where a greater response signifies a greater sensitivity of the forb to imazapic. The average response of above (Fig. 9a) and belowground (Fig. 9b) biomass production was significantly different ($p < 0.05$) across forb species ($n=20$). Specifically, the response of *A. filipes* was affected by imazapic applications the least.

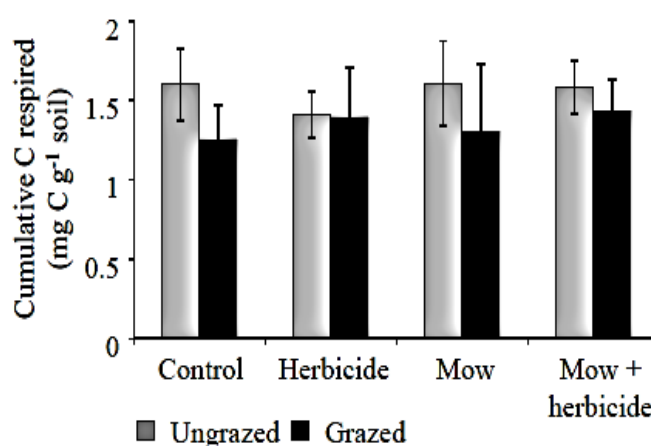


Figure 4. Cumulative microbial CO_2 respiration ($\mu\text{g C/g soil DW}$) from soils exposed to a variety of fuel reduction treatments and grazing. Values are means + SE ($n=3$).

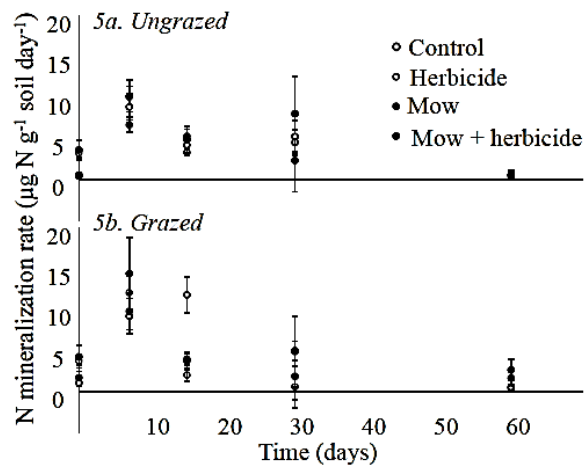


Figure 5. Net N mineralization from soils to a variety of fuel reduction treatments without (5a) and with (5b) grazing. Values are means + SE ($n=3$).

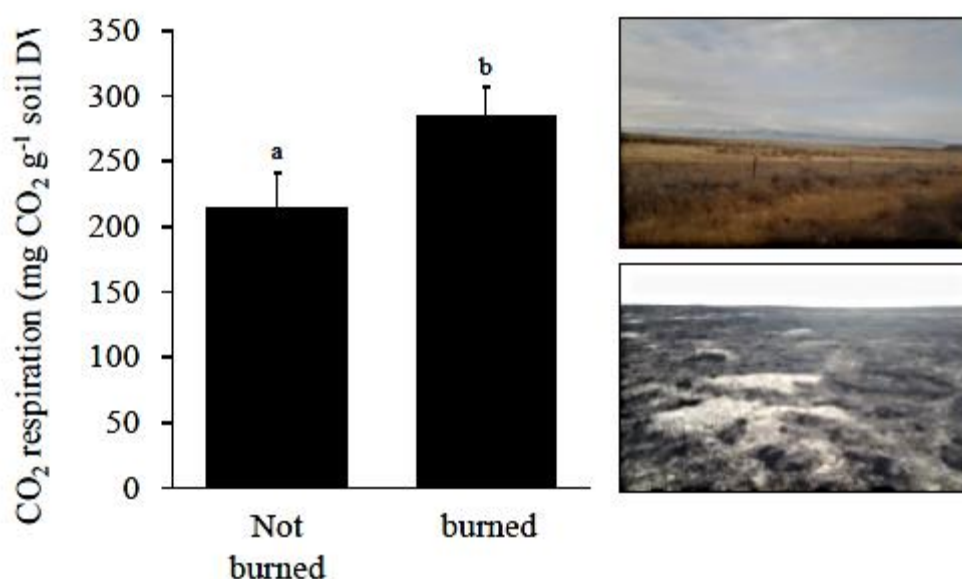


Figure 6. Impact of fire on soil microbial activity. Different letters indicate significant differences in CO₂ respiration between burned and unburned soils. Values are means + SE (n=5).

Since fire had no impact on imazapic effects on forb performance, we did not include the burned soils in the second greenhouse experiment where we focused on the timing of imazapic application to forbs relative to seeding. In addition, we included *B. tectorum* to ascertain if any impacts of imazapic on forb performance also impact *B. tectorum* growth. For each one of the forbs, biomass production in control soils (i.e., soils not receiving imazapic) was greater when plants were seeded into soil at a later date. In contrast, this trend was not observed in soils receiving imazapic application (Fig. 10a-d). Increased biomass production in control soils likely resulted from the multiple irrigation events that promoted soil organic matter decomposition and the release of nutrients in soil over time. Our results further indicate that imazapic applications negatively impacted biomass production of *A. millefolium*, *S. grossulariifolia*, and *B. tectorum* regardless of application timing (Fig 10a-d), with the response of *B. tectorum* being greater than that of the other two forbs across treatments.



Figure 7. Visual differences in forb performance across species exposed to different concentrations of imazapic application.

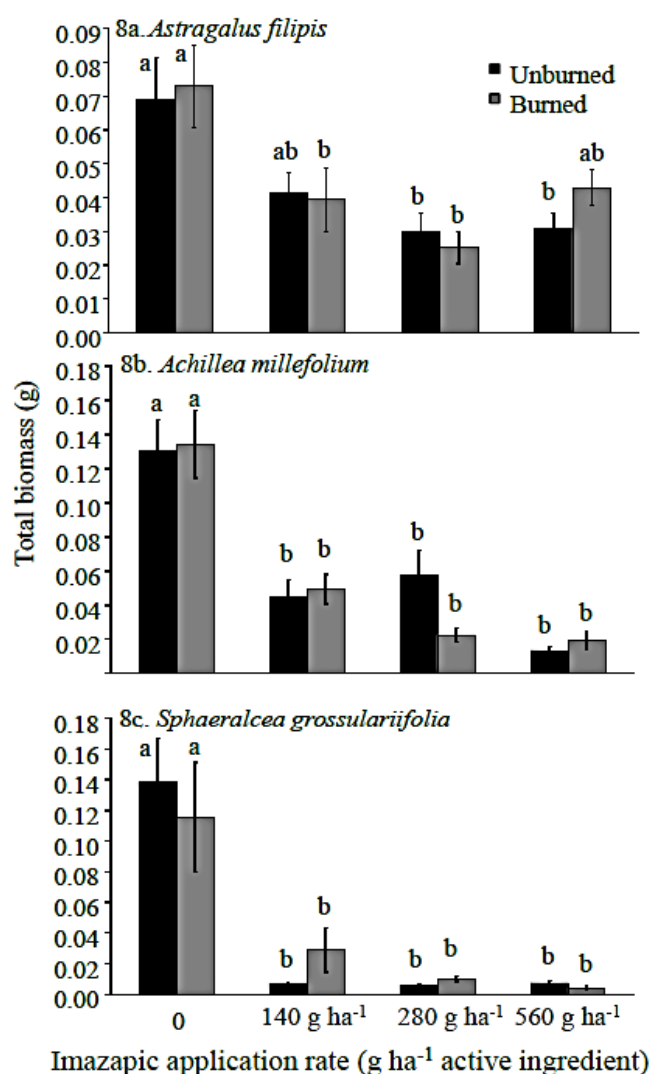


Figure 8a-c. Total standing biomass (shoots + roots) at harvest for a) *Astragalus filipes*, b) *Achillea millefolium*, and c) *Sphaeralcea grossulariifolia* grown in soils that were burned or not burned at four different concentrations of imazapic. Significant differences among imazapic treatments are shown by different letters above the graphs ($p < 0.05$). Values are means + SE ($n=10$).

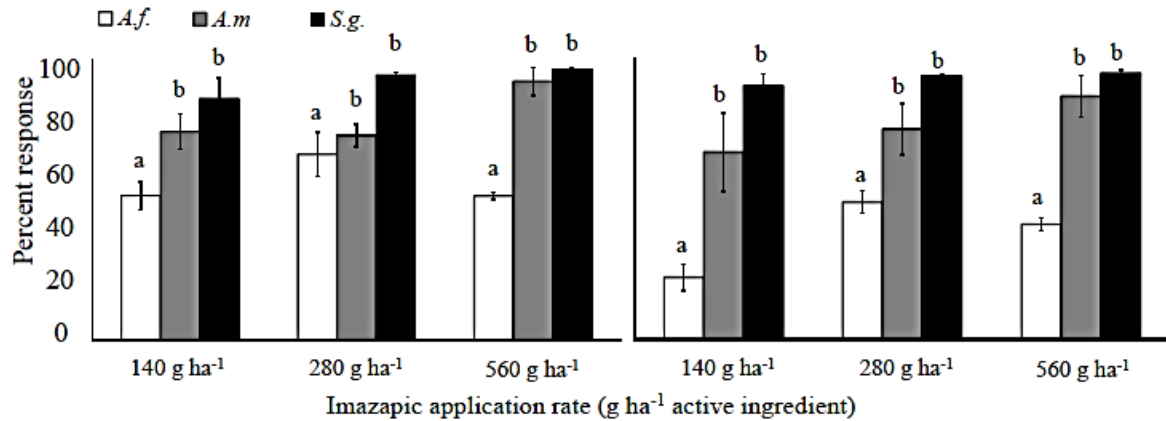
conditions, such as drought, limit biological processes in semi-arid ecosystems. Imazapic applications significantly impacts performance of *B. tectorum*, as well as performance of native forbs (*A. filipes*, *A. millefolium*, and *S. grossularifolia*) regardless of concentration and timing of application. This suggests that imazapic is not specific to cheatgrass, and that the use of imazapic could negatively impact native vegetation that are essential to the survival of sage grouse.

Although imazapic negatively impacted *A. filipes*, *A. millefolium*, and *S. grossularifolia* performance, the response of *A. filipes* to imazapic applications was significantly less negative than that of the other species, indicating a need for additional studies to evaluate how plant functional types may mediate impacts of imazapic on their performance.

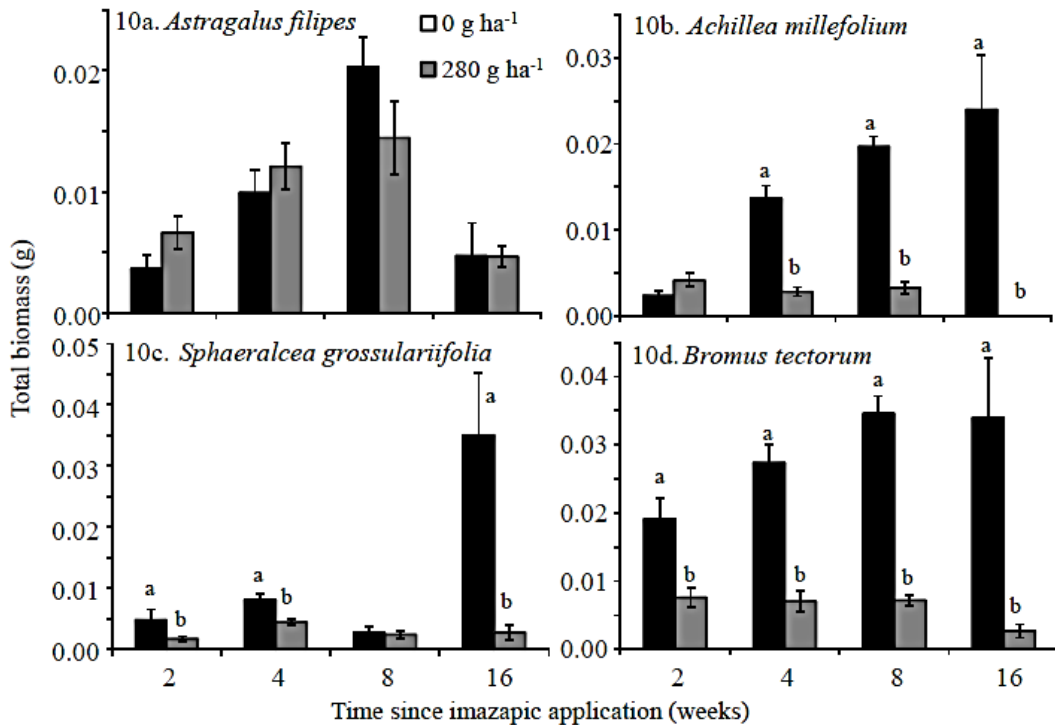
Additionally, there were some differences in the magnitude of response to imazapic application for each one of the forb species relative to our first greenhouse experiment, where the response was generally greater in the first compared to the second experiment. Since our two greenhouse experiments were conducted during two different seasons (i.e., the first experiment was conducted during the summer, while the second experiment was conducted during the winter months), we attribute any differences in the magnitude of response of forbs to imazapic applications to differences in abiotic conditions, most notably light conditions. Interestingly, performance of *A. filipes* was not negatively impacted by imazapic applications in the ‘timing of imazapic application experiment’. This result is in agreement with the results of our first greenhouse experiment (i.e., the imazapic concentration experiment) where *A. filipes* had a significantly lower response to imazapic applications than the other forb species. A major difference between *A. filipes* versus the other forb species is that *A. filipes* is a legume. These data indicate that legumes may mediate the impact of imazapic applications on their performance. Additional research is required to ascertain that different plants functional types respond differently to imazapic applications.

Management Applications and/or Seed Production Guidelines

Fuel load reduction treatments (i.e., mowing, herbicide applications, a combination of mowing and herbicide applications, and grazing) may not impact soil microbial activity and alter soil nutrient availability if abiotic



Figures 9a-b. Differences in the response to imazapic application among three forbs. *A. f.* (*Astragalus filipes*), *A. m.* (*Achillea millefolium*), *S. g.* (*Sphaeralcea grossulariifolia*). Different letters indicate significant differences in response to imazapic among forbs ($p < 0.05$). Values are means + SE ($n=20$).



Figures 10a-d. Differences in the total biomass of a) *Astragalus filipes*, b) *Achillea millefolium*, c) *Sphaeralcea grossulariifolia*, and d) *Bromus tectorum* in response to differences in the timing of imazapic application. Different letters indicate significant differences in response to imazapic application between control and imazapic treatments ($p < 0.05$). Values are means + SE ($n=10$).

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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

Introduction

We will evaluate sagebrush (*Artemisia* sp.) restoration success with five methods across an elevation gradient using a randomized block design. Treatments will be 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 will be big sagebrush. However, Wyoming and mountain big sagebrush subspecies (*A. tridentata* var. *wyomingensis*, *A. tridentata* var. *tridentata*) will vary based on the potential natural community type. Wyoming and mountain big sagebrush will be seeded and planted on sites where they were dominant prior to burning, respectively.

Treatments will be applied along five transects that span an elevation gradient from 1219 to 2134 m (4000 to 7000 ft.). Along each elevation gradient, treatments will be 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 and on each transect, treatments will be randomly assigned to five 5 x 10 m plots with a 2 m buffer between treatment plots in each year. Total number of blocks will be 35 (5 elevation transects x 7 elevations per transect = 35 blocks) and total number of treatment plots will be 350 (5 treatments x 2 years x 35 blocks = 350 plots). All sagebrush seeding treatments will be applied at a rate of 1.1 kg pure live seed per hectare in the fall. Roller-packing will be applied by pulling a small roller-packer by hand across the plot after seeding. Seed pillows will be a mixture that promotes survival, growth, and establishment of sagebrush (exact formulation is not reported because of proprietary rights). Seeds and seed pillows will be broadcasted using a non-automated centrifugal flinger fertilizer spreader. Sagebrush seedlings will be hand planted at a density of 1 seedling per m². Sagebrush seedlings will be grown to a pre-planting height of approximately 15 cm by planting five sagebrush seeds in seedling cone containers in a greenhouse. Cone containers will be 3.8 cm diameter at the top and 21 cm tall. Sagebrush seedlings will be thinned to one individual per cone container. Sagebrush seedlings will be 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.

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

Vegetation measurement 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 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 also expect to determine how natural sagebrush recovery varies by elevation and other site characteristics.

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

Project Agreement No. 15-IA-11221632-189

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Project Description

Introduction

Public land management agencies (BLM, FS) 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.

Methods

The unique, patented Hollow Frame Fence System (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 treatment) 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 just 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 and western prairie clover) treated with 15 specific seed coatings were seeded into 1.5-m long rows at a rate of 82 PLS m⁻² in each of the three treatments with a four-row Hege cone seeder. 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 in comparison with two check species, including small burnet (*Sanguisorba minor*) and sainfoin (*Onobrychis viciifolia*).

Organza bags containing seed of each of the species with specific seed treatments were placed alongside the site treatments and covered with soil at each site for retrieval in January, April, and June of 2015 to determine seed treatment effects on germination. Seedling emergence, plant growth, and phenological development will be determined in of the seeded rows at each site on a regular basis during spring, summer, and fall of 2016 to determine best treatment combinations. Soil water content and soil temperatures will be monitored continuously at the three study sites to provide a mechanistic understanding of seedling responses and for hydrothermal model analysis (Hardegree et al. 2013).

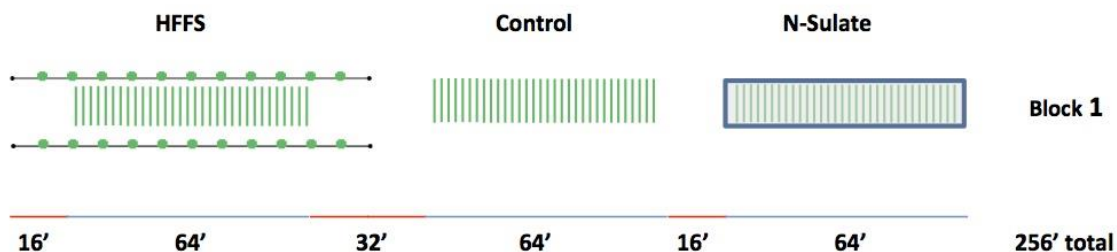


Figure 1. Plot configuration.

Anticipated Results

We anticipate that combinations of HFFS, N-Sulate fabric, and seed coating will create favorable winter and spring conditions that will warm the soil, retain spring surface moisture, and alleviate dormancy issues to enhance the establishment of forb species. If successful, these temporary mobile techniques could be used to create diverse forb islands across post-burn landscapes that will provide critical food for sage-grouse and native pollinators.

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Additional ProductsManagement Applications

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



APPENDIX I – PLANT INDEX

A

- Artemisia longiloba*
Early sagebrush – 35
- Achillea millefolium*
Common yarrow - 13, 66, 76, 214, 217, 218, 221, 222
- Achnatherum hymenoides*
Indian ricegrass - 3, 4, 22, 28, 68, 69, 108, 197
- Achnatherum thurberianum*
Thurber's needlegrass – 22, 76
- Agoseris glauca*
Pale agoseris – 75, 76, 77
- Agoseris grandiflora*
Bigflower agoseris - 7, 38, 39, 40, 42, 44, 96
- Agoseris heterophylla*
Annual agoseris - 96
- Agropyron cristatum*
Crested wheatgrass - 12, 13, 205, 206, 207, 208, 209, 210, 211, 212
- Allium acuminatum*
Tapertip onion - 22
- Aremone munita*
Flatbud pricklepoppy – 96
- Arenaria macradenia ssp. ferrisea*
Ferris' sandwort – 104
- Artemisia nova*
Black sagebrush – 69
- Artemisia sp.*
Sagebrush – 30, 225
- Artemisia tridentata*
Big sagebrush - 30, 31, 32, 33, 34, 35, 207, 223, 225

- Artemisia tridentata ssp. tridentata*
Basin big sagebrush - 32, 34, 35, 216, 225
- Artemisia tridentata ssp. wyomingensis*
Wyoming big sagebrush - 9, 12, 32, 34, 35, 66, 99, 100, 101, 102, 186, 189, 190, 191, 192, 207, 209, 210, 211, 212, 215, 216, 223, 225
- Artemisia tridentata ssp. vaseyana*
Mountain big sagebrush - 32, 34, 66, 109, 225
- Aster sp.*
Aster – 104
- Astragalus filipes*
Basalt milkvetch - 5, 8, 11, 13, 54, 79, 104, 145, 146, 147, 148, 149, 150, 171, 175, 214, 217, 218, 220, 221, 222, 229
- Astragalus utahensis*
Utah Milkvetch - 100
- Atriplex canescens*
Fourwing saltbush – 76, 77

B

- Balsamorhiza hookeri*
Hooker's balsamroot – 76
- Balsamorhiza sagittata*
Arrowleaf Balsamroot– 76, 96, 97, 100
- Blepharipappus scaber*
Rough eyelashweed - 7, 38, 41, 42
- Bouteloua gracilis*
Blue grama grass – 62, 63, 64
- Bromus rubens*
Red brome - 2, 65, 66, 67
- Bromus tectorum*
Cheat grass - 2, 4, 20, 65, 66, 67, 96, 97, 99, 101, 103, 195, 197, 198, 199, 214, 215, 217, 218, 220, 221, 222, 223, 224

C

- Chaenactis douglasii*
Douglas' dustymaiden - 38, 42, 109, 156, 157, 158, 159, 161, 162, 163, 165, 166, 167, 168, 229
- Chrysothamnus nauseosus*
Rubber Rabbitbrush - 76
- Cleome lutea*
Yellow beeplant - 11, 107, 151, 152, 153, 154, 155, 171
- Cleome serrulata*
Rocky Mountain beeplant - 11, 96, 151, 152, 153, 154, 155, 171
- Cleome* spp.
Bee plant - 11, 113, 151, 154
- Collinsia parviflora*
Blue eyed Mary - 7, 38, 40, 42
- Crepis acuminata*
Tapertip hawksbeard – 100, 104
- Crepis intermedia*
Limestone hawksbeard - 38, 41, 42, 156, 157, 158, 159, 161, 162, 163
- Cryptantha pterocarya*
Wingnut cryptantha - 7, 38, 39, 42
- Cryptantha* sp.
Cryptantha – 104
- Cymopterus bipinnatus*
Hayden's cymopterus - 156, 157, 158, 161, 162, 163, 171
- Cymopterus nivalis*
Snowline springparsley - 156

D

- Dalea ornata*
Western prairie clover - 5, 8, 11, 79, 104, 145, 146, 147, 148, 149, 150, 171, 175, 229
- Dalea searlsiae*
Searls' prairie clover - 8, 10, 79, 145, 146, 147, 149, 150, 171, 175, 229

E

- Enceliopsis nudicaulis*
Nakedstem sunray - 104, 156, 159, 161, 162, 163, 171
- Erigeron pumilus*
Navajo fleabane - 76
- Eriogonum heracleoides*
Parsnipflower buckwheat - 9, 10, 76, 77, 108, 113, 114, 115, 116, 117, 118, 119, 171
- Eriogonum ovalifolium*
Cushion buckwheat - 9, 92, 93, 94, 95
- Eriogonum umbellatum*
Sulphur-flower buckwheat - 7, 9, 22, 45, 46, 47, 49, 50, 51, 176, 77, 108, 113, 114, 115, 116, 117, 118, 119, 171
- Elymus elymoides*
Squirreltail - 4, 65, 66, 197, 207

G

- Gilia inconspicua*
Shy gilia - 7, 38, 42
- Grayia spinosa*
Spiny hopsage - 76

H

- Hedysarum boreale*
Northern sweetvetch 'Timp' – 96, 100
- Heliomeris multiflora*
Showy goldeneye - 96, 104, 105, 156, 161, 162, 163, 165, 166, 167, 168, 171
- Heliomeris multiflora nevadensis*
Nevada goldeneye – 96, 104

- Hesperostipa comata*
Needle and thread grass - 104

I

- Ipomopsis aggregata*
Skyrocket gilia - 104, 105, 156, 159, 162, 163, 165, 166, 167, 168, 171

K

Krascheninnikovia lanata
Winterfat - 12, 183, 184

L

Leymus cinereus
Basin wildrye - 6, 22, 24, 26, 27, 104, 105, 106, 107

Ligusticum canbyi
Canby's licorice-root - 156, 158, 165, 166, 167, 168

Ligusticum porteri
Porter's licorice-root - 156, 158, 165, 166, 168

Linum lewisii var. *lewisii*
Prairie flax – 104, 107

Linum perenne
Blue flax 'Appar' – 96, 100

Lomatium dissectum
Fernleaf biscuitroot - 10, 76, 90, 120, 121, 122, 124, 125, 126, 127, 128, 129, 130, 131, 132, 171

Lomatium grayi
Gray's biscuitroot - 10, 76, 120, 121, 122, 124, 125, 126, 127, 128, 129, 131, 132, 171

Lomatium nudicaule
Barestem biscuitroot – 10, 96, 120, 121, 122, 124, 125, 127, 128, 129, 131, 132, 171

Lomatium suksdorfii
Suksdorf's desert parsley - 10, 120, 121, 122, 124, 125, 127, 130, 132

Lomatium triternatum
Nineleaf biscuitroot - 10, 110, 120, 121, 122, 124, 125, 127, 128, 129, 131, 132, 171

Lotus utahensis
Utah trefoil - 3, 8, 88, 173, 174

Lupinus argenteus
Silvery lupine - 96, 100

M

Machaeranthera canescens
Hoary tansyaster - 9, 66, 108, 109, 110, 111, 156, 157, 158, 160, 161, 162, 163, 165, 166, 167, 168, 171

Mentzelia albicaulis
Whitestem blazingstar - 7, 38, 42

Microsteris gracilis
Slender phlox - 7, 38, 42, 44

N

Nicotiana attenuata
Coyote tobacco - 77, 96, 156, 157, 158, 165, 167, 168

O

Onobrychis viciifolia
Sainfoin – 228

P

Penstemon acuminatus
Sharpleaf penstemon - 10, 133, 134, 135, 137, 138, 139, 140, 141, 142, 143, 144, 171

Penstemon cyaneus
Blue Penstemon - 1, 10, 52, 53, 54, 55, 107, 133, 134, 136, 137, 138, 139, 140, 142, 143, 144, 171

Penstemon deustus
Scabland penstemon - 10, 133, 134, 135, 137, 139, 140, 141, 142, 143, 144, 171

Penstemon eatonii
Firecracker penstemon - 100

Penstemon pachyphyllus
Thickleaf penstemon - 10, 96, 104, 105, 133, 134, 136, 137, 138, 139, 140, 142, 144, 171

Penstemon palmeri
Palmer penstemon - 100

Penstemon speciosus
Royal penstemon - 10, 76, 133, 134, 135, 136, 137, 138, 139, 140, 142, 144, 164, 165, 166, 167, 171

Phacelia hastata
Silverleaf phacelia - 7, 8, 38, 42, 76, 89, 90, 156, 158, 159, 160, 161, 162, 163, 165, 167, 168, 171

Phacelia linearis

Threadleaf phacelia - 156, 157, 158, 159, 160,
161, 162, 163, 165, 166, 167, 168, 171

Phacelia crenulata var. *corrugata*

Cleftleaf wildheliotrope – 107

Poa fendleriana

Muttongrass - 96

Poa secunda

Sandberg bluegrass - 22, 27, 28, 66, 77, 216

Pseudoroegneria spicata

Bluebunch wheatgrass - 1, 6, 11, 12, 15, 16,
17, 18, 19, 20, 21, 22, 28, 29, 30, 31, 33, 56, 57, 58,
59, 76, 77, 178, 180, 181, 183, 184

Psoralegium sp.

Scurfpea - 108

Purshia tridentata

Bitterbrush – 108, 109

S

Sanguisorba minor

Small burnet - 228

Sisymbrium altissimum

Tumble-mustard – 216

Sphaeralcea grossulariifolia

Gooseberryleaf globemallow - 96, 107, 171,
217, 221, 222

Sphaeralcea munroana

Munro globemallow - 100

T

Thelypodium milleflorum

Manyflower thelypody – 96, 156, 158, 160,
161, 162, 165, 167, 168, 171

V

Vulpia octoflora

Sixweeks fescue - 65, 66

