Great Basin Native Plant Project

2017 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
2017 PROGRESS REPORT

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

COOPERATORS

USDA Forest Service, Rocky Mountain Research Station
Grassland, Shrubland and Desert Ecosystem Research Program, Boise, ID, Provo, UT, and Albuquerque, NM
USDI Bureau of Land Management, Plant Conservation Program, Washington, DC
Boise State University, Boise, ID
Brigham Young University, Provo, UT
Northern Arizona University, Flagstaff, AZ
Oregon State University, Corvallis and Bend, OR
Oregon State University Malheur Experiment Station, Ontario, OR
Private Contractors and Land Owners
Native Seed Industry
University of Idaho, Research and Extension Center, Aberdeen, ID
University of Nevada, Reno, NV
University of Nevada Cooperative Extension, Elko and Reno, NV
Utah State University, Logan, UT
USDA Agricultural Research Service, Eastern Oregon Agriculture Research Center, Burns, OR
USDA Agricultural Research Service, Forage and Range Research Laboratory, Logan, UT
USDA Agricultural Research Service, Great Basin Rangelands Research Unit, Reno, NV
USDA Agricultural Research Service, Western Regional Plant Introduction Center, Pullman, WA
USDA Forest Service, Olympic National Forest, Olympia, WA
USDA Forest Service, Geospatial Technology and Applications Center, Bend, OR
USDA Forest Service, Pacific Northwest Research Station, Corvallis, OR
USDA Natural Resources Conservation Service, Aberdeen Plant Materials Center, Aberdeen, ID
USDA Forest Service, Northern Plains Agricultural Laboratory, Pest Management Research Unit, Sidney, MT
USDI Bureau of Land Management, California, Idaho, Nevada, Oregon, and Washington State Offices
US Geological Survey Forest and Rangeland Ecosystem Science Center, Boise, ID
US Geological Survey Western Ecological Research Center, Henderson, NV
US Geological Survey Colorado Plateau Research Station, Flagstaff, AZ
Utah Division of Wildlife Resources, Great Basin Research Center, Ephraim, UT
Utah Department of Natural Resources, Division of Wildlife Resources, Salt Lake City, UT
Institute for Applied Ecology, Corvallis, OR
Conservation Biology Institute, Corvallis, OR

GREAT BASIN NATIVE PLANT PROJECT
2017 PROGRESS REPORT

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

Research priorities are to:

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

We thank our many collaborators for their dedication and their institutions for their in-kind contributions. The wide array of expertise represented by this group has made it possible to address the many challenges involved with this endeavor. Special thanks also to our resident technicians and volunteers: Kimberly Stocks and Chirs Link for help in compiling this report and for managing our field and laboratory research.

Francis Kilkenny
USDA Forest Service
Rocky Mountain Research Station
Boise, ID
ffkilkenny@fs.fed.us

Great Basin Native Plant Project
www.GreatBasinNPP.org

Citation
Kilkenny, Francis; Edwards, Fred; Irwin, Jessica; Barga, Sarah. 2018. Great Basin Native Plant Project: 2017 Progress Report. Boise, ID: U.S. Department of Agriculture, Rocky Mountain Research Station. 211 p.

FISCAL YEAR SUMMARY

GBNPP PROJECTS	
Closing Projects	4
Continuing Projects	14
New Projects	3

PROJECT ACTIVITY	
Presentations	25
Publications	12

TABLE OF CONTENTS

I. GBNPP PROJECT OVERVIEW

II. PROJECT HIGHLIGHTS

III. GENETICS AND CLIMATE CHANGE

IV. PLANT MATERIALS AND CULTURAL PRACTICES

V. RESTORATION STRATEGIES

VI. SCIENCE DELIVERY

VII. SPECIES INTERACTIONS

VIII. APPENDIX I

2017 HIGHLIGHTS

NEW PROJECTS

GENETICS AND CLIMATE CHANGE

Intraspecific Variation and Local Adaptation in Great Basin Plants: a Review of 75 Years of Experiments

Owen Baughman, Alison Agneray, Matthew Forister, Elizabeth Leger, Francis Kilkenny, Erin Espeland, Thomas Kaye, Rob Fiegener, Matthew Horning, R.C. Johnson, and Brad St. Clair 15

- We conducted a literature review of common garden studies of Great Basin plant species and asked if species share patterns of intraspecific variation and local adaptation.
- We scored and tallied studies for three primary signatures of local adaptation: 1) differences among populations in fitness-related traits, 2) correlations between these trait values and environmental or other habitat-related variables, and, if reciprocal transplants or common gardens have been conducted, 3) higher fitness of local over nonlocal populations in the local environment.
- For signature 1, 290 (95.1%) experiments reported finding variation among populations in at least one phenotypic trait, with 230 (75.4%) of these 290 reporting significant variation, and 60 (19.6%) claiming such variation in the absence of any supporting statistics.
- For signature 2, 131 (81.4%) experiments reported associations for at least one comparison, with 81 (50.3%) supported by statistical tests and 50 (31.1%) supported by claims in the absence of statistics.
- For signature 3, incidence of local-does-best patterns was highest in experiments that directly measured reproductive output, with 90% reporting higher values for locals at some point in an experiment, followed by survival (67%), fitness indices that incorporated biomass (50%), and biomass measures (33%).
- We found that Great Basin plant species contain large amounts of intraspecific diversity in a wide range of phenotypic traits, that differences in these phenotypic traits are often associated with the heterogeneous environments of origin, and that differences among populations are commonly relevant to outplanting fitness. Our results are consistent with other reviews of the prevalence of local adaptation, with some indications that local adaptation may be more prevalent in the Great Basin than elsewhere.
- Our results show that the strongest indication of local adaptation came from experiments that directly measured reproductive output, and that using biomass as a fitness proxy may not be an effective way to compare relative performance in the Great Basin. This is consistent with previous studies that demonstrated selection for smaller, rather than larger, individuals in disturbed arid systems.
- Given the speed and severity with which natural communities are being altered by anthropogenic factors, the application of an evolutionary perspective to restoration

ecology is more important than ever. Adjusting seed-selection priorities to account for the existence of locally adapted, intraspecific variation in the Great Basin will promote the maintenance and recovery of resilient, self-sustaining vegetation communities in this region.

Comparative Phylogeography for Great Basin Plant Species

John Bradford and Rob Massatti 23

- We propose to process and analyze genomic data from up to seven species, with the specific goals of: 1) assessing the similarities and differences of species' phylogeographic patterns; 2) resolving changes in genetic diversity across the landscape; 3) determining if and where unique genetic variation is harbored; 4) investigating historical and contemporary processes influencing genetic patterns; and 5) characterizing the spatial patterns of polyploid races.
- We anticipate that Great Basin plant species will display unique genetic patterns, but will likely have responded to glaciations in relatively similar ways.
- These data will be among the first and most descriptive genomic data available for the Great Basin region, and they will form a framework that can inform future genomics projects (e.g., sampling schemes, selection of species with specific functional traits, scope of analyses, etc.).

Population Genetics of Bluebunch Wheatgrass (*Pseudoroegneria spicata*)

Rob Massatti, Holly Prendeville, Steve Larson, Bryce Richardson, Blair Waldron, and Francis Kilkenny 54

- Recent research has focused on ensuring that native plant materials are "appropriate" for restoration sites. From a genetic perspective, appropriate native plant materials are those that avoid, or mitigate, risks associated with the mixing of local and nonlocal genotypes.
- We use a next-generation sequencing dataset developed for *Pseudoroegneria spicata* to elucidate the dynamics of *P. spicata* populations through time and the genetic relationships of the available commercial germplasm sources to regional wildland localities, with the goal of providing information relevant to the use of available native plant materials and the future development of additional native plant materials.
- Commercial germplasm sources are most genetically similar to the wildland sampling localities closest to where the original foundational materials were collected. The commercial germplasm sources represent a small fraction of the overall genetic diversity of *P. spicata*.
- We identified four major genetic clusters, or "populations," in the sampled *P. spicata* range. We further specify the western-most population to recognize the north/south differentiation through isolation by distance in this population.
- Seed zones developed using a genecological approach, which utilized phenotypic data from common gardens and climatic variability across the northwestern United States, can be informed by spatial patterns of genetic variation of *P. spicata*. Each of the populations identified in this study is distributed across several of the seed transfer zones. Given that sampling localities within a population are more closely related to one another (in a phylogenetic sense) than they are to localities from another population, we infer that the ancestors of all four populations independently adapted into the environmental space represented by the seed zones.

- All populations except one were distributed across multiple level III ecoregions, and similarly, almost all level III ecoregions contain multiple populations. The discordance between populations and level III ecoregions exemplifies the practical knowledge gained from investigating geographic patterns of genetic variation and population histories.

2017 HIGHLIGHTS

CONTINUING PROJECTS

GENETICS AND CLIMATE CHANGE

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

Lesley DeFalco, Daniel Shryock, and Todd Esque 27

- Global climate change is predicted to increase aridity across the southwestern United States, potentially shifting the distributions of plant taxa. We are testing the vulnerability of southern Great Basin restoration species to climate change by placing populations in common gardens located within the arid Mojave Desert. Transplanting southern Great Basin populations to warmer conditions mimics future climate change.
- We are evaluating the degree to which southern Great Basin populations of Indian ricegrass (*Achnatherum hymenoides*) exhibit intraspecific variability in response to climate change and in restoration of arid sites based on empirically-derived climate zones, climate change velocity predictions, and ecological distances.
- Tillers from two ricegrass populations from each of low and high climate change velocities and low and high ecological similarity to the Mojave Desert common gardens were sampled in fall 2016 for a total of eight populations. Individuals were propagated from tillers in the greenhouse during winter 2016/17 and outplanted into four common gardens in early spring 2017. Supplemental watering was provided approximately biweekly through early fall 2017 for establishment, at which time more than half the number of plants entered dormancy. Survival analysis indicates genetic variation among ricegrass populations and garden environments during this establishment phase, but no significant interaction. Statistical models with climate change velocity or ecological similarity were not significant but will continue to be tested following cessation of supplemental watering. Survival will continue to be monitored as well as phenological, growth, and reproductive traits into the 2018 growing season.
- These experiments will facilitate development of management guidelines to select germplasm suitable for the restoration of arid sites in transition to warmer, drier conditions.

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

Matt Germino 34

- Variation in traits affecting freezing and drought resistance were measured among GBNPP's 16 common gardens of bluebunch wheatgrass and 3 common gardens of sagebrush in the northern Great Basin

- Several publications - published, in review, or in draft – characterize population differences in climate-response thresholds in terms of which climate variables are most important and what the underlying physiological responses are.

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

R.C. Johnson, Vicki Bradley, Mike Cashman..........38

- Extensive genetic variation for key plant traits were identified among 72 diverse populations of sulfur-flowered buckwheat (*Eriogonum umbellatum* Torr.) from the Great Basin.
- Numerous plant traits correlated significantly with climatic factors at source locations, indicating a link between local climates and plant adaptation in sulfur-flowered buckwheat.
- Plasticity was found to represent a large portion of the variation among Sandberg bluegrass (*Poa secunda* J. Presl.) populations growing in different environments and appeared to complement genetic variation for adaptation of restoration materials.

Predicting Seed Bank Characteristics in Great Basin Sagebrush Steppe Using Site Characteristics

Elizabeth Leger and Sarah Barga..........44

- Seed bank composition can affect site recovery potential following disturbance, as well as success of restoration treatments
- Across 17 current or former sagebrush-steppe communities in NE Nevada, seed bank contents were predicted by shrub cover, fire history, and ground cover
- Cover of big sagebrush (*Artemisia tridentata*) was associated with richness of rare native species within the seed bank
- Cover of yellow rabbitbrush (C*hrysothamnus viscidiflorus*) was associated with higher seed densities of native annuals within the seed bank and higher above-ground richness of rare native species
- Cover of rubber rabbitbrush (*Ericameria nauseosa*) was associated with higher seed densities of introduced species within the seed bank
- Higher cover of bare ground and litter were associated with higher similarity in the species present in the above- and below-ground composition
- Higher frequency of recent fires on a site was associated with higher similarity in the densities of species in the above- and below-ground composition

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

Beth Newingham and Keirith Snyder..........64

- This project investigates the effects of climate change (altered precipitation) on native and non-native plant growth, survival, and reproduction. In a field experiment, we drill seeded native and non-native grasses and shrubs and hand broadcasted either annual or perennial forbs in herbicide and no herbicide plots to reduce *Bromus tectorum*.
- We installed the following treatments: precipitation addition in spring, precipitation reduction in spring, precipitation addition in summer, precipitation reduction in summer, or ambient precipitation.

- Our results will provide information on the basic biology and competiveness of native and non-native plant species under altered precipitation, as well as plant community development over time.
- Results will provide managers information on appropriate native species selection under future climate and their ability to compete with invasive annual grasses.

Efficacy of Empirical Seed Zones: *Pseudoroegneria Spicata* Reproductive Phenology & Seedling Stage Traits

- In this study, the fine-scale patterns of reproductive phenology (anthesis, ripening, and dispersal stages) for bluebunch wheatgrass (*Pseudoroegneria spicata*) were measured in a common garden to assess how well the seed zones delineated for this species account for differences in the mean timing and variance of these traits and to infer about risks of unintentional losses to genetic diversity during seed increase.
- We found that although the mean timing of anthesis varied by seed zone, the majority of the variance in this trait could not be explained. This unexplained variance could represent an important selective gradient that the seed zones for this species are not sensitive to. Secondly, we found that the mean timing of anthesis among populations from the same seed zone was similar. Therefore, the risk of genetic losses due to pollination timing are minimal when seed zones are used to source populations for seed increase.
- The variance in seed ripening timing was well explained by both seed zones and populations. This signifies that the use of bluebunch wheatgrass seed zones is likely to reduce risks of maladaptation in this trait. In addition, we found little difference in the timing of ripening among populations from the same seed zone, thus indicating that typical single-pass harvest techniques are unlikely to narrow genetic diversity when seed transfer guidelines are followed (even when mixed-population seed lots are grown).
- Lastly, we found that the timing of dispersal was similar among seed zones and populations signifying that genetic differences with regard to the timing of this trait is unlikely and that single-pass seed harvest is unlikely to unintentionally narrow seed lot genetic diversity.
- In this study, we explored the seedling traits of bluebunch wheatgrass with the objective of assessing how well the seed zones account for seedling stage genetic differences.
- We found that seedling traits differed genetically among populations and that the seed zones delineated based on the adult traits of this species did not account for these genetic differences. For certain seedling traits, phenotypic plasticity may also play an important role in trait expression. This indicates that the current seed zones for bluebunch wheatgrass could be improved by including seedling stage traits during the delineation process but should be weighed with the presence of phenotypic plasticity in certain traits.

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

- We planted two common gardens in Provo, Utah and Aberdeen, Idaho.

- We collected DNA samples from two additional *Penstemon cyanocaulis* sites in Eastern Utah.
- We extracted DNA for all additional plant samples.
- We are in the process of testing our sequencing protocols to ensure the proper genomic data is obtained using the molecular protocols that we have developed.

PLANT MATERIALS AND CULTURAL PRACTICES

Plant Material Work at the Shrub Science Lab

Scott Jensen 86

- Added 85 wildland seed collections to inventory
- Distributed 11.3 kg (25 lbs.) of Rocky Mountain beeplant and 4.0 kg (8.8 lbs.) of annual sunflower to commercial producers
- In 2017, approximately 1,297.3 kg (5,350 lbs.) of seed were produced by seed companies from stock seed sources distributed by our office

Great Basin Research Center Seed Increase

Melissa Landeen and Kevin Gunnell...90

- Continued small-scale production grow-out for seed increase of 11 species of native forbs.
- Harvested seed from eight native forb species (Table 2).
- Distributed Rocky Mountain bee plant (*Cleome serrulata),* scarlet gilia (*Ipomopsis aggregata),* and annual sunflower *(Helianthus annuus)* to growers for commercial-scale seed increase.
- Established 53 new seed-increase beds in fall 2017 at our Fountain Green Farm for 2018 production, bringing the total number of active native forb seed-increase plots to 121.

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

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

1. Irrigation Requirements for *Lomatium* Seed Production in a Semi-arid Environment.......97

- The seed yield response to four biweekly irrigations applying either 0, 1, or 2 inches of water (total of 0, 4, or 8 inches/season) was evaluated for four *Lomatium* species over multiple years starting in 2007.
- In order to try to improve the accuracy of estimated irrigation water requirements, seed yield responses to irrigation plus precipitation during the previous spring; winter and spring; and fall, winter, and spring were also evaluated.
- On average, over nine seed production seasons, fernleaf biscuitroot (*Lomatium dissectum*) seed yield was maximized by 7.7 to 9.5 inches of water applied plus spring precipitation depending on the seed source.
- On average, over 11 seed production seasons, Gray's biscuitroot (*L. grayi*) seed yield was maximized by 14.3 inches of water applied plus fall, winter, and spring precipitation.
- On average, over 11 seed production seasons, nineleaf biscuitroot (*L. triternatum*) seed yield was maximized by 12.4 inches of water applied plus spring precipitation.

- Over six seed production seasons, barestem biscuitroot (*L. nudicaule*) seed yield only responded to irrigation in 2017.
- In four seed production seasons, seed yield of Suksdorf's desertparsley (*L. suksdorfii*) responded to irrigation only in 2015.

2. Irrigation Requirements for Native Buckwheat Seed Production in a Semi-arid Environment..........110

- The seed yield of sulphur-flower buckwheat (Eriogonum umbellatum) and parsnipflower buckwheat (E. heracleoides) were evaluated over multiple years in response to four biweekly irrigations applying either 0, 1, or 2 inches of water (total of 0, 4, or 8 inches/season).
- Seed yield of sulphur-flower buckwheat responded to irrigation plus spring precipitation in 10 of the 11 years, with 5 to 11 inches of water applied plus spring precipitation maximizing yields, depending on year.
- Averaged over 11 years, seed yield of sulphur-flower buckwheat showed a quadratic response to irrigation rate plus spring precipitation and was estimated to be maximized at 232 lb/acre/year by irrigation plus spring precipitation of 9.4 inches.
- Over six seasons, seed yield of parsnipflower buckwheat was responsive to irrigation only in 2013, a dry year when seed yield was maximized by 4.9 inches of applied water.
- Averaged over 6 years, seed yield of parsnipflower buckwheat showed a quadratic response to irrigation rate with the highest yield achieved with 5 inches of water applied.

3. Irrigation Requirements for Seed Production of Five Native *Penstemon* Species in a Semi-arid Environment..........119

- The seed yield response of five *Penstemon* species to four biweekly irrigations applying either 0, 1, or 2 inches of water (a total of 0, 4, or 8 inches of water/season) was evaluated over multiple years.
- Sharpleaf penstemon (*Penstemon acuminatus*) seed yields were maximized by 4-8 inches of water applied per season in warmer, drier years and did not respond to irrigation in cooler, wetter years.
- In 7 years of testing, blue penstemon (*P. cyaneus*) responded to irrigation only in 2013, a dry year with 4 inches of water applied maximizing yields.
- In 7 years of testing, thickleaf beardtongue (*P. pachyphyllus*) seed yields responded to irrigation only in 2013 with 8 inches of water applied maximizing yields.
- In 7 years of testing, seed yields of scabland penstemon (*P. deustus*) responded to irrigation only in 2015, with highest yields resulting from 5.4 inches of water applied.
- From 2006 to 2017, royal penstemon (*P. speciosus*) showed a quadratic response to irrigation in 7 out of the 11 years. Royal penstemon showed either no response or a negative response to irrigation in three years with higher than average spring precipitation.
- Averaged over the 12 years of testing, royal penstemon seed yields were maximized by 8.8 inches of water applied plus spring precipitation.

4. Irrigation Requirements for Seed Production of Various Native Wildflower Species....132
- 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.

5. Prairie Clover and Basalt Milkvetch Seed Production in Response to Irrigation............142
- The seed yield response of three native legume species to irrigation was evaluated starting in 2011. Four biweekly irrigations applying either 0, 1, or 2 inches of water (a total of 0, 4, or 8 inches/season) were tested.
- Over the 7-year period of study, Searls' prairie clover (*Dalea searlsiae*) seed yield was maximized by 13-17 inches of water applied plus fall, winter, and spring precipitation per season.
- Western prairie clover (*Dalea ornata*) seed yield was maximized by 13-16 inches of water applied plus fall, winter, and spring precipitation per season.
- Seed yield of basalt milkvetch (*Astragalus filipes*) did not respond to irrigation.

6. Native Beeplant (*Cleome* spp.) Seed Production in Response to Irrigation in a Semi-arid Environment..149
- The seed yield response of Rocky Mountain beeplant (*Cleome serrulata*) and yellow beeplant (*Cleome lutea*) to irrigation was studied. Four biweekly irrigations applying either 0, 1, or 2 inches of water (total of 0, 4 inches, or 8 inches/season) was evaluated over multiple years.
- Beeplant stands were established through fall plantings each year and were maintained without weed competition. Rocky Mountain beeplant seed yield was maximized by 8 inches of water applied per season in 2011, but did not respond to irrigation in the following years.
- Yellow beeplant seed yield was highest with no irrigation in 2016. Yellow beeplant seed yield did not respond to irrigation in 2012, 2014, or 2015.
- Yellow beeplant stands were lost to flea beetles in 2013 and to poor emergence in 2017. Flea beetle control is essential for seed production when flea beetles occur.

7. Direct Surface Seeding Systems for the Establishment of Native Plants in 2016 and 2017...154
- In 2016 and 2017, 14 species for which stand establishment has been problematic were included and an additional species (royal penstemon; *Penstemon speciosus*) was chosen as a check, because it has reliably produced good stands at Ontario.
- Planting systems including row cover have been the most consistent factor for improving stand establishment over the years of trials at the Malheur Experiment Station.
- Seed treatment, sawdust, and sand are factors that, for some species, in some years, have shown value in improving stand but their performance has not been consistent.

RESTORATION STRATEGIES

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

- Evaluated five different methods to restore sagebrush after wildfires across a 914.4 m (3000 ft.) elevation gradient.
- Determined the effects of site characteristics on restoration treatment success and natural recovery.

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

- In 2016, a second set of test plots (Yr-2 plots) were added at all research sites including two field study sites in Utah (Spanish Fork, Clarkston) and one in Idaho (Downey). As in the 2015-16 field season, each study site had three main site treatments (snow fencing, N-sulate plant protection fabric, control) laid out in a randomized complete block design with four replications.
- Plots at each study site were seeded on a PLS basis and included a November 2016 seeding and an April 2016 seeding. Thirty-two 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 seven seed treatments for each of two Great Basin legume species (basalt milkvetch, (*Astragalus filipes*) western prairie clover (*Dalea ornata*)) – we call this ‘the Legume study’ throughout this report. The other half of the row involved an evaluation of six diverse Great Basin forb species with varying seed coating treatments for each species– we call this ‘The Diversity study.’
- In the 2016-17 field season, as in the previous season, we again found that only one of the two species (basalt milkvetch) targeted in the Legume study germinated in significant numbers. The second species (western prairie clover) did not germinate well, and we thus excluded it from all analyses.
- In the Legume study, we found that snow fencing treatments had no effect on basalt milkvetch germination across sites compared to controls, while germination in plant protection fabric treatments was less than controls. Data are still being analyzed for the Diversity study.
- In the Legume study, scarifying seed led to a significant increase in germination at one of our three sites (Downey), but not at either of the other two sites. Seed coatings did not further increase in germination at Downey, but did increase germination at both other sites (Clarkston, Spanish Fork). There were no differences among seed coatings on germination. Data are still being analyzed for the Diversity study.
- In the Legume study, snow fencing and plant protection fabric treatments affected emergence differently by site. Plant protection fabric increased emergence at Downey, decreased emergence at Spanish Fork, and had no effect at Clarkston compared to the control. Snow fencing decreased emergence at Clarkston, but had no affect at either of the other two sites. Data are still being analyzed for the Diversity study.

- At all sites, unscarified and acid scarified seeds had the lowest seedling emergence rates. All seed coatings increased seedling emergence compared to unscarified and acid scarified seeds. Data are still being analyzed for the Diversity study.
- Our Legume studies in 2015 and 2016 together indicate that seed coatings have noteworthy potential to improve forb restoration given that seed coatings enhanced seedling emergence and establishment at all sites. Of the coatings we tested, those including fungicides: Obvius® and FarMore® most affected seedling emergence, and should be studied further. In contrast, Captan® did not have a significant effect on emergence.

Long-term Effects of Post-fire Seeding Treatments

Jeff Ott and Francis Kilkenny 176

- To better understand long-term effects of post-fire seed mixes, we revisited study sites in Tintic Valley, Utah, where seeding experiments had been initiated following a 1999 wildfire. Four different mixes had been applied using rangeland drills at a shrubland site and aerial seeding followed by chaining at a woodland site. Two seed mixes were comprised entirely of native species; the other two were conventional mixes containing introduced species.
- New vegetation data collected 16-18 years post-fire (2015-2017) revealed changes relative to data collected during the first 3 years (2000-2002). Total vegetation cover was higher during the later period, but also fluctuated between years within both periods.
- The higher-elevation aerial-seeded site had more residual perennials and fewer exotic annuals than the lower-elevation drill-seeded site. Seeding was successful at the aerial-seeded site, but in the absence of seeding there was still substantial recovery of perennial shrubs, grasses, and forbs. Some residual perennials also recruited into unseeded areas at the drill-seeded site, but these areas became largely dominated by exotic annuals.
- Native and exotic annual forbs were abundant during years 1-3, but cheatgrass (Bromus tectorum) became the dominant annual by year 16. Suppression of exotic annuals was greatest in conventional mixes, but native-only mixes also suppressed exotic annuals more than unseeded control treatments.
- Seeded treatments became dominated by seeded species, especially perennial grasses. Most seeded species increased in cover between years 1-3 and 16-18, but some decreased, presumably because of competitive interactions and/or maladaptation to site conditions.
- Shrub cover was minimal in conventional seed mix treatments, likely because these seed mixes had contained little shrub seed and/or because species in these seed mixes competitively suppressed shrub recruitment.
-

SCIENCE DELIVERY

SeedZone Mapper Mobile App Development

Andrew Bower and Charlie Schrader-Patton 185

- Development of several mobile applications that function on both Android, iOS (Apple), and PC devices for both online and offline data collection and location information.
- Expanded coverage of state-wide maps for offline use.

- Documentation including download and installation instructions, and tutorial posted to the WWETAC TRM Mobile Seed Zone Mapping website page (https://www.fs.fed.us/wwetac/threat-map/TRMSeedZoneMobile.php).

Science Delivery for the Great Basin Native Plant Project

Corey Gucker 188

- 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).

Climate-Smart Restoration Tool

Brad St. Clair, Nokolas Stevenson-Molnar, Brendan Ward, Francis Kilkenny and Bryce Richardson 190

- The CSRT is a web-based application that allows users to match current seed sources with future climate conditions.
- Users will be able to view maps of current and future climates, seed zones, ecoregions, and other contextual layers.
- Users will be able to download outputs of the tool as PowerPoint presentations, PDF documents, and GeoTIFF datasets.
- The CSRT will be developed using the latest open-source software and incorporating mechanisms for its long-term maintenance.
- Source code and developer documentation for the CSRT will be made freely available on GitHub.

SPECIES INTERACTIONS

Assessing Host Preferences for Arbuscular Mycorrhizal Fungi in Wyoming Big Sagebrush Seedlings and Sudan Grass

Marcelo Serpe 195

- Previous studies indicated that seedlings of Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) growing in southwestern Idaho were colonized by a variety of arbuscular mycorrhizae fungi (AMF) but that certain taxa were dominant.
- To determine whether the dominance of certain AMF taxa reflected their abundance in the soil or seedling preferences for specific AMF, we grew sagebrush and Sudan grass (*Sorghum bicolor*) in soil collected from the Morley Nelson Birds of Prey National Conservation Area and identified the AMF taxa present in these plants using molecular techniques.
- A total of 23 operational taxonomic units (OTUs) with sequence similarities higher than 94% were identified and individual seedlings were simultaneously colonized by AMF belonging to 3 to 5 OTUs. No differences in the structure of the AMF communities

colonizing sagebrush and Sudan grass were observed, suggesting that the dominance of certain OTUs reflected their abundance in the soil, rather than host preferences for particular AMF.

- The similarities in AMF community composition between sagebrush and Sudan grass suggest that the latter is a suitable host to multiply AMF native to sagebrush habitats.

Comprehensive Assessment of Restoration Seedings to Improve Restoration Success

Kari Veblen and Thomas Monaco...201

- 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 are using 63 restoration sites that are monitored as part of the Utah Watershed Restoration Initiative (WRI) to 1) investigate the roles of different pre-seeding restoration treatments, seeding approaches, environmental factors, and plant species traits on success of seeded species and 2) quantify the cost effectiveness and efficiency of these seeding efforts.
- This effort will provide critical information to compare the biological- and cost-effectiveness of different restoration treatments and seeding approaches. Our effort will also quantitatively assess the performance of species based on biological traits, which can be used to enhance plant material development and influence seeding success over both short and long-term periods.

GENETICS AND CLIMATE CHANGE

Project Title Intraspecific Variation and Local Adaptation in Great Basin Plants: a Review of 75 Years of Experiments

Project Agreement No. 17-JV-11221632-017

Principal Investigators and Contact Information

Owen Baughman, **Alison C. Agneray**, **Matthew L. Forister, Elizabeth A. Leger** (lead contact)
Dept. of Natural Resources and Environmental Science, MS 186
University of Nevada, Reno, NV 89557
775.784.7582, Fax: 775.784.4789
eleger@cabnr.unr.edu

Francis Kilkenny (main contact), **Jeffrey E. Ott**
USDA Forest Service, Rocky Mountain Research Station
322 E Front Street Suite 401, Boise, ID 83702
208.373.4376, Fax 208.373.4391
ffkilkenny@fs.fed.us

Erin K. Espeland, Research Ecologist
Pest Management Research Unit, USDA-Agricultural Research
Service Northern Plains Agricultural
Laboratory, 1500 N Central Ave.
Sidney, MT 59270 USA
406.433.9416
erin.espeland@ars.usda.gov

Thomas Kaye (main contact), **Rob Fiegener**
Institute for Applied Ecology
563 SW Jefferson Ave.
Corvallis, OR 97333
541.753.3099 ext. 777
tom@appliedeco.org

Matthew E. Horning
USDA Forest Service Pacific Northwest Region
Deschutes National Forest
63095 Deschutes Market Rd.
Bend, OR 97701
541.383.5519
mhorning@fs.fed.us

R.C. Johnson, Research Agronomist
USDA-ARS, Western Regional Plant Introduction Station
Washington State University
Box 646402, Pullman, WA 99164
509.335.3771
rcjohnson@wsu.edu

Brad St. Clair, Research Geneticist
USDA Forest Service, Pacific Northwest Research Station
3200 SW Jefferson Way, Corvallis, OR 97331-4401
541.750.7294, Fax 541.750.7329
bstclair@fs.fed.us

Dedication:

We would like to dedicate this report and subsequent publication to the memory of Erin Espeland, who worked hard on this study but passed away before the manuscript was accepted to a journal. Erin was a shining light and we miss her greatly.

Project Description

Introduction

The text for this project was excerpted and modified from a version of the manuscript that has been submitted for publication.

Plants are subject to different conditions associated with their local environment, so populations of the same species will experience differential selection pressures, creating habitat-correlated intraspecific variation. When this intraspecific variation results in populations that are more fit in their home environment than foreign populations, these populations are considered to be locally adapted (Kawecki and Ebert 2004). The existence of local adaptation is well-established across different organisms and ecosystems, although our synthetic knowledge of this important topic rests on surprisingly few reviews of the subject (Leimu and Fischer 2008; Hereford 2009). In a literature review, we focused on the Great Basin and asked if plant species share patterns of intraspecific variation and local adaptation. The regional focus provides a strong test of expectations generated from more heterogenous samples, and provides an opportunity to link basic evolutionary patterns with applied concerns. The detection of local adaptation ideally involves reciprocal transplant experiments designed to test for a local advantage across environments (Bucharova et al. 2017). However, patterns associated with local adaptation (hereafter, signatures) can be detected in non-reciprocal comparisons of different populations of the same species (Endler 1986). When populations are locally adapted to abiotic or environmental variables, we expect to see three basic signatures: 1) differences among populations in fitness-related traits, 2) correlations between these trait values and environmental or other habitat-related variables, and, if reciprocal transplants or common gardens have been conducted, 3) higher fitness of local over nonlocal populations in the local environment.

The Great Basin Desert of North America is a ~540,000 km^2 cold desert landscape characterized by hundreds of internally-draining basin and range formations, which create high spatial and environmental heterogeneity and variability. While these are the kinds of conditions that would be expected to result in widespread local adaptation, the flora of the Great Basin is poorly represented in the relatively few reviews on the subject (Leimu and Fischer 2008; Hereford 2009), and this has resulted in uncertainty as to the prevalence, magnitude, and importance that local adaptation plays in this large and increasingly imperiled region (Chivers et al. 2016). Gaining a better understanding of potential fitness differences between populations of the same species is important in the Great Basin not only because it is a large, relatively intact floristic region in the Western US, but because it has direct impacts on conservation and restoration efforts. Large-scale, seed-based restoration has been very common in the Great Basin for many decades (Pilliod et al. 2017), and trends in large destructive wildfires and other disturbances ensure even higher demand for restoration efforts in the future. However, few of the widely-available sources of commercially-produced seeds of native species originate from populations within the Great Basin or have been selected based on their success in restoring Great Basin habitats (Leger and Baughman 2015), and demand for native seed has always exceeded supply (Johnson et al. 2010).

Though our understanding of the prevalence and scale of local adaptation in the Great Basin is far from complete, there is an abundant literature of peer-reviewed studies on the plants native to this region that have directly measured trait variation between populations via laboratory and greenhouse trials, common gardens, and reciprocal transplants. Many of these studies have also tested for correlations between intraspecific variation and environmental variables, and some were designed to detect local adaptation. This rich literature provides an opportunity to summarize local adaptation and its associated patterns, or signatures (defined above), in this region, as well as describe which phenotypic traits have the strongest signatures of local adaptation. Here, we present some results of a broad literature review using published studies that compared phenotypic traits of multiple populations of native Great Basin species in one or more common environments.

Objectives

Our objective was to record the frequency and nature of the three expected signatures of local adaptation (population variation, trait-by-environment association, and greater local fitness) within grasses, forbs, shrubs, and trees native to the Great Basin, and ask how common these signatures are, and which phenotypic traits and environmental variables were most commonly associated with these signatures. We also present results by taxonomic group, lifeform, lifespan, distribution, and mating system.

Methods

We conducted a literature search by using online search engines Google Scholar and Web of Science to search for combinations of appropriate key terms. In order to be included in our review, a study had to meet all of these criteria: A) examined a species that is native within the floristic Great Basin; B) examined and compared more than one population of that species; C) Measured at least one phenotypic, physiological, phenological, or other potentially fitness-related trait (e.g. survival; hereafter, trait), and; D) measured the trait(s) of the populations in at least one common environment (including laboratories, growth chambers, greenhouses, or outside gardens; hereafter, garden). Determination of nativity to the Great Basin was defined as at least one occurrence with native status within the floristic Great Basin according to occurrence information from the USDA Plants Database (USDA and NRCS 2018) and/or the U.S Virtual

Herbarium Online (Barkworth and Murrell 2012). A total of 170 published studies published between 1941 and July 2017 were encountered that met these criteria.

All studies meeting our criteria were categorized and scored for each signature. The coordinates of all gardens and populations in each study were recorded or, if possible, generated from localities described in the studies. The first two expected signatures of local adaptation were scored using a Yes/No designation for each experiment which considered all measured phenotypic traits. A score of "Yes", or, in the absence of supporting statistical evidence, "Authors claim Yes", was given when at least one measured trait significantly demonstrated the signature for at least two populations, and a score of "No" or "Authors claim No" was given when the signature was not detected between any pair of populations. In addition, each of the measured and reported traits and environmental variables were scored in the same way for each signature. Of the 327 experiments, 305 (93.3%) met the criteria to score for signature 1 and 161 (49.5%) met the criteria to score for signature 2.

To score whether there was higher fitness of a local population in a common garden (hereafter, signature 3), only experiments in which outdoor reciprocal transplants or common gardens were performed using a local population in at least one garden were considered. Additionally, the experiment had to measure survival, reproductive output (number of seeds or flowers, or other reproductive output), a fitness index (a combination of several size and production traits), or total aboveground biomass. Each experiment was given a composite score to fully capture variation in the performance of each garden's local population, across multiple gardens as well as through multiple sampling dates. These scores refer only to those gardens within each experiment that each had their own local population. The five scores were "Yes for all gardens at all times", "Yes for all gardens at some times", "Yes for some gardens at all times", "Yes for some gardens at some times", and "No for all gardens at all times" (see additional methods in electronic supplementary material). Of the 326 experiments, 27 (8.3%) were appropriate for this scoring.

Results and Discussion

Of the 305 experiments appropriate for addressing among-population trait variation (signature 1), 290 (95.1%) experiments reported finding variation among populations in at least one phenotypic trait, with 230 (75.4%) of these 290 reporting significant variation, and 60 (19.6%) claiming such variation in the absence of any supporting statistics (Figure 1A). Only 12 (3.9%) experiments reported no such differentiation in any trait after statistically testing for it, and 3 (1%) claimed no such variation without presenting statistical evidence. When categorized by basic life history traits, several differences appeared among groups. Dicots had significantly more population-differentiation than monocots ($X^2 = 7$, $P = 0.0081$), and forbs and shrubs had more population differentiation than grasses ($X^2 = 8.05$, $P = 0.0143$). There were no significant differences in signature 1 among plants with different geographic distributions, life span, or breeding systems.

Of the 161 experiments appropriate for testing trait-by-environment associations (signature 2), 131 (81.4%) reported associations for at least one comparison, with 81 (50.3%) supported by statistical tests and 50 (31.1%) supported by claims in the absence of statistics (Figure 1B). Conversely, 13 (8.1%) of experiments reported no such correlations after having statistically tested for it, and 17 (10.6%) reported no such correlations but lacked any supporting statistics.

There were no significant differences in the frequency of trait-by-environment associations for taxonomic status, lifeform, geographic distribution, or breeding system, but perennials (both long-lived and short-lived) had more frequent correlations between traits and environment than did annuals or short-lived perennials ($X^2 = 8.08$, $P = 0.0444$).

The 27 experiments that were suitable for detecting higher fitness of a local population in a local garden (signature 3) generated 39 scores (some experiments measured multiple fitness traits), with 27 scores (69.2%) reporting signature 3 for at least one fitness trait in at least one of the tested gardens during at least one sampling date, and the remaining 12 scores (30.8%) not reporting signature 3 at any point (Figure 1C). Thirty two of the 39 scores (82%) were generated from experiments with more than one garden. Survival was the most frequently measured fitness trait in these experiments, reported in 24 of the 27 experiments, followed by reproduction (10), biomass (3), and fitness indices (2). Incidence of local-does-best patterns was highest in experiments that directly measured reproductive output, with 90% reporting higher values for locals at some point in an experiment, followed by survival (67%), fitness indices that incorporated biomass (50%), and biomass measures (33%). For experiments in which only “some” gardens showed local-does-best patterns (Figure 1C, hashed bars), the percentage of gardens showing this trend was 40%, 50%, and 40% for reproduction, survival, and biomass traits, respectively (not shown). For experiments in which only “some” sampling dates showed local-does-best patterns (gray bars), the percentage of sampling dates showing this trend was 56%, 47%, and 25% for reproduction, survival, and biomass traits, respectively (not shown).

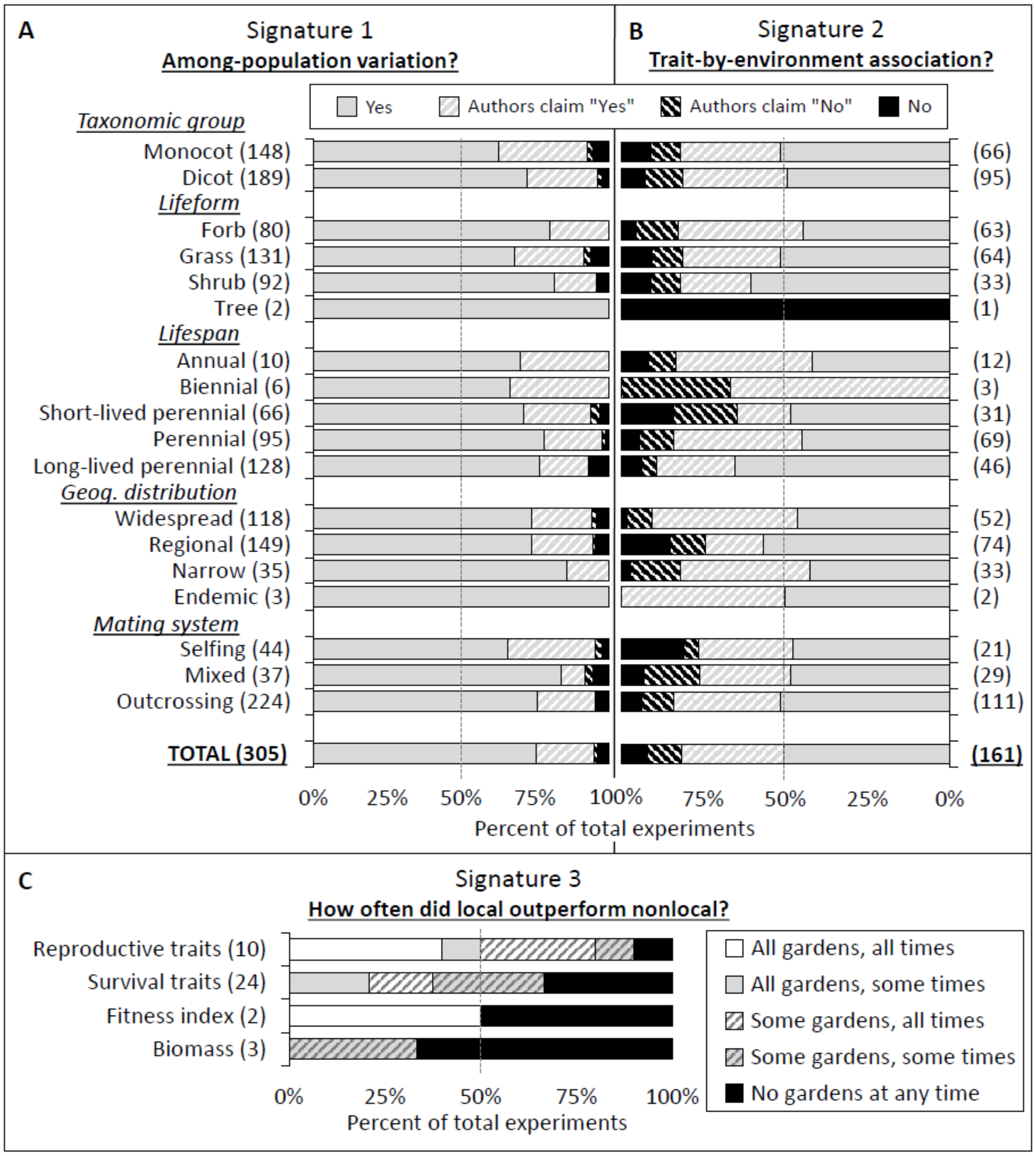


Figure 1. Frequency of among-population variation (A, signature 1) and trait-by-environment associations (B, signature 2) for any measured trait, grouped by five life history traits. Frequency of local advantage (C, signature 3) for reproductive traits, survival traits, fitness indices, or biomass. Data compiled from 327 experiments from 170 published studies on Great Basin plants. For signatures 1 and 2, “Yes” and “No” represent statistical comparisons, while “Authors claim “Yes”” and “Authors claim “No”” represent textual, claim-based results where supporting statistics were not reported (common in older studies). For signature 3, most experiments had multiple gardens, and many evaluated performance at multiple sampling dates, leading to 5 different scores. These scores, from “All gardens, all times” to “No gardens at any time” represent a gradient of incidence and frequency of this signature. For all panels, numbers in parentheses indicate the number of experiments scored in a given category, and the dashed gray lines indicate 50%.

We found that Great Basin plant species contain large amounts of intraspecific diversity in a wide range of phenotypic traits, that differences in these phenotypic traits are often associated with the heterogeneous environments of origin, and that differences among populations are commonly relevant to outplanting fitness. The importance of intraspecific variation may equal or exceed the importance of species diversity for the structure and functioning of communities and ecosystems, and our quantification of local adaptation and trait-environment associations should serve as encouragement to seriously consider intraspecific diversity in native plant materials used in restoration and conservation in this region throughout the selection, evaluation, and development process (Basey et al. 2015). The overall incidence of "local does best" in the Great Basin is similar to or higher than other reviews that have found local adaptation to be commonplace, but not ubiquitous. In a review of local adaptation in plants that compared survival, reproduction, biomass and germination traits in reciprocal transplants, Leimu and Fischer (2008) found that local plants outperformed non-local ones in 71% of 35 published experiments. Similarly, Hereford (2009) quantified local adaptation in 70 published studies (50 of them plants), reporting only survival or reproductive traits, and found evidence of local adaptation in 65-71% of experiments. Our results show that the strongest indication of local adaptation came from experiments that directly measured reproductive output, and that using biomass as a fitness proxy may not be an effective way to compare relative performance in the Great Basin. This is consistent with a previous study that demonstrated selection for smaller, rather than larger, individuals in disturbed arid systems (Kulpa and Leger 2013). Meta-analyses conducted across biomes may occlude regionally-important trait differentiation and mask patterns of local adaptation, as we might expect, for example, biomass to be more strongly linked to fitness in regions where light is a contested resource (Espeland et al. 2017).

Management Applications and/or Seed Production Guidelines

Reestablishing and maintaining native plant communities in arid regions has proven challenging, and the lack of practical knowledge guiding more appropriate selection of seed sources is a major barrier (Gibson et al. 2016). The forestry industry has long adopted the principles of local adaptation in their reforesting guidelines with great success (Johnson et al. 2004), and similar approaches to restoration in the rangelands of the Great Basin may also increase success as our data support similarly high levels of population differentiation within grass, forb and shrub life history groups. Our results are in agreement with observations of local adaptation in plant populations world-wide. Given the speed and severity with which natural communities are being altered by anthropogenic factors, the application of an evolutionary perspective to restoration ecology is more important than ever. Adjusting seed-selection priorities to account for the existence of locally adapted, intraspecific variation in the Great Basin will promote the maintenance and recovery of resilient, self-sustaining vegetation communities in this region.

References

Barkworth, M.; Murrell, Z. 2012. The US Virtual Herbarium: working with individual herbaria to build a national resource. ZooKeys 209: 55-73.

Basey, A. C.; Fant, J. B.; Kramer, A. T. 2015 Producing native plant materials for restoration: 10 rules to collect and maintain genetic diversity. Native Plants Journal 16: 37-53.

Bucharova, A.; Durka, W.; Hölzel, N.; Kollmann, J.; Michalski, S.; Bossdorf, O. 2017. Are local plants the best for ecosystem restoration? It depends on how you analyze the data. Ecology and Evolution 7: 10683-10689.

Chivers, I. H.; Jones, T. A.; Broadhurst, L. M.; Mott, I. W.; Larson, S. R. 2016. The merits of artificial selection for the development of restoration-ready plant materials of native perennial grasses. Restoration Ecology 24: 174-183.

Endler, John A. 1986. Natural selection in the wild. New Jersey: Princeton University Press. 339 p.

Espeland, E. K.; Johnson, R. C.; Horning, M. E.; 2017. Plasticity in native perennial grass populations: Implications for restoration. Evolutionary Applications 11, 340-349.

Gibson, A. L.; Espeland, E. K.; Wagner, V.; Nelson, C. R. 2016. Can local adaptation research in plants inform selection of native plant materials? An analysis of experimental methodologies. Evolutionary Applications 9: 1219-1228.

Hereford, J. 2009. A quantitative survey of local adaptation and fitness trade-offs. American Naturalist 173: 579-588.

Johnson, R.; Stritch, L.; Olwell, P.; Lambert, S.; Horning, M. E.; Cronn, R. 2010. What are the best seed sources for ecosystem restoration on BLM and USFS lands? Native Plants Journal 11: 117-131.

Johnson, G.; 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.; Ebert, D. 2004. Conceptual issues in local adaptation. Ecology Letters 7: 1225-1241.

Kulpa, S. M.; Leger, E. A. 2013. Strong natural selection during plant restoration favors an unexpected suite of plant traits. Evolutionary Applications 6: 510-523.

Leger, E. A.; Baughman, O. W. 2015. What seeds to plant in the Great Basin? Comparing traits prioritized in native plant cultivars and releases with those that promote survival in the field. Natural Areas Journal 35: 54-68.

Leimu, R.; Fischer, M. 2008. A meta-analysis of local adaptation in plants. PLoS One 3: e4010.

Pilliod, D. S.; Welty J. L.; Toevs, G. R. 2017. Seventy-Five Years of Vegetation Treatments on Public Rangelands in the Great Basin of North America. Rangelands 39: 1-9.

USDA; NRCS. 2018. The PLANTS Database. National Plant Data Team, Greensboro, NC 27401-4901 USA. http://plants.usda.gov (accessed on 8 January 2018).

Project Title Comparative Phylogeography for Great Basin Plant Species

Project Agreement No. 13.IA.11221632.161

Principal Investigators and Contact Information

John Bradford, Research Ecologist
U.S. Geological Survey
Colorado Plateau Research Station
Flagstaff, AZ 86011-5614
928.523.7766
jbradford@usgs.gov

Rob Massatti, Ecologist
U.S. Geological Survey
Colorado Plateau Research Station
Flagstaff, AZ 86011-5614
307.920.1028
rmassatti@usgs.gov

Project Description

Introduction

A fundamental question when developing conservation and restoration plans is how best to match plant materials to target site conditions. Selecting propagules that are locally adapted to the biotic and abiotic conditions they will encounter ensures that resources are used effectively (McKay et al. 2005; Wood et al. 2015), thereby broadening the reach of restoration and conservation activities (Plant Conservation Alliance 2015). When conditions are difficult to predict, enhancing adaptive potential by ensuring genetic diversity of propagule sources is a justifiable approach (Broadhurst et al. 2008). However, for most restoration species, information to guide propagule-site matching is limited. Next-generation sequencing (NGS) is emerging as a fundamental tool to assist plant material selection and development (Richardson et al. 2012; Massatti et al. *In review*). NGS data are now cost-effective to generate, can be obtained relatively quickly, and the tools to process, analyze, and interpret them in ways meaningful to restoration and that meet national goals (Plant Conservation Alliance 2015) are accessible.

For most important Great Basin restoration species, knowledge of adaptive differentiation, genomic diversity (e.g., polyploidy), and spatial variation in standing genetic diversity is lacking. This information is critical for determining which source populations of target species should be developed for the commercial seed market. Furthermore, such information may help avoid problems such as outbreeding depression (either within seed sources created by combining seed from populations distributed across seed transfer zones or between a seed source and the adjacent "natural" population at a restoration site), which can occur between populations from evolutionary lineages that have experienced little gene flow in the recent past (Frankham et al. 2011). Evolutionary lineages are implicit in the West, where many plant species' populations have been more commonly distributed according to glacial climates, which were temporally dominant during the last 2 million years.

Objectives

We propose to process and analyze genomic data from up to seven species, with the specific goals of: 1) assessing the similarities and differences of species' phylogeographic patterns; 2) resolving changes in genetic diversity across the landscape; 3) determining if and where unique genetic variation is harbored; 4) investigating historical and contemporary processes influencing genetic patterns; and 5) characterizing the spatial patterns of polyploid races.

Methods

We will work with raw genomic data and demultiplex/process them in the ipyrad genomics pipeline (Eaton 2014). We will construct datasets in several formats for each species and provide these to the Great Basin Native Plant Project (GBNPP) (along with all other relevant processed data, processing statistics, and processing parameters). Following data processing, we will perform exploratory analyses on species-specific datasets to visualize major axes of genomic variation using principal coordinates analysis (e.g., Massatti et al. *In review*), spatial principal coordinates analysis (Jombart et al. 2008), and STRUCTURE (Pritchard et al. 2000). In conjunction with GBNPP researchers, we will identify research questions of interest to guide initial data analyses within and across species. Regardless of what patterns preliminary analyses reveal, we will resolve geographic patterns of genetic variation within species (i.e., conduct phylogeographic analyses) and put them into a comparative context to investigate how historical and contemporary processes affect species' genomic patterns. Modeling methodologies that may assist with phylogeographic analyses include iDDC (He et al. 2013, Massatti and Knowles 2016) and FASTSIMCOAL2 (Excoffier et al. 2013).

Expected Results and Discussion

Species adapted to habitats across western North America display a wide range of phylogeographic patterns, largely due to their life history characteristics (Massatti and Knowles 2014) and interactions with historical climates (e.g., Pleistocene glaciations) and complex topography. While most of the regional phylogeographic research has been focused on the Pacific Northwest (see Shafer et al. 2010), we anticipate that Great Basin plant species will display unique genetic patterns, but will likely have responded to glaciations in relatively similar ways. These data will be among the first and most descriptive genomic data available for the Great Basin region, and they will form a framework that can inform future genomics projects (e.g., sampling schemes, selection of species with specific functional traits, scope of analyses, etc.).

The results of our research can be used to guide the development of seed lines that maintain the genetic diversity across the focal species' ranges. Moreover, these data will inform managers about the existence and distribution of polyploidy and evolutionary lineages that may reduce success of restoration projects if not properly accounted for. While our analyses will be limited to elucidating phylogeographic patterns, the data can be used in a variety of analyses, including to discern environmental gradients important to Great Basin species, to test hypotheses concerning population connectivity, and to resolve relationships among closely related species.

References

Broadhurst, Linda M; Lowe, Andrew; Coates, David J.; Cunningham, Saul A.; McDonald, Maurice; Vesk, Peter A; Yates, Colin. 2008. Seed supply for broadscale restoration: maximizing evolutionary potential. Evolutionary Applications 1: 587–597.
Eaton, D.A. 2014. PyRAD: Assembly of de novo RADseq loci for phylogenetic analyses. *Bioinformatics* 30: 1844–1849.

Excoffier, Laurent; Dupanloup, Isabelle; Huerta-Sanchez, Emilia; Sousa, Vitor C; Foll, Matthieu. 2013. Robust demographic inference from genomic and SNP data. PLOS Genetics 9: e1003905.

Frankham, Richard; Ballou, Jonathan D.; Eldridge, Mark D; Lacy, Robert C.; Ralls, Katherine; Dudash, Michele R.; Fenster, Charles B. 2011 Predicting the Probability of Outbreeding Depression. Conservation Biology. 25: 465–475.

He, Qizin; Edwards, Danielle L; Knowles, L. Lacey. 2013. Integrative testing of how environments from the past to the present shape genetic structure across landscapes. Evolution 67: 3386–3402.

Jombart, T; Devillard, S; Dufour, A.B.; Pontier, D. 2008. Revealing cryptic spatial patterns in genetic variability by a new multivariate method. Heredity 101: 92–103.

Massatti, R.; Knowles, LL. 2014. Microhabitat differences impact phylogeographic concordance of codistributed species: genomic evidence in montane sedges (*Carex* L.) from the Rocky Mountains. *Evolution* 68: 2833–2846.

Massatti, R; Knowles, LL. 2016. Contrasting support for alternative models of genomic variation based on microhabitat preference: species-specific effects of climate change in alpine sedges. *Molecular Ecology* 25: 3974–3986.

Massatti, R et al. *In review*. Using next-generation sequencing data to investigate population structure and local adaptation: A case study in *Syntrichia (Tortula) ruralis*, an important component of biological soil crusts.

McKay, John K; Christian, Caroline E.; Harrison, Susan; Rice, Kevin J. 2005. “How Local Is Local?”-A Review of Practical and Conceptual Issues in the Genetics of Restoration. Restoration Ecology 13: 432–440.

Plant Conservation Alliance. 2015. National Seed Strategy for Rehabilitation and Restoration | 2015–2020. URL: https://www.blm.gov/programs/natural-resources/native-plant-communities/national-seed-strategy. U.S. Department of the Interior, Bureau of Land Management.

Pritchard, Jonathan K.; Stephens, Matthew; Donnelly, Peter. 2000. Inference of population structure using multilocus genotype data. Genetics 155: 945–959.

Richardson, Bryce A.; Page, Justin T.; Bajgain, Prabin; Sanderson, Bruce C.; Udall, Joshua A. 2012. Deep sequencing of amplicons reveals widespread intraspecific hybridization and multiple origins of polyploidy in big sagebrush (*Artemisia tridentata*; Asteraceae). American Journal of Botany 99: 1962–1975.

Shafer, Aaron B.A.; Cullingham, Catherine I.; Cote, Steeve D.; Coltman, David W. 2010. Of glaciers and refugia: a decade of study sheds new light on the phylogeography of northwestern North America. Molecular Ecology 19: 4589–4621.

Wood, Troy E.; Doherty, Kyle; Padgett, Wayne. 2015. Development of Native Plant Materials for Restoration and Rehabilitation of Colorado Plateau Ecosystems. Natural Areas Journal 35: 134–150.

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

Principal Investigators and Contact Information

Lesley DeFalco, Research Plant Ecologist
U.S. Geological Survey
160 N. Stephanie St., Henderson, NV 89074
702.564.4507 fax 702.564.4600
ldefalco@usgs.gov

Daniel Shryock, Plant Ecologist
U.S. Geological Survey
160 N. Stephanie St., Henderson, NV 89074
702.564.4500 fax 702.564.4600
dshryock@usgs.gov

Todd Esque, Research Ecologist
U.S. Geological Survey
160 N. Stephanie St., Henderson, NV 89074
702.564.4506 fax 702.564.4600
tesque@usgs.gov

Project Description

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

Characterizing local adaptation in plants of the Great Basin is an important step towards increasing restoration effectiveness in a changing climate. Habitat for the greater sage-grouse (*Centrocercus urophasianus*) in the southern Great Basin ecosystem is imperiled by multiple-use activities – such as Solar Energy Zones, off-highway vehicle use, and mining – as well as wildfires fueled by invasive annual grasses. Revegetation of disturbed habitat has proven challenging for low elevation, arid sites in the Great Basin, particularly burned areas (Knutson et al. 2014). Understanding whether ecotypes exist that may both enhance re-vegetation efforts and exhibit resilience in the face of climate change is important but infrequently addressed.

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

Objectives

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

Our research addresses three key questions regarding southern Great Basin populations of contrasting aridity and predicted levels of exposure to climate change:

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

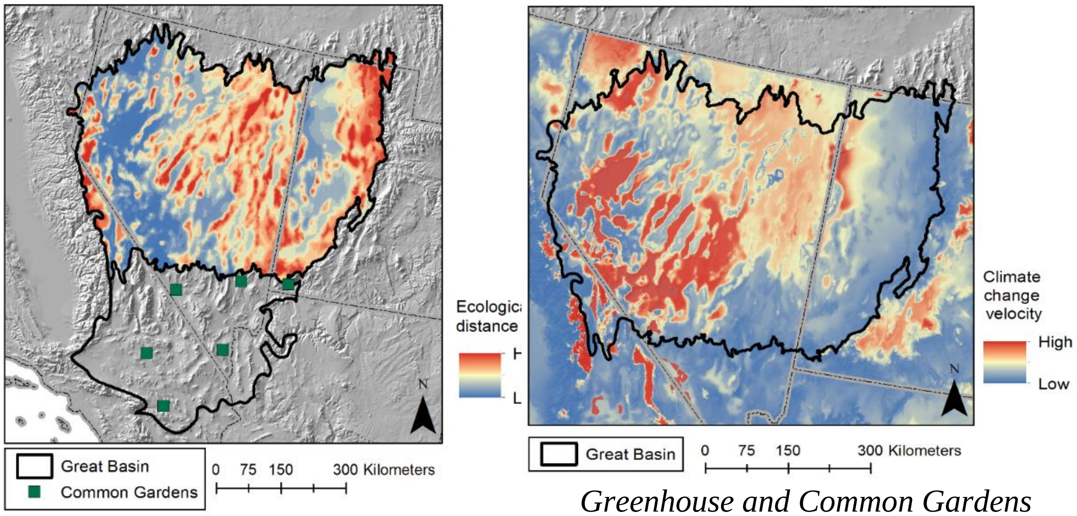
Methods

Sample Design

Potential locations supporting Indian ricegrass populations within the southern Great Basin were extracted from the SEInet and Calflora herbaria networks (http://swbiodiversity.org, http://ucjeps.berkeley.edu/consortium/). 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 km^2 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. 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 1); 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 2). 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).

Tiller Collections

Using herbarium records, we located sites for collecting tillers that produced plants for the common gardens. We collected two sources each from locations that represented low and high ecological distances to the Mojave Desert common gardens, and with low and high predicted climate change velocities (two ecological distances × two climate change velocities × two replicates = eight populations). We collected tillers from individuals that were spaced at least 20 m apart. Locations that supported too few plants, or where the ground was frozen at the time of collection, were not sampled. We returned to one site, Ainslee, to re-collect individuals because many from the initial sampling did not survive transplantation into the greenhouse.



Greenhouse and Common Gardens

Figure 1. Ecological distances (left map) between the southern Great Basin (northern polygon) and Mojave common gardens (southern polygon), and velocity of climate change (right map) predicted for the southern Great Basin (based on Hamann et al. 2015).

We collected tillers from 20 individual plants within each of the eight populations of ricegrass during fall/winter 2016 and planted them into 7.5 cm × 7.5 cm × 30 cm plant bands at the U.S. Geological Survey (USGS) greenhouse in Boulder City, Nevada. Soil mixture was comprised of a 3:1:1 ratio of washed sand, mulch, and perlite. Plants from these tillers, in combination with those from collections made within the Mojave Desert ecoregion (N=21 populations, data not presented), were transplanted into multiple Mojave Desert common gardens during February/March 2017. Water was applied using a fire hose that broadcast 0.75 cm water over the entire garden area and approximately biweekly from the time of planting through August 2017, after which time irrigation ceased. During monthly visits to the gardens we rated each plant as either alive (green tissue), dormant (loss of green coloration, senesced leaves attached), or dead (no green tissue or senesced leaves, stems brittle). We also characterized phenology (days to panicle emergence, seed drop, and senescence) and noted signs of herbivory during this establishment phase.

We tested the garden, source location, and garden × location effects for survival during the 6-month establishment phase when gardens received supplemental watering. We compared potential explanations for survival into separate accelerated failure time models (Wei 1992), selecting the most appropriate distribution type (*e.g.*, Weibull) for the failure model by comparing log-likelihood values of intercept-only models. We compared models that combined variables of garden and source location (represented as either ecological distance, climate change velocity or population). We computed a log-likelihood for each survival model using the LIFEREG procedure in SAS (SAS, Cary, NC) and then calculated AICc to find the best model with the lowest AICc (Burnham & Anderson 2002). We compared the difference in each AICc against the model with the lowest AICc to obtain ΔAICc: ΔAICc <2 shows substantial support for the model; ΔAICc between four and seven, considerably less support; and so on (Burnham & Anderson 2002). The importance of each variable (a value ranging from zero to one for least to most important) was derived by summing the Akaike weights (w_is) across all candidate models where the variable occurred.

Expected Results and Discussion

During the first six months following ricegrass outplanting into the four gardens, supplemental watering was provided across gardens to ensure plant establishment. Post-planting survival was best explained by the statistical model containing garden, population, and garden × population (Fig. 2; w_is = 1.0000), with ΔAICc for the next nearest model >20, including those with ecological zone or climate change velocity variables. Six-month survival at the Pahrump garden was higher than survival at the three other gardens (*p* = 0.0236; Fig. 2). While amounts of irrigation during establishment were similar across gardens, rainfall varied. The differences in rainfall, however, do not explain greater survival at the Pahrump garden where rainfall during establishment was low (17 mm) compared with Turkey Farm (112 mm), Cactus Mine (87 mm), and only slightly higher than Ridgecrest (4 mm). Survival also varied among populations (*p* = 0.0003; Fig. 2), but the garden × population interaction was not statistically significant. Detailed measurements of plant performance including phenology, growth, and reproduction will continue into the 2018 growing season under local garden environments (i.e., no supplemental water will be applied).

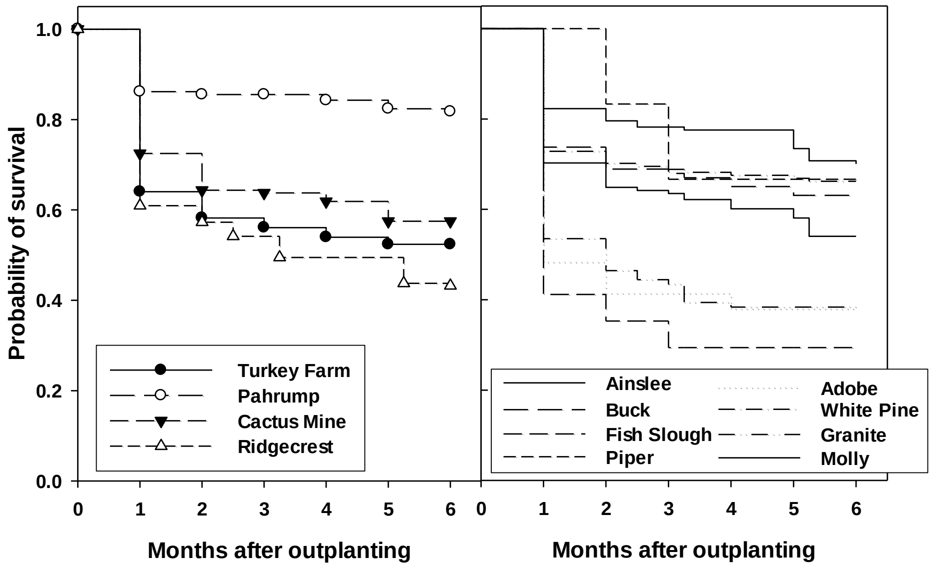


Figure 2. Survival functions for the best explanatory variables (highest weights in model with lowest AICc value) for Indian ricegrass planted into four common gardens during spring 2017: garden (left) and source location (right). For survivorship functions among source locations, filled and open symbols indicate low and high velocity populations, respectively; circles and triangles represent low and high ecological similarity, respectively.

Management Applications and/or Seed Production Guidelines

Continued monitoring of plant performance traits into 2018 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 southern 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.

Presentations

Shryock, Daniel F.; DeFalco, Lesley A.; Esque, Todd C. 2017. Linking common gardens with landscape genetics: A synergistic approach to guide restoration. Paper presented at the Ecological Society of America, Ignite Session “Multiple common garden experiments for meeting restoration challenges: Difficulties and Potential Pitfalls; August 9; Portland, OR.

Abstract: Common garden experiments and landscape genetic analyses are frequently applied to identify the genetic basis of local adaptation, yet rarely combined. In isolation, common gardens are potentially biased by phenotypic plasticity, maternal effects, and outplanting. Conversely, genome scans for selection may find spurious associations due to demographic history and non-adaptive spatial genetic structure. Linking potentially adaptive genetic loci and common garden fitness data to corresponding environmental gradients overcomes many sources of bias, particularly for non-model species. Further, this approach enables quantification of the fitness cost of seed transfer through environmental space – information most needed by restoration practitioners.

Publications

None submitted in 2017 that were supported by GBNPP funding.

Additional Products

- Presentation at symposium for managers: Shryock, Daniel F.; DeFalco, Lesley A.; Esque, Todd C. 2017. Spatial and genetic tools to guide native plant restoration in the Mojave Desert. Mojave Desert Native Plant Symposium, Barstow, CA.

References

Bansal, S.; Harrington, C. A.; Gould, P. J.; St. Clair, J. B. 2015. Climate-related genetic variation in drought-resistance of Douglas-fir (Pseudotsuga menziesii). Global Change Biology 21: 947-958.

Breshears, D. D.; Cobb, N. S.; Rich, P. M.; Price, K. P.; Allen, C. D.; Balice, R. G.; et al. 2005. Regional vegetation die-off in response to global-change type drought. Proceedings of the National Academy of Sciences of the USA 102: 15144-15148.

Brown, J. H.; Valone, T. J.; Curtin, C. G. 1997. Reorginization of an arid ecosystem in response to recent climate change. Proceedings of the National Academy of Sciences of the USA 94: 9729-9733.

Connelly, J. W.; Schroeder, M.; Sands, A. M.; Braun, C. E. 2000. Guidelines to manage sage grouse populations and their habitats. Wildlife Society Bulletin 28: 967-985.

Connelly, J. W.; Rinkes, E. T.; Braun, C. E. 2011. Characteristics of greater sage-grouse habitats: a landscape species at micro- and macroscales. In: Knick, S. T.; Connelly, J. W., eds. Greater sage-grouse: Ecology and Conservation of a landscape species and its habitats. Studies in Avian Biology, 38. University of California Press, Berkeley, CA: Cooper Ornithological Society: chapter 4.

Hamann, A.; Roberts, D. R.; Barber, Q. E.; Carroll, C.; Nielsen, S. E. 2014. Velocity of climate change algorithms for guiding conservation and management. Global Change Biology 21: 997–1004.

IPCC [Intergovernmental Panel on Climate Change]. 2013. Climate change 2013: the physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

Knutson, K. C.; Pyke, D. A.; Wirth, T. A.; Arkle, R. S.; Pilliod, D. S.; Brooks, M. L.; Chambers, J. C.; Grace, J. B. 2014. Long-term effects of seeding after wildfire on vegetation in Great Basin shrubland ecosystems. Journal of Applied Ecology 51: 1414-1424.

Loarie, S. R.; Duffy, P. B.; Hamilton, H.; Asner, G. P.; Field, C. B.; Ackerly, D. D. 2009. The velocity of climate change. Nature 462: 1052–1055.

Miriti, M. N.; Rodríguez-Buriticá, S.; Wright, S. J.; Howe, H. F. 2007. Episodic death across species of desert shrubs. Ecology 88: 32-36.

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

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

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

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

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

Project Agreement No. 14-IA-11221632-012

Principal Investigators and Contact Information

Matthew Germino, Supervisory Research Ecologist
US Geological Survey
Forest and Rangeland Ecosystem Science Center
970 Lusk Street, Boise ID 83702
Telephone 208.456.3353
mgermino@usgs.gov

Project Description

Knowing how different seed sources or plant provenances vary in their physiological response to climate contributes substantially to the basis for seed-transfer guidelines for restoration. We are measuring a comprehensive set of variables in common gardens that provide important insight on how seed provenances of foundational restoration species, specifically sagebrushes and bluebunch wheatgrass, differ in their climate responses. Measurements focus on how different populations from around the Great Basin vary in traits that relate to drought and temperature stress. Publications from Aug 2016 through 2018 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.

Introduction

Increased wildfire activity poses a major challenge for big and low sagebrush (*Artemisia* sp.) communities. Seeding and plantings of sagebrush and desirable bunchgrasses such as bluebunch wheatgrass (*Pseudoregneria spicata*) have been extensive and will continue as a central part of the Department of Interior's Integrated Rangeland Fire Management Strategy. However, restoration success has been mixed. Climate and weather variability, appropriateness of seeds, and site conditions relating to management are all factors that may help explain success of sagebrush restoration efforts. Additionally, new efforts to do seeding in the context of adaptive management have highlighted the need to better consider metrics for seeding success. Defining these metrics are essential because they affects how monitoring occurs and also the management of seeding areas, e.g. grazing. These topics are thus part of our GBNPP research and extension/outreach.

For our GBNPP contributions, we have developed or adapted measurement techniques and established a laboratory capable of high-throughput "phenotyping" of the many plants in many NPP gardens in the Great Basin. Measurement of a greater variety of functional traits in individual plants or populations increases the objectivity of assessments of climate adaptation, increasing the reliability of conclusions about which processes and climate parameters most limit plant establishment and distinguish different seed sources. Our measurements focus on traits that relate to temperature and water stress, which are the dominant factors affecting plant establishment in the cold deserts of the Great Basin. Several of our measurements quantify threshold temperatures or water levels for plant survival.

Objectives

1) provide quantitative and standardized analyses of climate adaptation for plants in common gardens in the Great Basin, and
2) determine how the climate adaptation varies among populations, subspecies or cultivars, seed zones, and species.

Methods

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

For our overall GBNPP efforts, we have devised a "sequential filtering" approach to isolating factors affecting survival and establishment. We quantified variation in ecophysiological traits of bluebunch wheatgrass 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 eco-physiological trait values that confer survival or mortality, and their specific climate drivers)

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

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

- carbon isotopes as an indicator of differences in water use efficiency and stress
- pressure-volume relationships to identify minimum water status thresholds
- freezing point and photosynthetic resistance to freezing (and heating; temperature thresholds)
- standard allometric measures that indicate growth strategy and inform interpretation of ecophysiological variables, and which relate to water and temperature responses (eg. specific leaf area, wood density)

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

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

In Brabec et al. (2017), we report that: 1) Wyoming big sagebrush *(Artemisia tridentata ssp. Wyomingensis*) had the most growth and survival, and tetraploid populations had greater survival and height than diploids. Seasonal timing of mortality varied among the subspecies/cytotypes and was related more to minimum temperatures rather than water deficit, 2) Temperatures required to induce ice formation were up to 6° C more negative in 4n-big sagebrush and Wyoming big sagebrush than other subspecies/cytotypes, indicating greater freezing avoidance. In contrast, freezing resistance of photosynthesis varied only 1° C among subspecies/cytotypes, being greatest in Wyoming big sagebrush and least in the subspecies normally considered most cold-adapted, mountain big sagebrush (*Artemisia tridentata ssp. vaseyana*). A large spectrum of reliance on freezing-avoidance vs. freezing-tolerance was observed and corresponded to differences in post-fire survivorship among subspecies/cytotypes. Differences in water-deficit responses among subspecies/cytotypes were not as strong and did not relate to survival patterns.

We (Brabec et al. 2017) concluded that low-temperature responses are a key axis defining climate adaptation in young sagebrush seedlings and vary more with cytotype than with subspecies, which contrasts the traditional emphases on 1) water limitations to explain establishment in these deserts, and 2) on subspecies in selecting restoration seedings. 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.

Presentations

Germino, M.J. 2017. Sagebrush ecosystems in a changing climate: key opportunities for adaptive management. Climate Change Science and Management Webinar Series. DOI National Climate Change and Wildlife Science Center. July 17.

Germino, M.J. 2017. Climate and sagebrush steppe. Northwest Climate Science Center Drought Synthesis meeting. Feb 9.

Publications

Brabec, M.; Germino, M.; Richardson, B. 2017. Climate adaption and post-fire restoration of a foundational perennial in cold desert: insights from intraspecific variation in response to weather. Journal of Applied Ecology 54: 293-302.

Chaney, L.; Richardson, B. A.; Germino, M. J. 2017. Climate drives adaptive genetic responses associated with survival in big sagebrush (Artemisia tridentata). Evolutionary Applications 10 (4): 313-322.

Lazarus, B., Germino, M. J., & Richardson, B. A. **In review**. Freezing-response strategies, safety margins, and risk-rewards for growth vary among sagebrush populations across the Western US. Plant, Cell, and Environment.

Germino, M.J., Moser, A.M., & Sands, A.R. **In review.** Local adaptation and adaptive variation require decades to become evident in common gardens. Ecological Applications.

Additional Products

- Helped organize and run sessions and writeups for the Great Basin Consortium meeting (GBC#7), on developing the implementation plan for the Science Framework in the DOI's Integrated Rangeland Fire Management Strategy, Feb 2017 in Reno.
- Co-organized the Joint meeting of the Great Basin Native Plant Project and Great Basin Chapter of Society for Ecological Restoration. Boise ID April 11-12, 2016; organized a special session entitled "Ecophysiological Studies on Native Plant Gardens for the meeting and organized and led a field tour of the Soda Fire.
- Received a grant from the Joint Fire Sciences Program to complement GBNPP efforts
- Gave many presentations to the BLM and participated in discussions
- Helped organize of the "All Hands/All Lands" meeting of Great Basin Consortium meeting (GBC#5), February 2016 in Salt Lake City.
- Quoted or featured in three articles on the topics of GBNPP common gardens of big sagebrush, sagebrush seeding, and climate change in rangelands, all through Associated Press, and disseminated in the Idaho Statesman newspaper (main paper for Boise ID) and others nationally.
- Serving on several committees regarding native plant materials for restoration for the Department of Interior secretarial order #3336. Co-led the program development for the GBC6 meeting (held in 2017).

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

Project Agreement No. 14-IA-11221632-013

Principal Investigators and Contact Information:

R.C. Johnson
USDA-ARS, Western Regional Plant Introduction Station
Box 646402, Washington State University
Pullman, WA 99164
509.335.3771
rcjohnson@wsu.edu

Vicki Bradley, Genetic Resources Curator
USDA-ARS, Western Regional Plant Introduction Station
Box 646402, Washington State University
Pullman, WA 99164
509.335.3616
Vicki.Bradley@ars.usda.gov

Mike Cashman, Biologist
USDA-ARS, Western Regional Plant Introduction Station
Box 646402, Washington State University
Pullman, WA 99164
509.335.6219
mike.cashman@ars.usda.gov

Project Description

Introduction

Native plant species are critical for wildlife habitat, livestock grazing, soil stabilization, and ecosystem function in the Western U.S. and the Great Basin. Current germplasm releases are often utilized without regard to their genetic suitability and adaptation to a given area. For this project, seed zones that match genetic variation in adaptive traits with source climates have been developed for numerous key species to guide seed source management decisions, ensure restoration with adapted plant material, and promote biodiversity needed for future natural selection (Johnson et al. 2010; Johnson et al. 2012; Johnson et al. 2013; St Clair et al. 2013; Johnson et al. 2015; Johnson and Vance-Borland 2016; Johnson et al. 2017).

In 2017, plasticity--differences in plant growth in different environments--was assessed in relation to genetic variation in Sandberg bluegrass. Plasticity was found to represent a large portion of the variation in populations (Espeland et al. 2017). The specific plant trait and the source location climate from which plants were collected were also associated with plasticity. Plants from warm and dry climates produced plants with more plasticity in phenology, panicle number, and biomass; cool and wet locations were associated with more plasticity in leaf size, panicle length, plant habit (prostrate or erect), and survival. As a result, plasticity may complement genetic variation for adaptation of restoration materials and may be a future consideration in seed sourcing.

Also in 2017, field evaluations of adaptive plant traits were completed on 75 diverse populations of sulfur-flowered buckwheat. This was in addition to data collected in 2016. Data from both years is being used to understand the role of climate in natural selection for plant traits and to develop seed zones to guide restoration activities of sulfur-flowered buckwheat in the Great Basin.

Objective

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

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

Sulfur-flowered buckwheat is an integral part of the Great Basin native plant community. Its seeds, leaves, and associated insects are important food sources for many small mammals and birds, including sage grouse. It also attracts many native bees and other pollinators important to sage-steppe communities (Young-Mathews, 2012). Yet a comprehensive determination of genetic variation in relation to different climates is lacking.

Methods

Seeds collected by Western Regional Plant Introduction Station (WRPIS) staff and though the Bureau of Land Management (BLM) Seeds of Success (SOS) program were used to grow 72 populations of sulfur-flowered buckwheat in the greenhouse in 2014. In the fall of 2014, these were transplanted to a common garden at the WRPIS farm at Pullman, WA. Transplants established in 2015 and comprehensive data on adaptive plant traits were collected in 2016 and 2017.

We collaborated with Dr. Steve Love (University of Idaho) in a taxonomic evaluation of the study populations (Table 1). Sulfur-flowered buckwheat varieties are extremely variable in morphological expression, especially if populations exist in geographical isolation at different elevations and habitats. Most, if not all varieties will freely intercross. Where varieties share habitat locations, hybrid swarms will occur and intermediate types will be present. There was a range of varieties with *ellipticum* by far the largest group. Still, given the complexity, identification of some populations were less certain and three were identified as parsnip-flower buckwheat (*Eriogonum heracleoides* Nutt.).

Table 1. Botanical variety for sulfur-flowered buckwheat collected in the Great Basin and growing in a common garden at Pullman, WA

†Species	Botanical variety	Number in common garden
Eriogonum umbellatum	*aureum*	5
Eriogonum umbellatum	*cognatum*	1
Eriogonum umbellatum	*desereticum*	1
Eriogonum umbellatum	*dichrocephalum*	4
Eriogonum umbellatum	*ellipticum*	23
Eriogonum umbellatum	*majus*	5
Eriogonum umbellatum	*modocense*	9
Eriogonum umbellatum	*nevadense*	6
Eriogonum umbellatum	*polyanthum*	1
Eriogonum umbellatum	*porteri*	1
Eriogonum umbellatum	*stragalum*	6
Eriogonum umbellatum	*subaridum*	5
Eriogonum umbellatum	*umbellatum*	2
Eriogonum heracleoides	*heracleoides*	3
	Total	72

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

Results and Discussion

Analyses of variance of 2016 and 2017 data indicated strong genetic differences for plant traits. The data was modified by growth year, varieties, and source locations within varieties (Table 2). Our hypothesis was that differences in plant traits among sulfur-flowered buckwheat growing in a common garden would be related to differences in seed source location climates across the Great Basin.

This hypothesis was verified by significant correlations between plant traits and key climatic factors at each source population location (Table 3). Significant correlations were especially frequent between plant traits and average temperature (MAT), continentality (TD), and extreme maximum temperature frequent.

The differences in plant traits in the common garden indicated strong genetic variation in sulfur-flowered buckwheat and correlations with climatic factors suggested climate driven adaptive evolution. Continued analysis will determine the relative roles of taxonomic variety, source location, and location climate in adaptation leading to seed zone recommendations for restoration projects.

Table 2. Significance levels (p-values) from analyses of variance of sulfur-flowered buckwheat populations collected at diverse locations in the Great Basin and growing in a common garden at Pullman WA in 2016 and 2017.

Trait	Mean	Year (Y)	Variety (V)§	Location (V)	Y*V
Bolt date†	128	<.0001	<.0001	<.0001	0.064
Bloom date†	158	<.0001	<.0001	<.0001	0.005
Maturity date†	199	0.0002	<.0001	<.0001	<.0001
Stem length, cm	20.1	<.0001	<.0001	<.0001	0.0352
Umbel length, cm	6.2	0.0138	<.0001	<.0001	0.0632
Umbel width, cm	9.3	<.0001	<.0001	<.0001	0.0251
Petiole length	2.5	<.0001	<.0001	<.0001	<.0001
Specific leaf wt.	59.9	<.0001	<.0001	<.0001	0.0031
Leaf area, cm^2	3.76	<.0001	<.0001	<.0001	<.0001
Leaf mass, g	0.709	<.0001	<.0001	<.0001	<.0001
Umbels, per plant	68.5	<.0001	<.0001	<.0001	<.0001
Plant base area, cm^2	630	<.0001	<.0001	<.0001	<.0001
Survival	0.89	<.0001	<.0001	<.0001	0.0381

†Day of year

§ Taxonomic variety within sulfur-flowered buckwheat (*Eriogonum* u*mbellatum* Torr.)

Table 3. Pearson correlations between adaptive traits and source population climates for sulfur-flowered buckwheat from the Great Basin and growing in a common garden in Pullman, WA (n=72).

Trait	MAT†	TD	MAP	SHM	FFP	PAS	EMT	EXT
Bolt	0.18	-0.02	0.06	0.08	0.03	0.03	0.09	0.02
Bloom	0.60**	0.31**	-0.06	0.18	0.47**	-0.29**	0.25*	0.40**
Maturity	0.61**	0.23*	-0.10	0.19	0.45**	-0.34**	0.27*	0.34**
Stem Lth.	0.25*	0.36**	-0.09	0.13	0.19	-0.23*	0.01	0.39**
Umbel Wth.	0.60**	0.32**	-0.09	0.22	0.48**	-0.32	0.28*	0.41**
Petiole Lth.	0.63**	0.42**	-0.26*	0.41**	0.53**	-0.42**	0.33**	0.61**
SLW	-0.35**	0.29**	0.18	-0.27*	-0.22	0.24*	-0.44**	-0.05
Leaf area	0.46**	0.65**	0.04	0.16	0.48**	-0.14	0.07	0.63**
Umbel num.	0.32**	0.04	-0.22	0.21	0.24*	-0.37**	0.21	0.24*
Plant area	0.32**	0.50**	-0.03	0.15	0.28*	-0.10	-0.02	0.46**
Leaf wt.	0.58**	0.58**	-0.03	0.23	0.54**	-0.23	0.18	0.64**
Survival	0.08	0.15	-0.16	0.12	0.14	-0.22	0.04	0.20

*,**Significant at P<0.05 and 0.01, respectively.

†MAT (mean annual temperature), TD (continentality, temp. difference between mean warmest and coldest months), MAP (mean annual precip.), SHM (summer heat-moisture index, (mean temp warmest month)/(mean summer precipitation/1000)), FFP (frost free period), EMT (30 year extreme min. temp.), EXT (30 year extreme max. temp.)

Management Applications and Seed Production Guidelines

- Seed zone have been developed for numerous Great Basin restoration species to ensure that seed sources for restoration are adapted and ecologically suitable.
- Maps visualizing seed zones are available at the Threat and Resource mapping website (https://www.fs.fed.us/wwetac/threat-map/TRMSeedZoneData.php) and are being utilized for restoration projects in the Great Basin.
- Seed zone boundaries may be modified based on management resources and land manager experience without changing their basic form or the relationship between genetic variation and climate.
- We recommend utilization of multiple populations of a given species within each seed zone to promote biodiversity needed for sustainable restoration and genetic conservation.
- Collections representing each seed zone for a given species should be released, grown, and used for ongoing restoration projects.

Presentations

None

Publications

Johnson, R.C.; Leger, E.A.; Vance-Borland, K. 2017. Genecology of Thurber's needlegrass (Achnatherum thurberianum [Piper] Barkworth) in the Western United States. Rangeland Ecology and Management 70: 509-517.

Espeland, E.K.; Johnson, R.C.; Horning, M.E. 2017. Plasticity in native plant populations: Implications for restoration. Evol. Appl. DOI: 10.1111/eva.12560.

Additional Products

- Collection and conservation of native plant germplasm through cooperation between the National Plant Germplasm System (NPGS), the Western Regional Plant Introduction Station, Pullman, WA (WRPIS), the U.S. Forest Service, and the Seeds of Success (SOS) program under BLM.
- Distribution of seeds of native species for research and development is ongoing through the NPGS.

References

Espeland, E.K.; Johnson, R.C.; Horning, M.E. 2017. Plasticity in native plant populations: Implications for restoration. Evol. Appl. DOI: 10.1111/eva.12560.

Johnson, R. C.; Erickson, V. J.; Mandel, N. L.; St. Clair, B.; Vance-Borland, K. W. 2010. Mapping genetic variation and seed zones for *Bromus carinatus* in the Blue Mountains of Eastern Oregon, U.S.A. Botany-Botanique 88: 725-736.

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

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

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

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

St. Clair, J. 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.

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

Project Title Predicting Seed Bank Characteristics in Great Basin Sagebrush Steppe Using Site Characteristics

Project Agreement No. 10-CR-11221632-174

Principal Investigators and Contact Information

Elizabeth Leger
Dept. of Natural Resources and Environmental Science, MS 186
University of Nevada, Reno, NV 89557
775.784.7582, Fax: 775.784.4789
eleger@cabnr.unr.edu

Sarah Barga
Dept. of Natural Resources and Environmental Science, MS 186
University of Nevada, Reno, NV 89557
306.528.7368, Fax: 775.784.4789
sarahcatherinebarga@gmail.com

Project Description

Introduction

There is increasing interest in restoring native forbs to degraded sagebrush steppe communities. The Great Basin desert contains expanses of sagebrush steppe vegetation that exists in a variety of conditions, ranging from relatively intact systems (often at higher elevations) to highly degraded sites (Young et al. 1972; West 1999). Restoration opportunities can vary depending on site characteristics, and this can make it difficult to predict when seeding in an area after disturbance will be necessary or whether native seed banks may be sufficient to regenerate understory vegetation without seeding. Large-scale seeding practices have the potential to impede regeneration from existing seed banks and forb seeds are costly and difficult to obtain, thus it is important to carefully consider alternatives for restoring native diversity to disturbed and degraded sites. In addition, the relative proportion of seeds from introduced species within the soil can influence the outcome of restoration efforts. Thus, identifying easy-to-measure factors that can predict seed bank characteristics in an area would be valuable to land managers, as the success of actions to increase diversity in degraded systems, such as chaining, herbicides, or prescribed fire, can be positively affected by the existence of seed banks of desirable species, or negatively affected by abundant weed seeds (Bakker and Berendse 1999; Pywell et al. 2002; Smith et al. 2002; Meyer 1994)

Objectives

Dormant seeds within the soil seed bank contribute to the regenerative potential of a community and can affect the long-term species composition of an area (Hopfensperger 2007), especially after disturbance. While much research has focused on describing seed bank processes in hot deserts (Kemp 1989), we still lack information regarding seed bank dynamics in cold deserts (but see Pekas and Schupp 2013). Here, we characterized seed banks in a Great Basin sagebrush steppe system, using field surveys and seed bank studies to compare 17 sites that differed in above-ground vegetation, fire history, and grazing use. We asked whether shrub cover, ground cover, climate, or disturbance history were predictive of seed densities, the presence of rare species, and similarity between above- and below-ground species composition.

Methods

Site Selection

Seventeen sites were selected in north-eastern Nevada (Fig. 1) within eco-regions characterized by their high abundance of sagebrush steppe vegetation (Omernik and Griffith 2014). Specific study sites were randomly selected using a nesting habitat model for the greater sage-grouse (*Centrocercus urophasianus*) (Gibson et al. 2016). We used historic fire maps (1910-2013) and historic grazing animal use (permitted animal unit months, or AUMs) from the United States Bureau of Land Management (BLM) to estimate site disturbance history. We noted whether fires occurred either on the site (hereafter, "on-site") or within 1 km of a site ("nearby"), and further noted whether the fire(s) were within 10 years ("recent") or greater than 10 years from the sampling date ("past").

Field Sampling

Plant surveys and seed bank sampling took place in June 2014. Each site was represented by one 4-hectare plot, which was sampled using twenty randomly-placed 1 m^2 quadrats in a stratified random design. Within each quadrat, we assessed the percent cover of each species and collected four 128 cm^3 soil samples from the top 5 cm of soil. We assessed shrub cover across the plot using a point-intercept sampling method at 1 m intervals along five 25 m transects. We noted all living shrub species encountered, as well as dead shrubs that were still providing woody structure on the landscape, referred to as standing dead.

Seed Bank Assessment

We assessed seed banks using our standard lab method (Espeland et al. 2010). Samples were processed in October 2014. Tables and trays (Garland - Mini Seed Tray 6.5"L X 4"W X 2"H) were prepared to allow for wicking of moisture in and out of the soil samples, and a 118.3 cm^3 portion of each soil sample was used in each tray. Trays were arranged in four blocks using a stratified random design, with each block having an equal number of samples from each plot. The location assignment on the table for blocks, and trays within blocks, were randomized every two weeks throughout the experiment. The experimental design consisted of eight treatments, with each treatment period lasting until seedling emergence tapered to nearly zero for at least two weeks (Table 1). Samples were checked for emergence at least once per week. At the beginning of the sixth treatment period, we applied 3 ml of a 5% liquid smoke solution (pH 3, Lazy Kettle Brand Hickory Liquid Smoke) prepared using methods outlined in Doherty and Cohn (2000). The final treatment was the application of 3 ml of gibberellic acid solution (10 mg/L - Super-Grow SG-GA3 20), a plant hormone that can trigger emergence in dormant seeds, to each tray. As seedlings emerged from the trays, we cataloged each distinct morphotype, and raised representative individuals to maturity for identification.

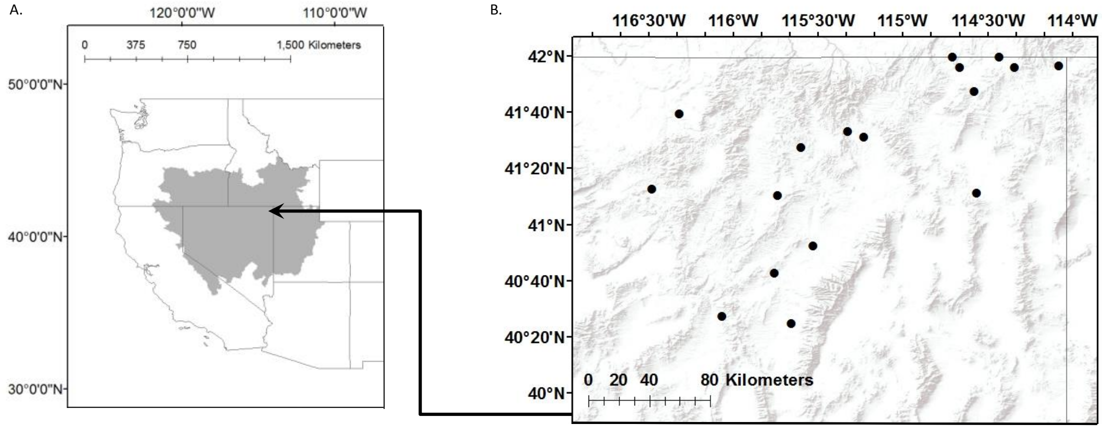


Figure 1. Map of field sites showing (A) the western United States with the floristic Great Basin highlighted in gray and (B) north-eastern Nevada site locations within two sagebrush steppe dominated ecoregions, as designated by the U.S. Environmental Protection Agency (13M - Central Basin and Range, 80A - Northern Basin and Range).

Data Analysis

We analyzed our data using generalized linear models (GLMs) in program R (R Development Core Team 2016). We asked how well different types of environmental characteristics predicted above- and below-ground characteristics, running separate models for each set of characters. Categories of environmental characteristics were: shrub cover, ground cover, climate, and disturbance. The predictor variables for the shrub cover model included the fraction of shrub cover of the three most dominant shrubs on our sites: big sagebrush, yellow rabbitbrush, and rubber rabbitbrush. The predictor variables for the ground cover model included the fraction of different types of ground cover at our sites based on our quadrat sampling, including: standing dead, bare ground, litter, and rock. The predictor variables for the climate model included annual measures of precipitation (mm), minimum temperature (°C), and maximum temperature (°C) at the sites based on 64 year averages derived using PRISM data from 1950-2014 (Daly et al. 2008). Lastly, the predictor variables for the disturbance model included AUMs, number of recent fires nearby, number of past fires nearby, number of recent fires on site, and number of past fires on site. We performed a Pearson’s correlation analysis among all predictor variables to confirm that they were not highly correlated ($R < \pm 0.7$). We also used plots of residual versus fitted values to check for trends within the residuals for each of the models. When analyzing our GLMs, we selected the best model using Akaike’s information criterion (AIC) scores, with better models possessing lower AIC scores and models <2 from the best model considered to be comparable to the best model.

Table 1. Schedule of seed bank treatments. Each treatment period lasted until seedling emergence tapered to nearly zero for at least two weeks. All watering occurred three times each week for 10 minutes using a watering system with overhead misters

Date of Onset	Treatment Phase	Duration (weeks)	Treatment
15 October 2014	First	20	Watering
4 March 2015	Second	8	Stir Soil, Watering
27 April 2015	Third	8	Dry
1 July 2015	Fourth	5	Watering

4 August 2015	Fifth	11	Dry
20 October 2015	Sixth	3	Watering
10 November 2015	Seventh	10	Smoke Water
22 January 2016	Eighth	6	Gibberellic Acid

We tabulated seed bank densities for each site by species status, noting whether each species was annual, perennial, native or introduced (USDA NRCS 2017). We averaged seed densities across all 20 samples taken from a site for use as a response variable in our GLMs. We designated a species as “rare” if it only occurred at one of our sites; forty-five species in the above-ground community and fifteen species in the below-ground community received this distinction. Seed densities of native and introduced species and the number of rare species on a site were used as response variables in our GLMs.

Finally, we calculated two measures of similarity between the above- and below-ground species composition at our sites for use as response variables in our GLMs. First, we calculated the Bray-Curtis (Sorensen) similarity index (Gardener 2014) for the presence/absence of species, with higher values indicating that the above- and below-ground communities are more similar. Next, we calculated the Bray-Curtis dissimilarity index (Gardener 2014) for the density of species, with higher values indicating that the above- and below-ground communities are more different from each other. Standardized effect sizes for our models were obtained using the *QuantPsyc* package in program R (Fletcher 2012).

Results and Discussion

In total, we identified 126 species in the above-ground community and 62 species in the seed bank. Across sites, the mean total percent cover was 5.8 - 42.0% native species and 0.3 - 26.8% introduced species (Fig. 2A). Below-ground, 53.3 - 85.7% of the species identified in the seed bank were native, and invasive species made up between 20 - 96.7% of the density of seeds in the seed bank across all sites (Fig. 2B).

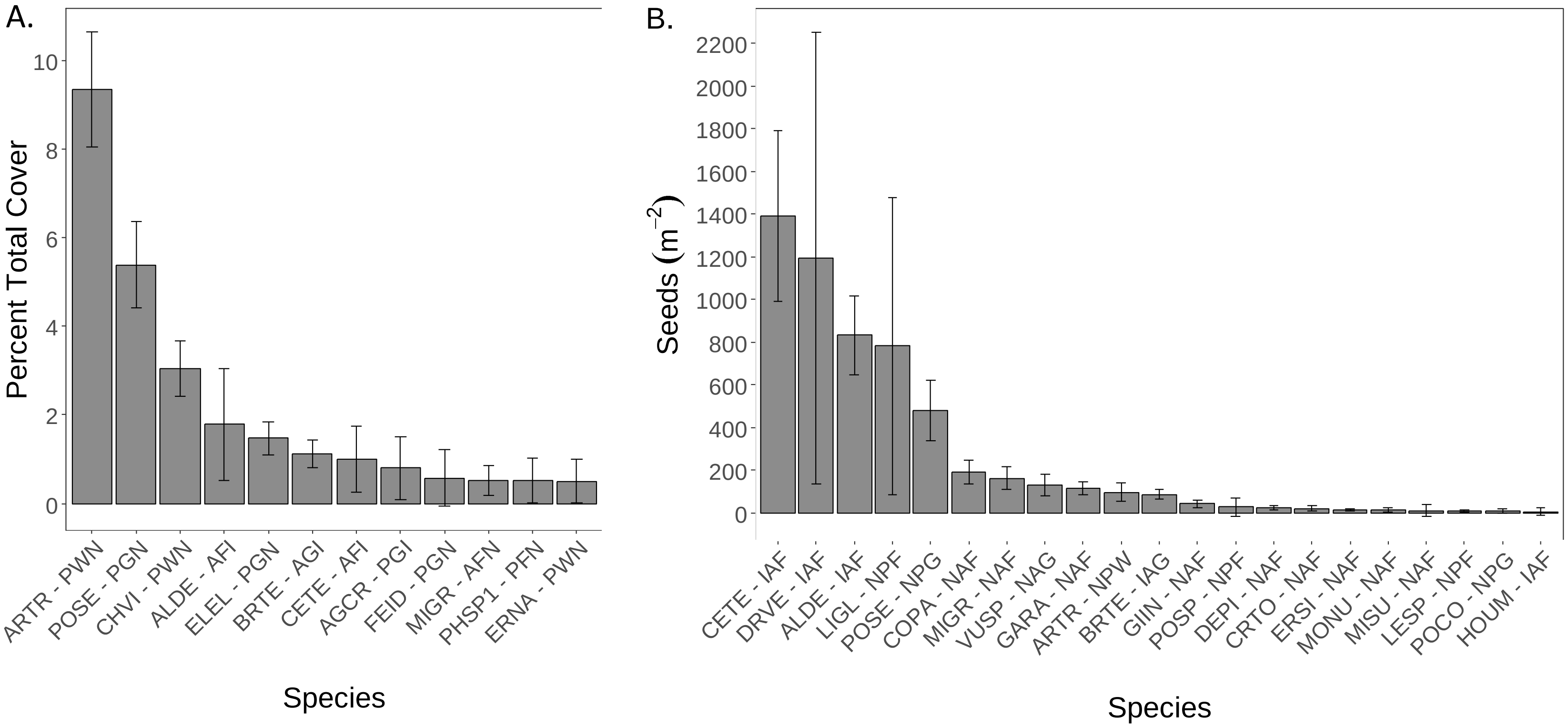


Figure 2. Mean composition of species composing ≥ 0.5% of (A) total above-ground cover or (B) seed bank density, averaged across all sites. Error bars show standard error across sites. Acronyms are: AGCR - *Agropyron cristatum*, ALDE - *Alyssum desertorum*, ARTR - *Artemisia tridentata*, BRTE - *Bromus tectorum*, CETE - *Ceratocephala testiculata*, CHVI - *Chrysothamnus viscidiflorus*, COPA - *Collinsia parviflora*, CRTO - *Cryptantha torreyana*, DEPI - *Descurainia pinnata*, DRVE - *Draba verna*, ELEL - *Elymus elymoides*, ERNA - *Ericameria nauseosa*, ERSI - *Eriastrum signatum*, FEID - *Festuca idahoensis*, GARA - *Gayophytum ramosissimum*, GIIN - *Gilia inconspicua*, HOUM - *Holosteum umbellatum*, LESP - *Lesquerella* sp., LIGL - *Lithophragma glabrum*, MIGR - *Microsteris gracilis*, MISU - *Mimulus suksdorfii*, MONU - *Monolepis nuttalianus*, PHSP1 - *Phlox* sp., POCO - *Poa compressa*, POSE - *Poa secunda*, POSP - *Potentilla* sp., VUSP - *Vulpia* sp. - N = native, I = introduced, A = annual, P = perennial, F = forb, G = grass, W = woody

Shrub cover was the best predictor of the seed density of both native and introduced species (Table 2A). Introduced species density was higher when there was increased cover of rubber rabbitbrush ($p = 0.008$), and seed bank densities of native annual species were higher in areas with more cover of yellow rabbitbrush ($p = 0.004$) (Fig. 3). Density of native perennial species in the seed bank tended to increase with increasing cover of rubber rabbitbrush ($p = 0.087$), but though this was the best predictor identified with model selection, this factor was not significant (Fig. 3).

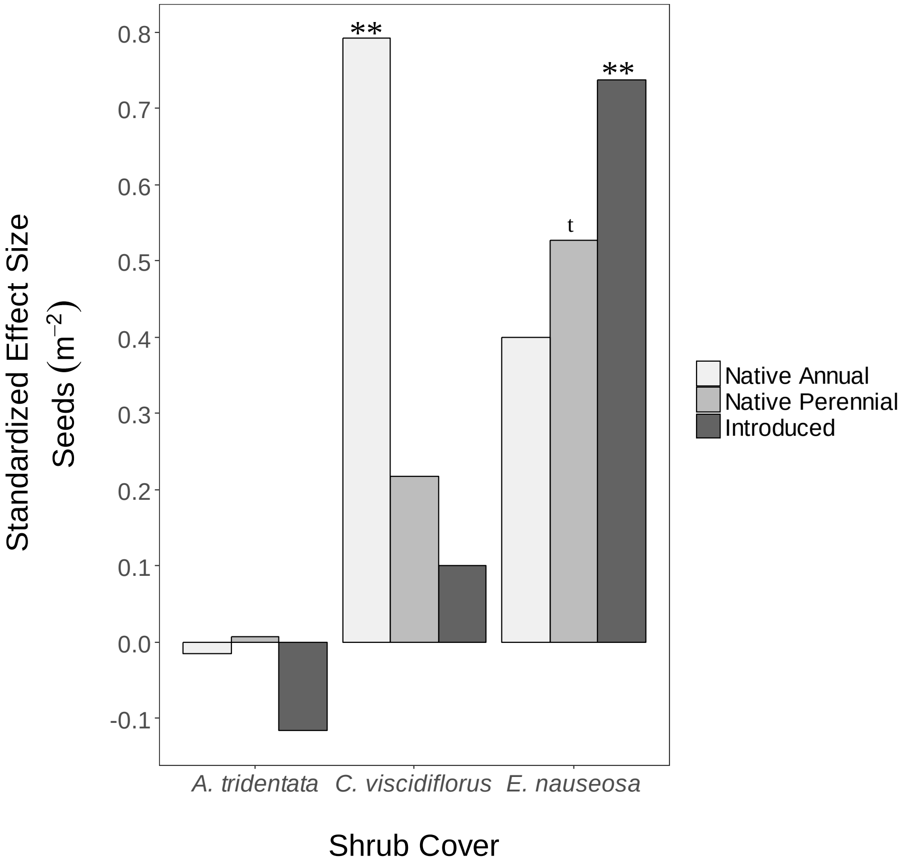


Figure 3. Relationship between shrub cover of three dominant shrub species and seed bank densities (seeds m^2) of native annual, native perennial, and introduced species. Significance is indicated, with ** = $p < 0.01$, t = $p < 0.10$

Table 2. Results for generalized linear models assessing relationships between (A) seed density, (B) rarity, and (C) above- vs. below-ground similarity and site characteristics. The relationship column shows the specific relationships between the response and the model variables. Significance is indicated as * = $p < 0.05$, ** = $p < 0.01$

A. Seed Density (m^{-2})

	Best Model	Relationship
Native Annual	Shrub Cover	↑ CHVI**
Native perennial	Shrub Cover	↑ ERNA^{t}
Introduced	Shrub Cover	↑ ERNA**

B. Rarity

	Best Model	Relationship
Above-Ground	Shrub Cover	↑ CHVI*
Below-Ground	Shrub Cover	↑ ARTR**

C. Above vs. Below-Ground

	Best Model	Relationship
Similarity - Presence	Ground Cover	↑ Litter*, ↑ Bare Ground*
Dissimilarity - Density	Disturbance	↓ Fire On <10 Years*

Shrub cover was the best predictor of both the above- and below- ground presence of rare plants (Table 2B). Above-ground, the presence of rare species increased with increasing cover of yellow rabbitbrush ($p = 0.031$) (Fig. 4). Below-ground, the presence of rare species increased with increasing shrub cover of big sagebrush ($p = 0.007$) (Fig. 4).

Ground cover was the best predictor of the similarity between the presence of above- and below-ground plant species (Table 2C). Sites possessing a higher degree of similarity were those with higher cover of bare ground ($p = 0.043$) and more litter cover ($p = 0.018$) (Fig. 5A). This similarity was mostly due to the presence of introduced species, such as desert madwort (*Alyssum desertorum*), burr buttercup (*Ceratocephala testiculata*), cheatgrass (*Bromus tectorum*), and crested wheatgrass (*Agropyron cristatum*); however, native species, such as maiden blue eyed Mary (*Collinsia parviflora*) and Sandburg bluegrass (*Poa secunda*), also contributed to the observed similarities. Disturbance history was the best predictor of the dissimilarity between the density of species above- and below-ground (Table 2C). Sites experiencing fire <10 years ago possessed a higher degree of similarity ($p = 0.017$) (Fig. 5B). These similarities were predominantly due to their low above- and below-ground species richness. The most similar communities were characterized by the presence of the introduced species cheatgrass, desert madwort, and burr buttercup, although Sandburg bluegrass also contributed to the similarity in these communities, and maiden blue eyed Mary, slender phlox (*Microsteris gracilis*), and big sagebrush were also partially responsible for these results.

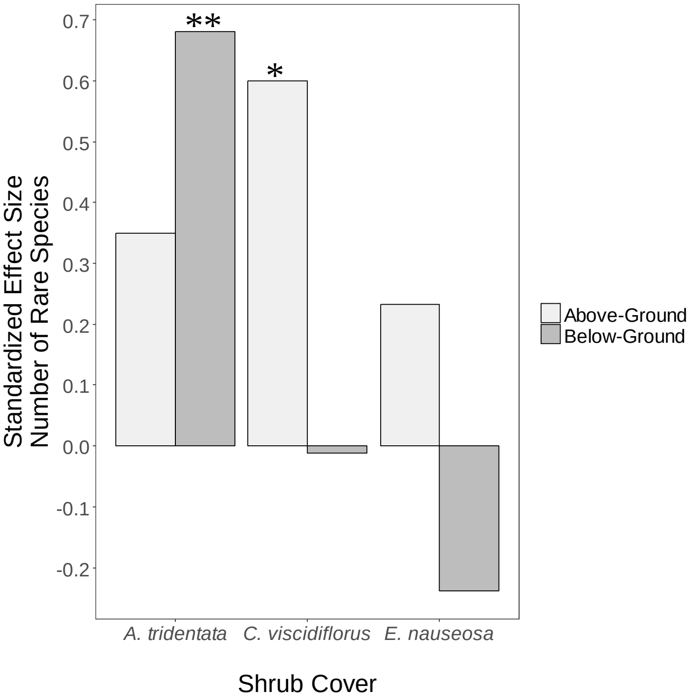


Figure 4. Relationships between A) shrub cover of the three dominant shrubs and the number of rare species above- and below-ground. Significance is indicated as * = $p < 0.05$, ** = $p < 0.01$

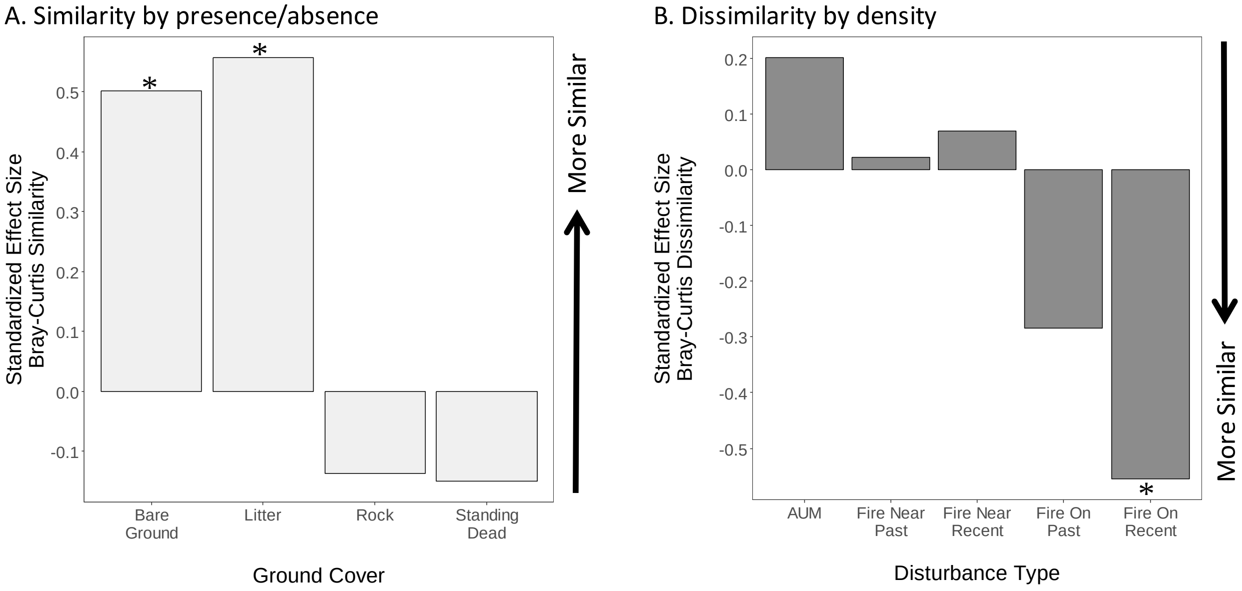


Figure 5. Above- and below-ground similarity in community composition as predicted by (A) ground cover and (B) disturbance history. In (A), values are standardized Brays-Curtis similarity indices based on presence/absence of species, with higher numbers indicating greater similarity. In (B), values are Brays-Curtis dissimilarity indices based on species densities, with lower numbers indicating greater similarity. Significance is indicated as * = $p < 0.05$

Overall, our results show how field surveys of vegetation and ground cover may provide useful information for predicting seed bank characteristics in areas of sagebrush steppe. These data can be acquired using fairly straightforward techniques, and can potentially offer insight regarding the long-term disturbance history of an area and the relative abundance of native and introduced species. Other research has also shown that plants act as strong indicators of the effects of land use on rangeland biodiversity (Landsberg and Crowley 2004). We recommend further work to explore the patterns we have identified and to ascertain differences in the ecology between yellow rabbitbrush and rubber rabbitbrush that may explain their contrasting relationships to the seed bank dynamics of native and introduced species.

Management Applications

This research provides tools for land managers to estimate the seed densities of native and introduced species within the soil and other below-ground characteristics. This can be useful for predicting when seeding may be necessary, or whether native seeds within the seed bank many be sufficient for regeneration of understory communities, and for prescribing appropriate restoration methods based on the disturbance history of a site.

Publications

Barga, Sarah; Leger Elizabeth A. In review. Shrub cover and fire history predict seed bank composition in Great Basin shrublands. Journal of Arid Environments.

References:

Bakker, Jan P.; Berendse, Frank. 1999. Constraints in the Restoration of Ecological Diversity in Grassland and Heathland Communities. Trends in Ecology and Evolution 14 (2): 63–68.
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): 2031–64.

Doherty, Lucia C; Cohn, Marc Alan. 2000. Seed Dormancy in Red Rice (Oryza Sativa). XI. Commercial Liquid Smoke Elicits Germination. Seed Science Research 10: 415–21.

Espeland, Erin K; Perkins, Lora B; Leger, Elizabeth A. 2010. Comparison of Seed Bank Estimation Techniques Using Six Weed Species in Two Soil Types. Rangeland Ecology & Management 63 (2): 243–47.

Fletcher, Thomas D. 2012. QuantPsyc: Quantitative Psychology Tools. V. 1.5. https://CRAN.R-project.org/package=QuantPsyc. https://cran.r-project.org/package=QuantPsyc.

Gardener, Mark. 2014. Similarity and Cluster Analysis. In: Community Ecology: Analytical Methods Using R and Excel, 366–418. Exeter, UK: Pelagic Publishing.

Gibson, Daniel; Blomberg, Erik J.; Atamian, Michael T.; Sedinger, James S. 2016. Nesting Habitat Selection Influences Nest and Early Offspring Survival in Greater Sage-Grouse. The Condor 118 (4): 689–702.

Hopfensperger, KN. 2007. A Review of Similarity between Seed Bank and Standing Vegetation across Ecosystems. Oikos 116 (9): 1438–48.

Kemp, PR. 1989. Seed Banks and Vegetation Processes in Deserts. In: Leck, M.A.; Parker, V.T.; Simpson, R.L., eds. Ecology of Soil Seed Banks. San Diego, CA: Academic Press: 257–82.
Landsberg, Jill; Crowley, Gabriel. 2004. Monitoring Rangeland Biodiversity: Plants as Indicators. Austral Ecology 29: 59–77.

Meyer, Susan E. 1994. Germination and Establishment Ecology of Big Sagebrush: Implications for Community Restoration. In: Monsen, S.B.; Kitchen, S.G. Proceedings - Ecology and Management of Annual Rangelands: Gen. Tech. Rep. INT-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 244–51.

Omernik, JM; Griffith, GE. 2014. Ecoregions of the Conterminous United States: Evolution of a Hierarchical Spatial Framework. Environmental Management 54 (6): 1249–66.

Pekas, K. M.; Schupp, E.W. 2013. Influence of Aboveground Vegetation on Seed Bank Composition and Distribution in a Great Basin Desert Sagebrush Community. Journal of Arid Environments 88: 113–20.

Pywell, Richard F.; Bullock, James M.; Hopkins, Alan;Walker, Kevin J.; Sparks, Tim H.; Burke, Mike J.W.; Peel, Steve. 2002. Restoration of Species-Rich Grassland on Arable Land: Assessing the Limiting Processes Using a Multi-Site Experiment. Journal of Applied Ecology 39: 294–309.

R Development Core Team. 2016. R: A Language and Environment for Statistical Computing. Vienna, Austria. http://www.r-project.org.

Smith, R. S.; Shiel, R.S.; Millward, D.; Corkhill, P.; Sanderson, R.A. 2002. Soil Seed Banks and the Effects of Meadow Management on Vegetation Change in a 10-Year Meadow Field Trial. Journal of Applied Ecology 39: 279–93.

USDA NRCS. 2017. The PLANTS Database - National Plant Data Team, Greensboro, NC. (Accessed: 13 Feb 2017): U.S. Department of Agriculture, Natural Resources Conservation Service . http://plants.usda.gov.

West, Neil E. 1999. Synecology and Disturbance Regimes of Sagebrush Steppe Ecosystems. In: Entwistle, Patricia G.; Debolt, Ann M.; Kaltenecker, Julienne H.; Steenhof, Karen. Sagebrush Steppe Ecosystems Symposium, Boise, ID: Bureau of Land Management, Idaho State Office, Boise, ID, USA: 15–26.

Young, James A.; Evans, Raymond A.; Major, J. 1972. Alien Plants in the Great Basin. Journal of Range Management 25 (3): 194–201.

Project Title Population Genetics of Bluebunch Wheatgrass (*Pseudoroegneria spicata*)

Project Agreement No. 13-IA-11221632-161

Principal Investigators and Contact Information

Rob Massatti, Research Ecologist
Southwest Biological Science Center, U.S. Geological Survey,
2255 N. Gemini Drive, Flagstaff, AZ 86001
928.556.7304, Fax 928.556.7092
rmassatti@usgs.gov

Holly Prendeville, Research Geneticist
USDA Forest Service, Pacific Northwest Research Station
3200 SW Jefferson Way, Corvallis, OR 97331-4401
541.750.7300, Fax 541.750.7329
hollyrprendeville@fs.fed.us

Steve Larson, Research Geneticist
USDA Agricultural Research Service, Forage and Range Research Laboratory
Utah State University, 690 N. 1100 E., Logan, UT 84322
435.797.1703, Fax 435.797.3075
Steve.Larson@ars.usda.gov

Bryce Richardson, Research Geneticist
US Forest Service, Rocky Mountain Research Station
735 N. 500 E., Provo, UT
801.356.5112, Fax 801.319.0114
brichardson02@fs.fed.us

Blair Waldron, Research Geneticist
USDA Agricultural Research Service, Forage and Range Research Laboratory
Utah State University, 690 N. 1100 E., Logan, UT 84322
435.797.3073, Fax 435.797.3075
Blair.Waldron@ars.usda.gov

Francis Kilkenny, Research Biologist
USDA Forest Service, Rocky Mountain Research Station
322 E Front Street Suite 401, Boise, ID 83702
208.373.4376, Fax 208.373.4391
ffkilkenny@fs.fed.us

Project Description

Introduction

The text for this project was excerpted and modified from a version of the manuscript that has been submitted for publication.

Recent research has focused on ensuring that native plant materials are "appropriate" for restoration sites (e.g. McKay et al. 2005; Havens et al. 2015). From a genetic perspective, appropriate native plant materials are those that avoid, or mitigate, risks associated with the mixing of local and nonlocal genotypes (Vander Mijnsbrugge et al. 2010). For example, nonlocal genotypes may not be adapted to the local environment at a restoration site and therefore have lower fitness (Bischoff et al. 2006). In addition, nonlocal genotypes are increasingly being implicated in negatively impacting local plant and animal species (Bucharova et al. 2016). Furthermore, the intraspecific hybridization of local and nonlocal genotypes could result in outbreeding depression due to the introgression of maladapted genes or hybrid breakdown (Edmands 2007), or nonlocal genotypes may prove to be better adapted to local ones and become invasive (Saltonstall 2002). Regardless of the potential intraspecific or interspecific impacts resulting from using nonlocal genotypes in restoration treatments, genetic diversity has been recognized as a unit of conservation concern (Hoban et al. 2013), suggesting the maintenance of geographic patterns of genetic variation by avoiding the mixture of local and nonlocal genotypes should be an implicit restoration goal (Bucharova et al. 2018). Therefore, gathering information on the genetics of native plants important to restoration is imperative for making the appropriate seed sourcing decisions for ecosystem restoration (Breed et al. 2018).

Given the potentially negative impacts of using inappropriate native plant materials, multiple approaches have been developed to spatially guide their transfer (i.e., seed transfer zones). Bower et al. (2014) created 64 generalized provisional seed zones for the continental United States using biologically important climatic data, as well as regional ecological categorizations (i.e., Omernik level III ecoregions; Omernik, 1987). However, these zones are not species-specific, and regionally important environmental gradients may not be incorporated due to the continental scale of their analysis. A species-specific provisional approach using distribution data and a broader suite of environmental data was developed by Doherty et al. (2017); this approach more closely captures and partitions the environmental space occupied by a species to inform seed transfer. Genecological studies that combine phenotypic trait data, as informed by common gardens and/or reciprocal transplants, and climate data have resulted in the inference of seed transfer zones for a variety of species across the western United States (summarized in Kilkenny 2015). Finally, correlating adaptive genetic variation, as inferred from outlier loci, to climate data can help deduce environmental gradients important to species, thus assist the development of seed transfer zones (Shryock et al. 2017). These latter two approaches are the most informative with respect to the transfer of native plant materials because they resolve species-specific adaptation to environmental gradients using empirical data. While all of these approaches may alleviate the potential problems of nonlocal native plant materials at a restoration site, they only tangentially address how plants across their distributions are related to one another from an evolutionary perspective. An evolutionary perspective benefits restoration because it reveals the genotypic suitability of native plant materials for a restoration site based on the relatedness of the materials with local conspecifics.

Contemporary population structure reflects the historical events that caused a species' populations to merge, split, shrink, expand, establish, and disappear. Given that historical connectivity may have profound impacts on contemporary gene flow (Edmands 2007), defining population structure and how those populations have interacted in the past should be of utmost importance when determining a local versus nonlocal genotype. This is underscored by the fact that individuals within a species can share phenotypic traits that are putatively adapted to a specific climate space yet have independent evolutionary histories, such that crossing individuals from these localities may produce unfit hybrids because of the breakdown of coadapted gene complexes (McKay et al. 2005). Evolutionary histories are not usually considered when constructing seed transfer zones (although see Bucharova et al. 2018 for an example of indirect consideration).

Objectives

Here, we use a next-generation sequencing dataset developed for *Pseudoroegneria spicata* to elucidate the dynamics of *P. spicata* populations through time and the genetic relationships of the available commercial germplasm sources to regional wildland localities, with the goal of providing information relevant to the use of available native plant materials and the future development of additional native plant materials. We describe *P. spicata*'s population structure across the Intermountain West. Our analyses include *P. spicata* commercial germplasm sources that are commonly used in restoration to facilitate comparison with wildland populations. This research strategy is widely applicable as more native plant materials are generated and used in restoration and conservation projects.

Methods

P. spicata was sampled throughout the Intermountain West during multiple collection efforts. At each of 154 wildland sampling localities, reproductive stalks were collected from 60 to 500 individuals distributed across 0.5–5 acres. Seeds were pooled by sampling locality, cleaned to remove chaff, and stored in airtight containers in a refrigerated room. From these collections, random samples of seed were germinated and grown in a greenhouse for leaf tissue to use in DNA extraction. These efforts resulted in 887 unique individuals from localities distributed across five western states (average of 5.8 individuals per site). In addition to wildland-collected seed, we obtained seed from six commercial germplasm sources that are commonly used in restoration treatments (Anatone, Columbia, Goldar, P-7, Wahluke, and Whitmar). Leaf material was generated as described above and sampled for DNA extraction (10 individuals per commercial germplasm source). A total of 967 individual plants (887 wildland-collected + 80 individuals from commercial germplasm sources) were selected for genotyping- by-sequencing (Elshire et al. 2011).

We used three approaches to infer genetic structure within *P. spicata*: (a) principal component analysis that included both the wild collected and commercial populations, (b) Bayesian clustering implemented in STRUCTURE version 2.3.4 (Falush et al. 2003; Pritchard et al. 2000) and (c) a multivariate ordination method that accounts for spatial patterns, spatial principal component analysis (sPCA), implemented in the adegenet package (Jombart 2008) in program R (R Core Team 2017). We used both STRUCTURE and sPCA to allow comparison of results across approaches with different sets of assumptions. For example, STRUCTURE assumes that loci are in equilibrium and unlinked while sPCA does not. Furthermore, Bayesian clustering may be inappropriate when populations are structured across a gradient of introgression (Jombart et al. 2008) because it may overestimate genetic structure, while a spatially explicit multivariate method can identify genetic structure, including clines, and accounts for spatial autocorrelation (Frantz et al. 2009). STRUCTURE was run across *K*-values, which represent putative genetic clusters or "populations," ranging from 1 to 10 without assigning population membership a priori. STRUCTURE harvester (Earl and VonHoldt 2012) and DISTRUCT (Rosenberg 2004) were used to visualize results, and the most probable *K* was chosen based on Δ*K* (Evanno et al. 2005). For sPCA analysis, geographic locations of individuals were created by jittering the latitude/longitude of their sampling localities (factor = 3), and a Delauney triangulation graph was used to create the connection network required by the sPCA function.

Results and Discussion

The PCA on diploid *P. spicata* individuals describes major geographic groups across our sampling area (Figure 1). Principal component 1 is positively correlated with east-to-west variation (i.e., Wasatch Mountains in Utah to Oregon and Washington). Principal component 2 is dominated by variation predominantly sampled from localities on the eastern half of the Snake River Plain in Idaho. In general, individuals from sampling localities cluster with one another and close to individuals from geographically proximate localities (Figure 1). Individuals representing commercial germplasm sources form a tight cluster that overlaps individuals from Oregon and Washington (Figure 1). Upon closer examination, commercial germplasm sources cluster with (i.e., are most genetically similar to) the wildland sampling localities closest to where the original foundational materials were collected.

STRUCTURE analyses indicate *K* = 5 as the most likely number of genetic clusters (the *K*-value with the highest Δ*K*, hereafter referred to as the most likely *K*). We present illustrations of *K* = 2–5, as they are all helpful in unpacking the major, hierarchical axes of genetic variation within *P. spicata* (Figure 2). At *K* = 2, genetic variation breaks down into northwestern (blue) and southeastern (red) genetic clusters. An orange genetic cluster centered in southeastern Washington to northeastern Oregon is separated from the blue cluster at *K* = 3, and a yellow genetic cluster located primarily in the eastern Snake River Plain and eastern Nevada splits from the red cluster at *K* = 4. Finally, the blue genetic cluster decomposes again at *K* = 5, resulting in a southern gray cluster. In general, admixture is more common where genetic clusters meet, compared to the "cores" of their respective geographic distributions. These STRUCTURE results contrast with the 21 clusters of variation reported by Larson et al. (2004), which were based on a model selected solely from the log probability of data resolved by STRUCTURE without consideration of model complexity, as suggested by Evanno et al. (2005). Despite the differences between these studies, Larson et al. (2004) break down hierarchical variation into finer units we focus on here. While it is likely our genetic clusters would hierarchically decompose if analyzed in isolation (e.g., Massatti and Knowles 2014), this level of detail is not necessary for the questions at hand.

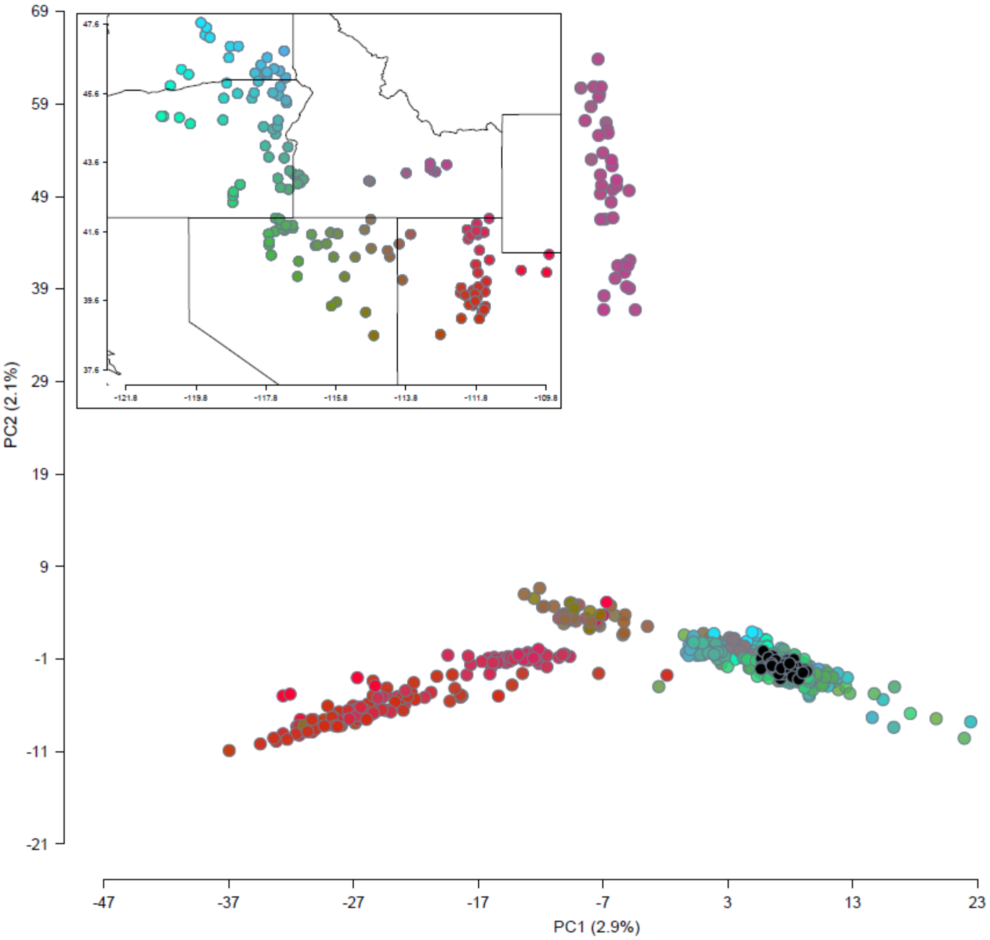


Figure 1. Distribution of *Pseudoroegneria spicata* individuals along principal component 1 and principal component 2 axes of genetic variation. Variation explained by the axes is given in parentheses. Individuals in PC space are colored by their sampling locations, which are displayed in the inset. Individuals colored black represent the commercial germplasm sources. Colors in this figure do not correlate to colors that describe populations in Figure 2.

The first three sPCA eigenvalues associated with global structure were used to characterize genetic variation among *P. spicata* sampling localities (not shown). In general, patterns among spatial principal components 1–3, which explain 49.4% of genetic variation, reiterate the clusters resolved by STRUCTURE analyses. Spatial principal component 1 identifies the northwestern/ southeastern grouping similar to *K* = 2, and spatial principal component 2 resolves differentiation between the southeastern Washington to northeastern Oregon sampling localities and localities surrounding this area to the west and south (akin to *K* = 3; Supporting Information Figure S3). Finally, spatial principal component 3 differentiates sampling localities from the eastern half of the Snake River Plain and eastern Nevada from the rest (i.e., *K* = 4). Unlike STRUCTURE analyses, where the blue genetic cluster breaks down from *K* = 4 to *K* = 5, sPCA does not resolve this as a significant genetic axis. Because sPCA accounts for geographic distance among sampling localities when identifying global and local structures, we hypothesize that *K* = 5 represents isolation by distance along a latitudinal cline of the blue genetic cluster identified at *K*

= 4 (Figure 2). Hereafter, we focus on the genetic clusters (which we call “populations”) identified at *K* = 4. Furthermore, we assign these populations the following names, which are reiterated in Figure 2: red genetic cluster—Wasatch (WAS); yellow cluster—EGB; orange cluster—Palouse/Wallowa (P/W); and blue cluster—WGB. We further specify WGB-North and WGB-South to recognize the north/south differentiation in this population (i.e., the blue and gray clusters, respectively) discerned in the *K* = 5 STRUCTURE result. P/W and WGB are the most similar populations, as inferred from the lowest *F*ST value (Table 1). Each of these populations is differentiated from EGB and WAS as would be expected based on geographic distance (Table 1). While WAS and EGB are highly supported as sister populations, they are also the most differentiated (Table 1).

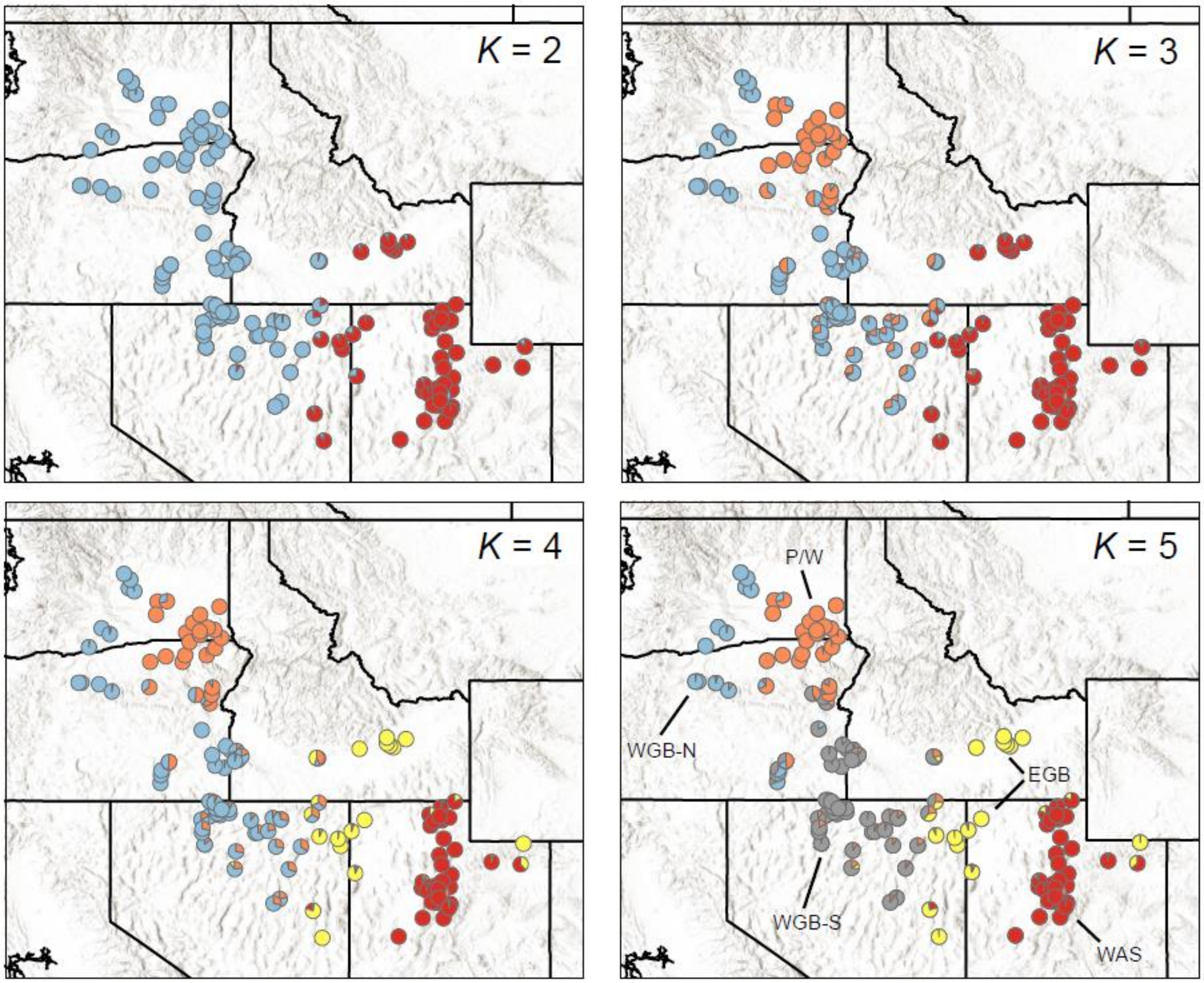


Figure 2. Results of STRUCTURE analyses for *K* = 2 to *K* = 5. The posterior probabilities of individual assignments are averaged within sampling localities and represented by pie charts. Populations discussed in the text are noted for *K* = 5 and include Palouse/Wallowa (P/W); Western Great Basin (WGB-North and WGB-South); Eastern Great Basin (EGB); and Wasatch (WAS).

Table 1. Pairwise F_{ST} calculated between populations used in FASTSIMCOAL2 modeling. All values are significant at $P < 0.05$. See Figure 2 to determine which sampling localities are included in each population.

	WGB	EGB	Wasatch
P/W	0.041	0.068	0.075
WGB		0.079	0.085
EGB			0.099

Management Applications and/or Seed Production Guidelines

Genetic analyses of genomewide SNP variation yielded information pertinent to restoration efforts. With respect to native plant materials available for restoration, the commercial germplasm sources remain genetically representative of the wildland localities from which plant materials were originally collected (Figure 1). However, the commercial germplasm sources represent a small fraction of the overall genetic diversity of *P. spicata*. Given the close relationship between the WGB and P/W populations, the risk of unintended consequences (e.g., the negative impacts of nonlocal genotypes on local plant and animal species or outbreeding depression) may be lowest when the commercial germplasm sources are used in restoration treatments across the geographic area covered by these populations. Risks may increase when commercial germplasm sources are used in restoration treatments located within the distribution of the WAS or EGB genetic clusters due to the low levels of gene flow and/or long divergence times between these populations and the P/W and WGB populations from which commercial germplasm sources were developed. As such, future restoration treatments outside of the geographic area covered by P/W and WGB may benefit from the development of plant materials representing the EGB and/or WAS genetic identity.

The collection, development, and deployment of plant materials as suggested by the seed zones of St. Clair et al. (2013) may also be informed by spatial patterns of genetic variation of *P. spicata*. These seed zones were developed using a genecological approach, which utilized phenotypic data from common gardens and climatic variability across the northwestern United States. Considering the geographic distributions of the populations resolved here in relation to the distribution of the seed zones (see their Figure 3), we note that each of our populations is distributed across several of the seed transfer zones. Given that sampling localities within a population are more closely related to one another (in a phylogenetic sense) than they are to localities from another population, we infer that the ancestors of all four populations independently adapted into the environmental space represented by the seed zones. This speaks to the adaptability of wildland populations and supports the idea that managing for genetic diversity should be an important conservation goal (Hoban et al. 2013). In addition, all populations except WAS are distributed across multiple level III ecoregions (Omernik 1987), and similarly, almost all level III ecoregions contain multiple populations. Practically, this suggests, for example, that while individuals distributed in Seed Zone 1 (see red in Figure 3 from St. Clair et al. 2013) in the western, central, and eastern Central Basin and Range ecoregion may have similar phenotypic characteristics that are putatively adapted to that specific climate, they also have different genetic backgrounds that should be considered prior to transferring plant materials across this ecoregion. The discordance between populations and level III ecoregions exemplifies the practical knowledge gained from investigating geographic patterns of genetic variation and population histories- namely, resolving populations and their histories facilitates the identification of broad-scale seed transfer zones so that practitioners do not have to rely on environmental proxies (e.g., ecoregions) that likely correspond poorly with the biology and history of a species of interest.

References

Bischoff, A.; Vonlanthen, B.; Steinger, T.; Muller-Scharer, H. 2006. Seed provenance matters - Effects on germination of four plant species used for ecological restoration. Basic and Applied Ecology 7: 347-359.

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

Breed, M. F.; Harrison, P. A.; Bischoff, A.; Durruty, P.; Gellie, N. J. C.; Gonzales, E. K.; Havens, K.; Karmann, M.; Kilkenny F. F.; Krauss, S. L.; Lowe, A. J.; Marques, P.; Nevill, P. G.; Vitt, P. L.; Bucharova, A. 2018. Priority actions to improve provenance decision-making. BioScience 68: 510-516.

Bucharova, A.; Bossdorf, O.; Holzel, N.; Kollmann, J.; Prasse, R.; Durka, W. 2018. Mix and match: Regional admixture provenancing strikes a balance among different seed-sourcing strategies for ecological restoration. Conservation Genetics, https://doi.org/10.1007/s10592-018-1067-6

Bucharova, A.; Frenzel, M.; Mody, K.; Parepa, M.; Durka, W.; Bossdorf, O. 2016. Plant ecotype affects interacting organisms across multiple trophic levels. Basic and Applied Ecology 17: 688-695.

Doherty, K. D.; Butterfield, B. J.; Wood, T. E. 2017. Matching seed to site by climate similarity: Techniques to prioritize plant materials development and use in restoration. Ecological Applications 27: 1010-1023.

Earl, D. A.; VonHoldt, B. M. 2012. STRUCTURE harvester: A website and program for visualizing STRUCTURE output and implementing the Evanno method. Conservation Genetics Resources 4: 359-361.

Edmands, S. 2007. Between a rock and a hard place: Evaluating the relative risks of inbreeding and outbreeding for conservation and management. Molecular Ecology 16: 463-475.

Elshire, R. J.; Glaubitz, J. C.; Sun, Q.; Poland, J. A.; Kawamoto, K.; Buckler, E. S.; Mitchell, S. E. 2011. A robust, simple genotyping-by-sequencing (GBS) approach for high diversity species. PLoS ONE 6: e19379

Evanno, G.; Regnaut, S.; Goudet, J. 2005. Detecting the number of clusters of individuals using the software Structure: A simulation study. Molecular Ecology 14: 2611-2620.

Falush, D.; Stephens, M.; Pritchard, J. K. 2003. Inference of population structure using multilocus genotype data: Linked loci and correlated allele frequencies. Genetics 164: 1567-1587.

Frantz, A. C.; Cellina, S.; Krier, A.; Schley, L.; Burke, T. 2009. Using spatial Bayesian methods to determine the genetic structure of a continuously distributed population: Clusters or isolation by distance? Journal of Applied Ecology 46: 493-505.

Havens, K.; Vitt, P.; Still, S.; Kramer, A. T.; Fant, J. B.; Schatz, K. 2015. Seed sourcing for restoration in an era of climate change. Natural Areas Journal 35: 122-133.

Hoban, S.; Hauffe, H.; Perez-Espona, S.; Arntzen, J. W.; Bertorelle, G.; Bryja, J.; Frith, K.; Gaggiotti, O. E.; Galbusera, P.; Godoy, J. A.; Hoelzel, A. R.; Nichols, R. A.; Primmer, C. R.; Russo, I-R.; Segelbacher, G.; Siegismund, H. R.; Sihvonen, M.; Vernesi, C.; Vilà, C.; Bruford, M. W. 2013. Bringing genetic diversity to the forefront of conservation policy and management. Conservation Genetics Resources 5: 593-598.

Jombart, T. 2008. ADEGENET: A R package for the multivariate analysis of genetic markers. Bioinformatics 24: 1403-1405.

Jombart, T.; Devillard, S.; Dufour, A. B.; Pontier, D. 2008. Revealing cryptic spatial patterns in genetic variability by a new multivariate method. Heredity 101: 92-103.

Kilkenny, F. F. 2015. Genecological approaches to predicting the effects of climate change on plant populations. Natural Areas Journal 35: 152-164.

Larson, S. R.; Jones, T. A.; Jensen, K. B. 2004. Population structure in *Pseudoroegneria spicata* (Poaceae: Triticeae) modeled by Bayesian clustering of AFLP genotypes. American Journal of Botany 91: 1789-1801.

Massatti, R.; Knowles, L. L. 2014. Microhabitat differences impact phylogeographic concordance of codistributed species: Genomic evidence in montane sedges (*Carex* L.) from the Rocky Mountains. Evolution 68: 2833-2846.

McKay, J. K.; Christian, C. E.; Harrison, S.; Rice, K. J. 2005. 'How local is local?' - A review of practical and conceptual issues in the genetics of restoration. Restoration Ecology 13: 432-440.

Omernik, J. M. 1987. Ecoregions of the conterminous United States. Annals of the Association of American Geographers 77: 118-125.

Pritchard, J. K.; Stephens, M.; Donnelly, P. 2000. Inference of population structure using multilocus genotype data. Genetics 155: 945-959.

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

Rosenberg, N. A. 2004. DISTRUCT: A program for the graphical display of population structure. Molecular Ecology Notes 4: 137-138.

Saltonstall, K. 2002. Cryptic invasion by a non-native genotype of the common reed, Phragmites australis, into North America. Proceedings of the National Academy of Sciences 99: 2445-2449.

Shryock, D. F.; Havrilla, C. A.; DeFalco, L. A.; Esque, T. C.; Custer, N. A.; Wood, T. E. 2017. Landscape genetic approaches to guide native plant restoration in the Mojave Desert. Ecological Applications 27: 429-445.

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

Vander Mijnsbrugge, K.; Bischoff, A.; Smith, B. 2010. A question of origin: Where and how to collect seed for ecological restoration. Basic and Applied Ecology 11: 300-311.

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

Project Agreement No. 15-IA-11221632-202

Principal Investigators and Contact Information

Dr. Beth A. Newingham, Research Ecologist
US Department of Agriculture-Agricultural Research Service
920 Valley Road, Reno, NV 89512
775.784.6057 ext 233, Fax 775.784.1212
beth.newingham@ars.usda.gov

Dr. Keirith Snyder, Research Ecologist
US Department of Agriculture-Agricultural Research Service
920 Valley Road, Reno, NV 89512
775.784.6057 ext 245, Fax 775.784.1212
keirith.snyder@ars.usda.gov

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 CO_2 on *B. tectorum* (Ziska et al. 2005), little is known about how altered precipitation may affect this invasive grass. 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 precipitation may result in shifts in competitive abilities between native and non-native species. Previous studies have explored native species that may be resistant to invasion by *B. tectorum* (Leger 2008; Uselman et al. 2015). These studies suggest that early seral natives (*Poa* and *Elymus* grasses for *B. tectorum*) 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 annual forbs with *B. tectorum* under various precipitation regimes

Objectives

In a field experiment, we will determine the effects of altered precipitation on non-native and native plant growth, survival, and reproduction, as well as plant community development over time.

Methods

The site is on the Monroe fire near Reno, NV, which burned in August 2016, and is on the Winnemucca BLM district (Figure 1). We have capitalized on an herbicide and drill seeding rehabilitation by the BLM. The fire was sprayed with the herbicide, Plateau (Imazapic), in 2016.

In the fall of 2017, the area was drill seeded with the following species: *Ericameria nauseosa*, *Poa secunda*, *Pseudoroegneria spicata* spp. *spicata* (Wahluke), and *Agropyron cristatum x A. desertorum* (Hycrest II). We have established 30 macroplots at the site with three replicates per treatment. Treatments in the macroplots include:

1. Herbicide/no herbicide
2. Precipitation
    a. Ambient
    b. Spring +
    c. Spring -
    d. Summer +
    e. Summer -

Macroplots are set up so that a rainout shelter (precipitation reduction) is next to a sprinkler system (precipitation addition) (Figure 2). In each macroplot, we established nine subplots (three replicates per treatment) of the following forb treatments:

1. No forbs
2. Annual forbs (*Amsinckia intermedia*, *Lagophylla ramossisima*)
3. Perennial forbs (*Lupinus argenteus*, *Sphaeralcea coccinea*)

Plots were raked, hand broadcasted, and pressed with a mini imprinter. Percent cover and seedling counts were made on all subplots before climate treatments were installed and will be monitored monthly.

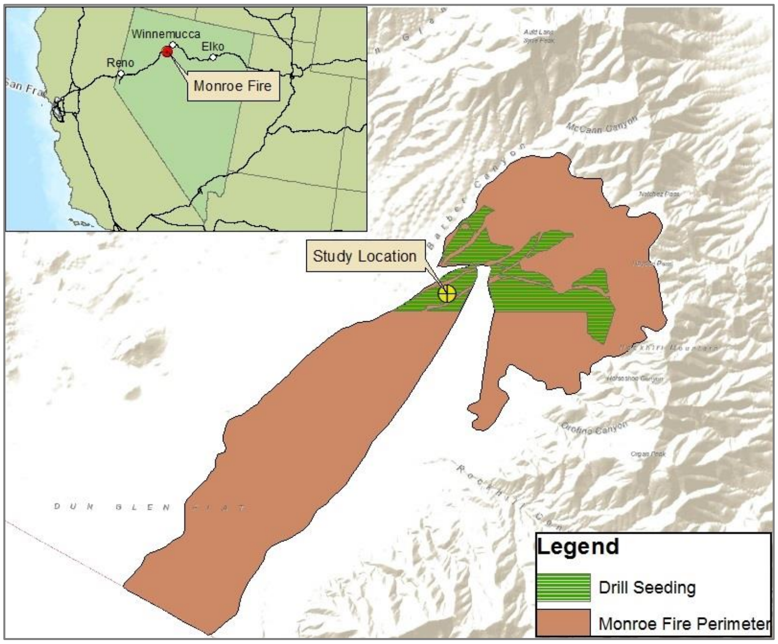


Figure1 Location of experimental site.

Figure 2 Rainout shelter (left), which collects rain and is added to the rainfall addition plot (right) using an automatic rainfall manipulation system (ARMS). Frame intercepts 50% rainfall and barrel collects rainfall for 50% addition.

Results and Discussion

All equipment has been installed. Before precipitation treatments were installed, herbicide plots had lower cheatgrass cover, higher bare ground, and no effect on litter cover (Figure 3). There was no difference in seedling counts although there tended to be more seedlings in herbicide plots (Figure 4).

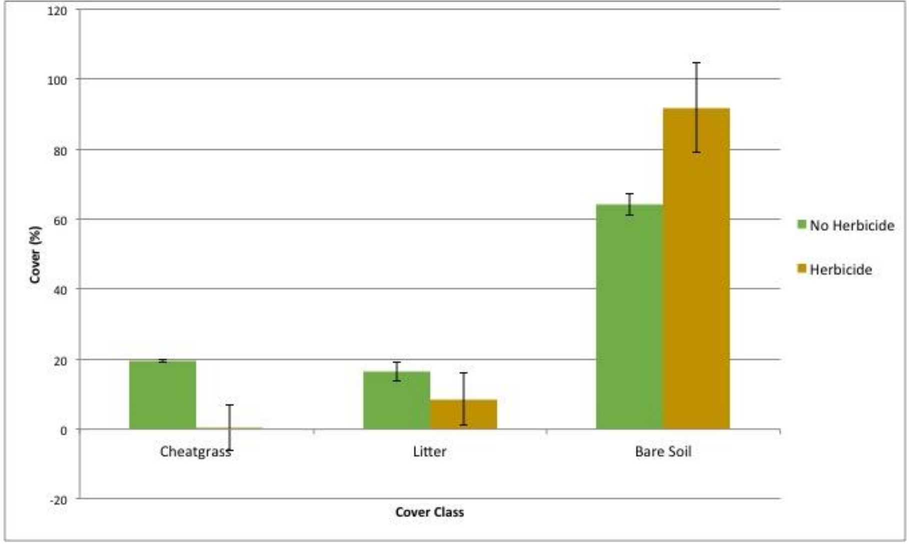


Figure 3 Percent cover in herbicide versus no herbicide plots.

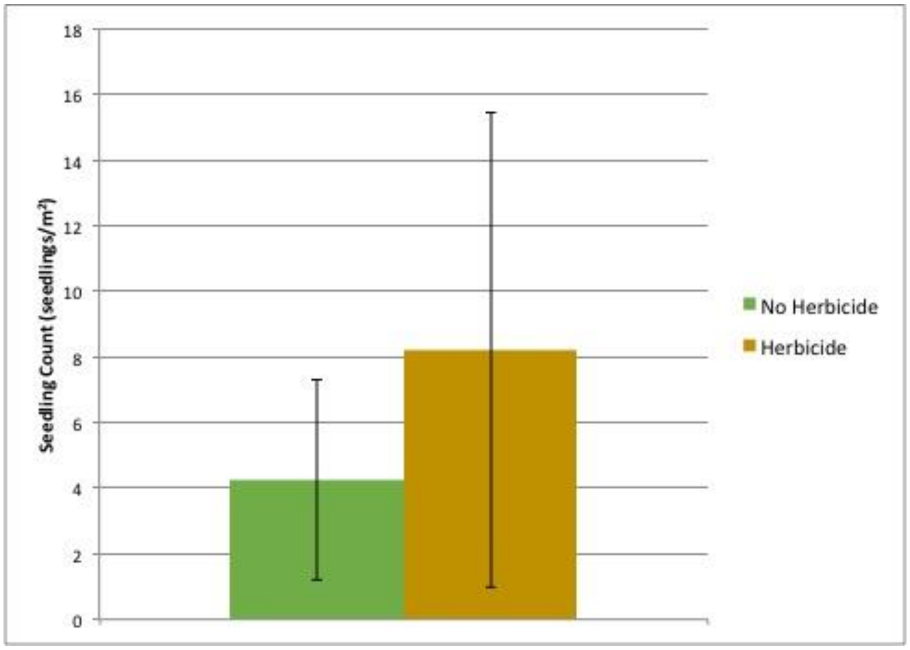


Figure 4 Seedling counts in herbicide versus no herbicide plots.

Management Applications and/or Seed Production Guidelines

Our study will 1) increase our understanding of the basic biology and ecology of several native species, 2) determine native and non-native plant sensitivity to altered precipitation, 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.

Presentations

None to date

Publications

None to date

Additional Products

Dr. Newingham obtained additional project funds for a technician through the USDA-Agricultural Research CRIS project.

References

Abatzoglou, J. T.; Kolden, C. A. 2011. Climate change in western US deserts: Potential for increased wildfire and invasive annual grasses. Rangeland Ecology & Management 64: 471-478.

Leger, E. A. 2008. The adaptive value of remnant native plants in invaded communities: an example from the great basin. Ecological Applications 18: 1226-1235.

Newingham, B. A.; Suazo, A. A.; Germino, M. J. 2015. *Bromus tectorum* and native grass establishment under drought and warming in sagebrush steppe after fire. Great Basin Consortium Meeting; 2015 February 17-19; Boise, ID.

Uselman, S. M.; Snyder, K. A.; Leger, E. A.; Duke, S. E. 2015. Emergence and early survival of early vs. late seral species in Great Basin restoration in two different soil types. Applied Vegetation Science. 18:624-636.

Ziska, L. H.; Reeves, J. B.; Blank, B. 2005. The impact of recent increases in atmospheric CO_2 on biomass production and vegetative retention of cheatgrass (*Bromus tectorum*): implications for fire disturbance. Global Change Biology 11: 1325-1332.

Project Title Efficacy of Empirical Seed Zones: *Pseudoroegneria Spicata* Reproductive Phenology & Seedling Stage Traits

Project Agreement No. 15-JV-11221632-174

Principal Investigators and Contact Information

Kathryn Prive, Graduate Research Assistant
Oregon State University, College of Forestry
3180 SW Jefferson Way, Corvallis, OR. 97333
541.973.4303
kathryn.prive@gmail.com

Matt Orr, Assistant Professor, Biology
Oregon State University-Cascades
2600 NW College Way Bend, OR 97701
541.771.8846
Matt.orr@osucascades.edu

Ron Reuter, Associate Professor, Soils
Oregon State University-Cascades
2600 NW College Way, Bend, OR 97703
541.322.3109
ron.reuter@oregonstate.edu

Francis Kilkenny, Research Biologist
USDA Forest Service, Rocky Mountain Research Station
322 E Front Street Suite 401, Boise, ID 83702
208.373.4376, Fax 208.373.4391
ffkilkenny@fs.fed.us

Brad St. Clair, Research Geneticist
USDA Forest Service, Pacific Northwest Research Station
3200 SW Jefferson Way, Corvallis, OR 97331-4401
541.750.7294, Fax 541.750.7329
bstclair@fs.fed.us

Holly R. Prendeville, Northwest Climate Hub Coordinator
USDA Forest Service, Pacific Northwest Research Station
3200 SW Jefferson Way, Corvallis, OR 97331-4401
541.750.7300, Fax 541.750.7329
hollyrprendeville@fs.fed.us

Project Description

Introduction

Ecological restoration often occurs over large spatial scales, necessitating the use of large quantities of seed to re-establish native species that have been lost to encroachment, grazing, and wildfire. Seed increase is an agricultural technique used to provide large volumes of native seed for restoration projects from relatively small wild-source populations. The advantages of using agricultural processes to produce the quantities of seed needed for ecological restoration over large areas is diminished when genetic diversity (the basis for plant adaptation) cannot be maintained. To address this, a growing body of literature has been aimed at finding a balance between agricultural efficiency and genetic diversity (e.g. Lesica & Allendorf 1999; Broadhurst et al. 2008; Johnson et al. 2010; Basey et al. 2015). Despite this, a body of knowledge for understanding how fine scale differences in reproductive timing (i.e. anthesis, ripening and dispersal) impact the genetic diversity of agriculturally produced native seed sources is lacking.

Another issue central to ecological restoration is understanding where genetic structuring exists within plant communities and the environmental forces affecting these genetic differences. Since evidence of local adaptation has been found for many plant species, it is often important to match seed used in restoration to the environment of the restoration site while maintaining genetic diversity so that restored populations can continue to adapt (Leimu & Fischer 2008). Although the process of species-specific seed zone delineation is successful in detecting local adaptation in adult plant traits, unanswered questions about adaptation at the seedling life stage remain. At the seedling life stage, adverse abiotic conditions can cause strong selective pressures on plants resulting in genotypes adapted to these conditions (Giménez-Benavides et al. 2007; Rowe & Leger 2011; Smith et al. 2011). Early recruitment stages such as germination, emergence, and seedling growth have been shown to be major bottlenecks in the establishment of a variety of plant species (Jongejans et al.; Clark et al. 2007; 2006; Larson et al. 2015) yet it is unknown if the general pattern of adult trait adaptations to environmental conditions holds true for plants at the seedling stage. Since a large number of restoration projects in the Intermountain West rely on the direct-seeding of native species, it is crucial to be able to anticipate the potential for maladaptation at this stage of plant growth.

In this work we ask whether there is evidence of genetic differences among bluebunch wheatgrass populations with regard to reproductive timing, and whether any of these observed differences are relevant to the management of seed-lot genetic diversity at seed-increase facilities. The purpose of this research is to better understand a potential pathway for losses to genetic diversity during seed increase while also highlighting how well the established seed zones for this species avoid possible reproductive timing related maladaptation to restoration sites. Secondly, we explore genetic differences in the seedling stage traits among populations to determine whether these differences are accounted for by the current seed zones for bluebunch wheatgrass.

The overriding goal for these two complementary studies (i.e. reproductive phenology and early development) is to support or refine the seed zones developed for bluebunch wheatgrass, and to gain a more nuanced understanding of this 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 reproductive phenology study will help to improve the cultivation protocols for bluebunch wheatgrass, and the early development study will help land managers better understand the link between local adaptation and early development of these plants in the field.

Objectives

Reproductive Phenology

The first aim of this study is to determine if the timing of three important reproductive events (anthesis, seed ripening and seed dispersal) differ genetically, and if so, determine whether the seed zones delineated for this species account for the variation in these traits. We hypothesize that the stages of reproductive phenology of bluebunch wheatgrass differ genetically and that the seed zones delineated for bluebunch wheatgrass characterize important selective gradients on the landscape leading to these genetic differences. Thus, we expect to find more variation in these traits among seed zones than among populations within the same seed zone. If these traits have plastic responses to the environment, then consistent responses among all plants to a common environment will be observed.

The second aim of this study is to determine the extent of variation in these traits among populations from the same seed zone to infer whether any observed differences are relevant to maintaining seed-lot genetic diversity in seed increase operations. We expect to find similar trait expression among populations within each seed zone and different trait expression among populations from different seed zones.

Early Development

The early development study focuses on 10-day old seedlings of bluebunch wheatgrass. We ask whether the seedling traits (leaf length, leaf width, leaf length to width ratio, root mass, shoot mass, root to shoot ratio, and total plant mass) vary among populations thus indicating genetic differences. Secondly we explore whether bluebunch wheatgrass seed zones account for these genetic differences. If the seed zones delineated for bluebunch wheatgrass account for genetic differences in seedling stage traits, then variation in these traits should be explained by seed zone and the variation observed among different populations from the same seed zone will be minimal.

This research will accomplish the following; 1) a detailed understanding of the timing of reproductive events in the lifecycle of bluebunch wheatgrass and the genetic implications of any differences observed. 2) Seed harvest protocol recommendations for seed producers that selects for the most genetically diverse seeds based on fine scale reproductive dynamics; 3) and an understanding of the efficacy of current seed zones in accounting for seedling stage genetic differences for bluebunch wheatgrass.

Methods

Reproductive Phenology

To determine the range of flowering and seed maturity dates for bluebunch wheatgrass, we monitored each individual in an on-going common garden experiment in the Crooked River Grasslands (Figure 1). The common garden was planted with 29 bluebunch wheatgrass populations from six seed zones for a total of 600 plants (20 replicates per population).

Reproductive phenology was monitored on up to 25 flower spikes per plant approximately every four days on all surviving bluebunch wheatgrass plants in the common garden from late May through early August 2016. Flowering spikes on each plant were grouped into five distinct 12-14 day time periods (cohorts). For any plant, the first cohort included 1-5 new flowering spikes that had entered into the anthesis stage within the first thee site visits (12-14 calendar days). The second cohort included 1–5 new flower spikes entering the anthesis stage on visits 4-6 and so on. We recorded when each flower spike within each cohort developed flowers, when seeds were produced and become mature, and when these seeds were dispersed. Generalized linear mixed modeling and likelihood ratio tests were used to assess whether the mean values of each stage varied among seed zones and populations within the same seed zone. Secondly, random effects models and intra-class correlation coefficients were used to determine the relative amount of variance in these phenological stages associated with seed zones and populations respectively.

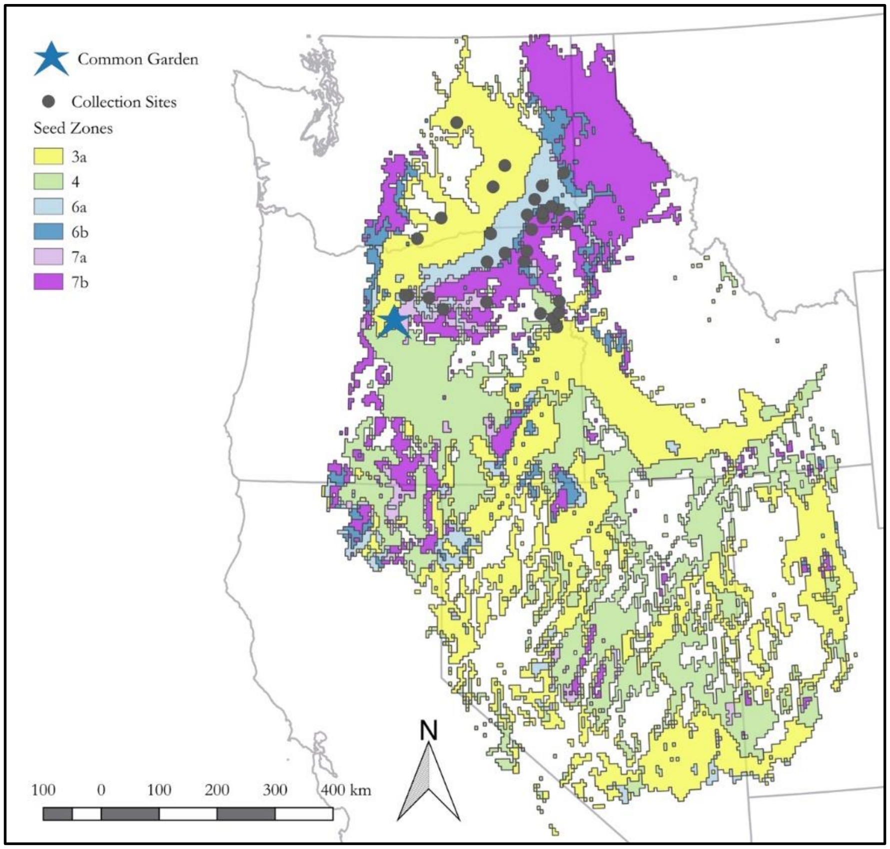


Figure 1. Map of empirically delineated seed zones 3a, 4, 6a, 6b, 7a and 7b for bluebunch wheatgrass used in the reproductive phenology study. Grey circles indicate population seed source locations. Blue star indicates common garden study site location.

Early Development

In a greenhouse facility at Oregon State University, seeds from 12 populations and four seed zones (Figure 2) were planted one per container into unfertilized moist sand over the course of seven successive rounds of planting starting on January 8th 2016 and ending in February 22nd 2016. Seeds were randomized within trays and planting rounds and every planting round contained an equal number of seeds from each population (2-5 replicates of each population). In total, 33 seeds from each population were sown for a total seed count of 396. Seeds were monitored for emergence on a daily basis. 10 days post-emergence, seedlings were removed from the growing medium and scanned using a digital scanner. The images were used to gather leaf length and width measurements. After imaging, the root and shoot portions of the seedling were dried and then weighed using a microbalance. Linear mixed modeling and likelihood ratio tests were used to determine if particular seeding traits differed among populations and seed zones. Random effects models were used to determine the relative amount of variance in each seedling trait associated with seed zones and populations respectively. Lastly, non-metric multidimensional scaling (NMS) and multi-response permutation procedures (MRPP) were used to understand the pattern of similarity attributed to the multivariate set of seedling traits observed within seed zones and populations.

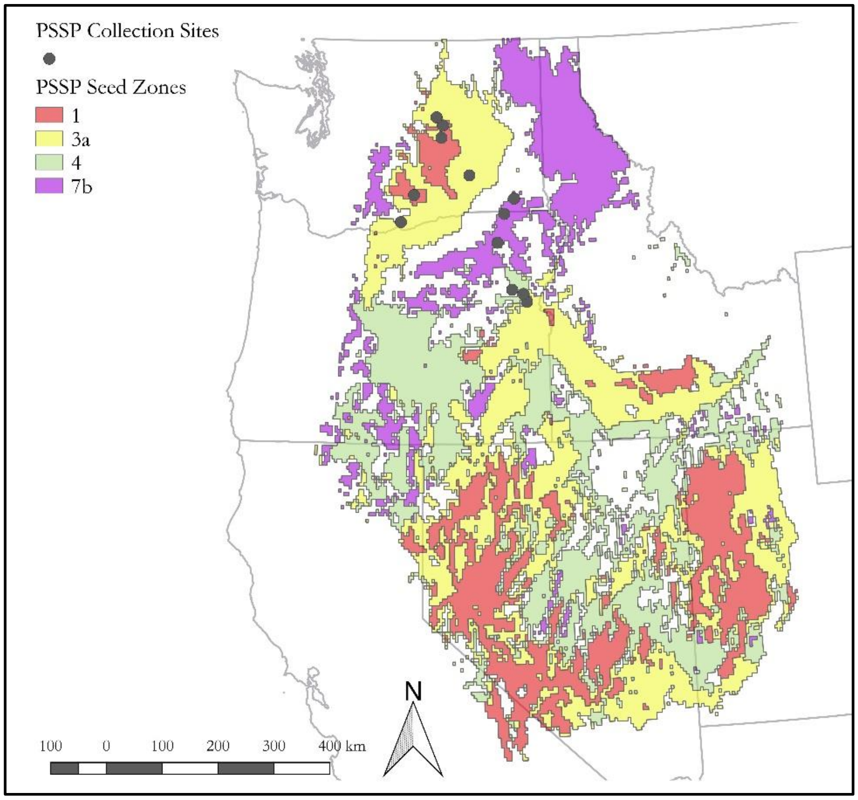


Figure 2. Map of seed transfer zones for bluebunch wheatgrass and the locations of wild populations used in the early development study. Grey circles indicate population locations.

Results and Discussion

Reproductive Phenology

We found that the seed zones delineated for bluebunch wheatgrass only partially account for the observed variance in reproductive phenology, but that in most cases, single-pass harvest procedures are unlikely to narrow genetic diversity when seed zones are used to source wild populations.

Anthesis
Although the mean timing of anthesis varied among seed zones (Figure 3), the unexplained variance in this trait was large compared to what could be accounted for by seed zone (Table 1). The unexplained variance could represent a selective gradient that these seed zones are not sensitive to. This may be problematic because misalignment between anthesis timing and out-planting sites may preclude successful pollination with other bluebunch wheatgrass plants already occurring at the restoration site. Secondarily, with the exception of seed zone 7b, we did not find significant differences in the mean timing of anthesis among populations from the same seed zone. Although the timing of anthesis varied by population in seed zone 7b, this difference was only marginally statistically significant (x^2 (4) = 8.70, p = 0.069) and may therefore have little biological significance. This indicates that a narrowing of genetic diversity in mixed population seed increase beds sourced from the same seed zone is unlikely due to the largely synchronous anthesis/pollination timing of this species.

Table 1. Intra-class correlation coefficient (ICC) scores based on random effect models built for each reproductive stage. ICC scores within a column indicate that a group accounted for the given percentage of variation in that stage. In each model, the timing of the reproductive stage was the response variable and seed zone, population, block, plant, and the interactions block: zone, and block: population were random effects.

Stage	Zone	Population	Block	Plant	Block: Zone	Block: Pop
Anthesis	0.9%	0.1%	0.0%	0.0%	0.2%	0.0%
Ripening	34.6%	33.1%	6.4%	0.0%	17.1%	0.0%
Dispersal	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Dispersal
For the seed dispersal stage, we found that the timing of mean dispersal did not vary by seed zone and that the observed variance in this trait could not be attributed to seed zone or population (Table 1). This indicates that either genetic differences in this trait do not exist or they were not detected in this study. Seed dispersal timing among populations from the same seed zone was similar for all seed zones except 6b. This difference in dispersal for seed zone 6b is likely tied to the differential timing of seed ripening observed for this seed zone. The absence of differential timing of seed dispersal timing in all seed zones except 6b therefore reduces the likelihood genetic losses due to pre-harvest seed dispersal in the seed increase setting.

Ripening Rate
Field observations of differing ripening dynamics among cohorts of flowering spikes led us to ask whether bluebunch wheatgrass spikes produced later in the season reached the ripening stage more quickly than spikes produced earlier in the season and whether this dynamic differed among plants from different seed zones. The ripening rate (defined as the day of ripening – day of anthesis) differed with marginal significance according to seed zone (x^2 (5)=10.27, p< 0.068). Pairwise comparisons among cohorts revealed that flowering spikes produced later in the season (cohorts 2 and 3) were able to ripen more quickly than flower spikes produced earlier in the season (cohort 1) regardless of seed zone or population. A summary of the results from the mean

differences and variance analyses for anthesis, ripening, dispersal and ripening rate are provided in Table 2.

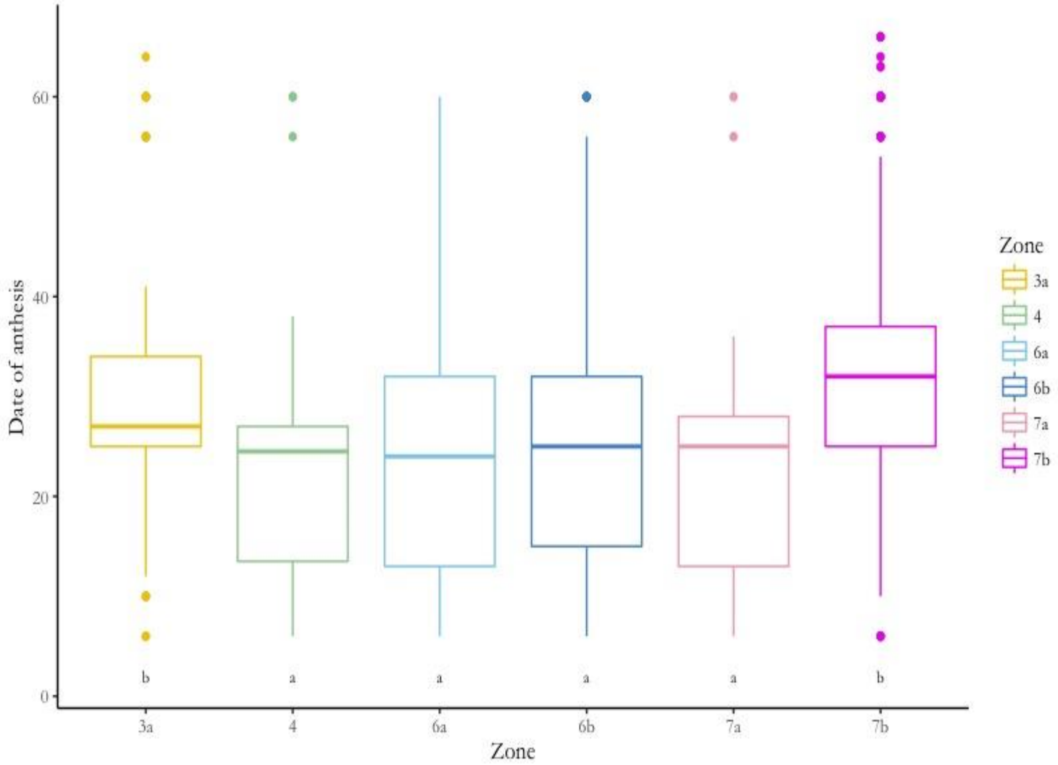


Figure 3. Boxplot of cohort-level dates of anthesis grouped according to seed zones 3a, 4, 6a, 6b, 7a, and 7b. Zones with different lowercase letters indicate p-values of < 0.05 after the Tukey adjustment for multiple testing.

Table 2. Summary of results from likelihood ratio tests of means (mean differences) and intra-class correlation coefficient scores (variance explained). Y/N indicates if means varied statistically among seed zones. Seed zones with significant among-population variation in the timing of each reproductive stage are indicated below anthesis, ripening and dispersal respectively. * Indicates a moderately significant *p*-value of between 0.07 and 0.05. ICC scores within a column indicate that either seed zones or population accounted for the given percentage of variation in that stage.

Mean Differences	**Anthesis**	**Ripening**	**Dispersal**		**Ripening Rate**
Seed Zones	Y	Y	N	**Seed Zones**	Y*
Populations	7b*	6b	6b	**Cohorts**	Y
Variance Explained					
Seed Zones	0.90%	34.60%	0%		
Populations	0.10%	31.10%	0%		

Although this study was able to illuminate the fine scale reproductive phenology dynamics for bluebunch wheatgrass, a knowledge gap with regard to anthesis, ripening, and dispersal timing for many native species still remains. In particular, it seems worthwhile to address whether the timing of anthesis, ripening, and dispersal stages are adaptive traits for other native species used in seed-increase, and provide species-specific guidance to growers and restoration practitioners on best practices in light of this information.

Early development

Our central finding was that the empirically delineated seed zones for bluebunch wheatgrass do not account for seedling traits with demonstrated genetic differences among populations. This indicates that the use of these seed zones may have unintended consequences for restoration projects reliant on seedling establishment. Since seedling survival is a bottleneck to recruitment of new adult plants in ecological restoration, the use of seed zones could be problematic in cases where the seedling ecotype does not match the out-planting site.

Relatively strong evidence of genetic differences in seedling traits among populations was found. Despite a common growing environment, seedling trait-means varied with statistical significance by population (Table 3) and a somewhat large to moderate amount of variance in each of these traits was explained by population (Table 4). If these traits were highly plastic, their response to a common growing environment would be expected to be similar despite population membership. Round represents differences in the environment experienced by the seedlings during growth due to planting date. With the exception of length to width ratio, round accounted for more variation than seed zone for every trait measured (Table 4). For certain seedling traits, round explained more of the variation than population (Table 4). The finding that planting round was more influential than population and/or seed zone in determining certain seedling traits shows that phenotypic plasticity may play an important role for these traits. Overall, this study indicates that seedling traits should be considered during seed zone delineation in order to better account for these genetic differences but that phenotypic plasticity may be an equally important factor in the expression of certain seedling traits.

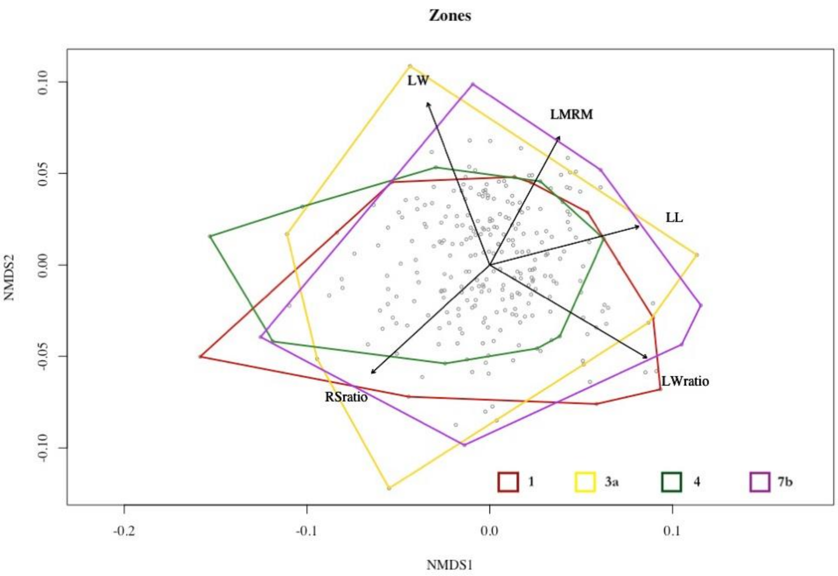
Table 3. Adjusted p-values for population level linear mixed model (LMM) trait analyses. Each LMM included a single seedling trait as the response, population as a fixed effect, and round and the interactions between rounds, populations and zones as random effects. *P*-values were adjusted using the Bonferroni correction for multiple testing. *denotes log transformed data.

Trait	Chi Square	Df	Adj. p-value
Leaf length	44.784	11	<.001
Leaf Width	59.351	11	<.001
LW Ratio*	46.335	11	<.001
RS Ratio*	32.955	11	<.001
Total Mass	79.418	11	<.001

Table 4. Intra-class correlation coefficient (ICC) scores based on random effect models built for each seedling trait. ICC scores within a column indicate that the structuring of the data into that group accounted for the given percentage of variation in that trait. In each model, the seedling trait was the response variable and seed zone, population, round, and the interactions between round and seed zone, and round and population were random effects. * denotes log transformed data was used in the model. 'LW Ratio' signifies seedling leaf length to width ratio and 'RS Ratio' signifies root to shoot ratio.

Trait	Population	Zone	Round	Round: Zone	Round: Pop
LW Ratio*	26.9%	9.1%	3.8%	5.1%	1.3%
Total Mass	18.5%	0.0%	8.8%	1.3%	0.0%
Leaf Width	14.1%	0.0%	16.4%	0.0%	6.2%
RS Ratio*	9.0%	0.5%	11.7%	0.0%	2.5%
Leaf Length	8.7%	3.1%	11.4%	0.0%	2.3%

Although evidence of differentiation in multivariate seedling traits among seed zones was observed, a small effect size indicates that these differences may not be biologically significant (Figure 4). Typically, important differences in the constellation of traits that define a group (in this case a seed zone) can be observed in ordinations by way of physical separation of these groups in trait space (McCune & Grace, 2002). In the ordination with an overlay of seed zone (Figure 4), there is little spatial separation among groupings and instead shows that seed zones share the same set of core seedling traits while most differences occur at the fringes. This, along with the small MRPP effect sizes (Table 5), indicate that the constellation of traits expressed are not well accounted for by the seed zones despite a significant *p*-value. Given these results, it is possible that seedling stage adaptations to site conditions could be occurring at different spatial scales, or for different reasons, then adult plant traits and the use of seed zones may lead unanticipated maladaptation to certain restoration sites. A summary of the univariate comparisons of means and variances as well as multivariate analyses is provided in Table 5.



($A = 0.038$, $p < 0.01$)

Figure 4. Non-metric multidimensional scaling (NMS) ordination of seed zones and populations in trait space. The horizontal axis represents the greatest amount of variation and the vertical axis represents the second greatest amount of variation in the data. Grey circles represent individual seedlings. The distances between points (seedlings) are approximately proportional to their dissimilarity in traits. Black vectors symbolize the seedling traits; leaf width (LW), total plant mass (LMRM), leaf length (LL), leaf length/width ratio (LWratio), and root/shoot ratio (RSratio). The length of the trait vectors represents the strength and direction of the correlation. Polygons represent seed zones.

Table 5. Summary of results from likelihood ratio tests of means (mean differences), intra-class correlation coefficient scores (variance explained), and multi-response permutation procedures (multivariate differences). Y/N indicates if means varied statistically among seed zones. Seed zones with significant among-population variation for each seedling trait are indicated below each trait. * denotes small effect size (*A*-statistic). 'LW Ratio' signifies seedling leaf length to width ratio.

Mean Differences	**Leaf Length**	**Leaf Width**	**LW Ratio**	**Root/Shoot Ratio**	**Total Mass**
Seed Zones	N	N	N	N	N
Populations	Y	Y	Y	Y	Y
Variance Explained					
Seed Zones	3%	0%	9%	1%	0%
Populations	9%	14%	27%	9%	19%
Rounds	11%	16%	4%	12%	9%
Multivariate Differences					
Seed Zones	Y*				
Populations	1	3a*	4*	7b*	
Rounds	Y*				

The results of this study indicate that adult stage phenotypic traits do not provide a reliable proxy for seedling traits. Although including seedling stage traits in the seed zone delineation process is more complex and costly, and plastic responses to environmental cues undoubtedly play a role in determining seedling traits, discontinuity among adult and seedling stage traits could still be problematic. In addition, this kind of discontinuity could easily be a common pattern in species other than bluebunch wheatgrass that are also important to ecological restoration.

Management & Seed Production Guidelines

Reproductive Phenology

Since there is no strong evidence of among population variation in anthesis, ripening, or dispersal stages in the seed zones studied (other than 7b and 6b), typical single-pass combining is not likely to cause inadvertent selection for these traits when seed zone guidelines are used for selecting source populations. In the field, it was apparent that early and late flowering spikes on the same plant tended to converge towards similar ripening dates despite differences in the timing of anthesis among them. This variable ripening rate appears to be a strategy shared by bluebunch wheatgrass plants in general. Despite there being a tendency for early flowering spikes and late flowering spikes to converge at similar ripening dates, among population and among seed zone differences in ripening timing are nonetheless detectable. This shows that the timing of ripening may be somewhat decoupled from the timing of anthesis. Growers should therefore be cautious about using anthesis timing to predict seed ripening.

These findings are of interest to land managers sowing commercially produced bluebunch wheatgrass in seed zone 7b. Populations from this seed zone had variable anthesis timing and therefore mixed seed lots from seed zone 7b could risk unintentional artificial selection for populations with earlier or later anthesis during the seed increase process. This unintentional selection could result in maladaptation to out-planting locations where the particular timing of anthesis is an adaptive trait. Additionally, the heterogeneity of the timing of seed ripening in seed zone 6b could pose a challenge to growers attempting to harvest mixed-source seed lots at peak ripeness.

Early Development

We identified the seedling-stage of plant growth as an important and understudied bottleneck to establishment and recruitment in ecological restoration. This important life-stage is currently under-represented in the seed zone delineation methodology. Since including seedling-stage adaptive traits as part of seed zone delineation requires more energy and resources, it is crucial to understand whether adult plants provide a workable proxy for seedling stage adaptive strategies. In general, seedling stage traits vary in different ways than do adult traits for bluebunch wheatgrass. This indicates that the current seed zones for this species do a relatively poor job of accounting for seedling-stage adaptations to environmental gradients. Therefore, the use of these zones may have unintended consequences for seedling survival at restoration sites given that seedling survival is a bottleneck to establishment and recruitment. Although including seedling-stage plant traits is experimentally more complex, both the current seed zones for bluebunch wheatgrass and future seed zones delineated for other native species could be improved by including seedling-stage traits in the delineation process.

Presentations

Prive, Kathryn A.; Orr, Matt; Reuter, Ron; St. Clair, Brad; Kilkenny, Francis; Prendeville, Holly. 2017. Bluebunch Wheatgrass: Seedling Traits and Reproductive Phenology. Oral presentation at the Great Basin Native Plant Project Workgroup Meeting; 2017 November 8; Reno NV.

Prive, Kathryn A. 2017. Efficacy of Empirical Seed Zones: Bluebunch Wheatgrass Reproductive Phenology and Seedling Stage Traits. Master's defense oral presentation at Oregon State University; 2017 December 7; Corvallis OR.

References

Basey, A. C.; Fant, J. B.; Kramer, A. T. (2015). Producing native plant materials for restoration: 10 rules to collect and maintain genetic diversity. *Native Plants Journal*, *16*(1), 37–53. https://doi.org/10.3368/npj.16.1.37

Broadhurst, L. M.; Lowe, A.; Coates, D. J.; Cunningham, S. A.; McDonald, M.; Vesk, P. A.; Yates, C. (2008). Seed supply for broadscale restoration: maximizing evolutionary potential. *Evolutionary Applications*, *1*(4), 587–597. https://doi.org/10.1111/j.1752-4571.2008.00045.x

Clark, C. J.; Poulsen, J. R.; Levey, D. J.; Osenberg, C. W. (2007). Are Plant Populations Seed Limited? A Critique and Meta-Analysis of Seed Addition Experiments. *The American Naturalist*, *170*(1), 128–142. https://doi.org/10.1086/518565

Giménez-Benavides, L.; Escudero, A.; Iriondo, J. M. (2007). Local Adaptation Enhances Seedling Recruitment Along an Altitudinal Gradient in a High Mountain Mediterranean Plant. *Annals of Botany*, *99*(4), 723–734. https://doi.org/10.1093/aob/mcm007

Johnson, R.; Stritch, L.; Olwell, P.; Lambert, S.; Horning, M. E.; Cronn, R. (2010). What are the best seed sources for ecosystem restoration on BLM and USFS lands? *Native Plants Journal*, *11*(2), 117–131. https://doi.org/10.2979/NPJ.2010.11.2.117

Jongejans, E.; Soons, M. B.; de Kroon, H. (2006). Bottlenecks and spatiotemporal variation in the sexual reproduction pathway of perennial meadow plants. *Basic and Applied Ecology*, *7*(1), 71–81. https://doi.org/10.1016/j.baae.2005.04.004

Larson, J. E.; Sheley, R. L.; Hardegree, S. P.; Doescher, P. S.; James, J. J. (2015). Seed and seedling traits affecting critical life stage transitions and recruitment outcomes in dryland grasses. *Journal of Applied Ecology*, *52*(1), 199–209. https://doi.org/10.1111/1365-2664.12350

Leimu, R.; Fischer, M. (2008). A Meta-Analysis of Local Adaptation in Plants. *PLoS ONE*, *3*(12), e4010. https://doi.org/10.1371/journal.pone.0004010

Lesica, P.; Allendorf, F. W. (1999). Ecological Genetics and the Restoration of Plant Communities: Mix or Match? *Restoration Ecology*, *7*(1), 42–50. https://doi.org/10.1046/j.1526-100X.1999.07105.x

McCune, B.; Grace, J. B. (2002). *Analysis of Ecological Communities*. Gleneden Beach, Oregon: MjM Software Design.

Rowe, C. L. J.; Leger, E. A. (2011). Competitive seedlings and inherited traits: a test of rapid evolution of Elymus multisetus (big squirreltail) in response to cheatgrass invasion. *Evolutionary Applications*, *4*(3), 485–498. https://doi.org/10.1111/j.1752-4571.2010.00162.x

Smith, D. S.; Schweitzer, J. A.; Turk, P.; Bailey, J. K.; Hart, S. C.; Shuster, S. M.; Whitham, T. G. (2011). Soil-mediated local adaptation alters seedling survival and performance. *Plant and Soil*, *352*(1–2), 243–251. https://doi.org/10.1007/s11104-011-0992-7

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

Project Agreement No. 15-JV-11221632-181

Principal Investigators and Contact Information

Dr. Mikel R. Stevens, Professor
Department of Plant and Wildlife Sciences
Brigham Young University
5131 LSB, Department of Plant and Wildlife Sciences
Brigham Young University
Provo, Utah 84602
Phone 801.422.4032, Fax 801.422.0008
Email address mikel_stevens@byu.edu

Dr. Robert L. Johnson, Associate Research Professor
Department of Biology
Brigham Young University
3115A MLBM, Department of Biology
Brigham Young University
Provo, Utah 84602
Phone 801.422.7094, Fax 801.422.0093
Email address robert_johnson@byu.edu

Project Description

Introduction

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

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

Objective

To identify potentially useful ecotypes/genotypes of blue penstemon (*Penstemon cyaneus* Pennell) to be used in restoration by characterizing the morphological and genetic variation within the species.

Methods

We planted two common gardens that consisted of 30 accessions with four replications in Provo, Utah and Aberdeen, Idaho. We have monitored these common gardens closely and replaced any seedlings that failed to establish due to transplant shock. These common gardens will be evaluated next spring to assess winter mortality and spring flowering dates. We will also collect data on the number of flower stems, plant height, and other plant metrics that will be used to assess the genotype-by-environment interaction for each accession. We will use this data, along with molecular data, to understand which accessions are best suited for use in the Northern Great basin and Snake River Plain.

Results and Discussion

While in Eastern Utah doing fieldwork for an unrelated project, we found 2 populations of *P. cyanocaulis*, and collected tissues samples for use as an additional outgroup in our molecular characterizations. We have extracted DNA from all of our plant samples, for a total of 1,000 samples from 125 accessions. We are in the final stages of preparing samples for DNA sequencing (library preparation). Our methodologies for library preparation include: random fragmentation of DNA, addition of a DNA barcode for sample identification, addition of an Illumina sequencing platform adaptor, size selection for DNA fragments ~500 bp in length, and sequence capture of ~1,000 known *Penstemon* loci distributed throughout the genome. The *Penstemon* loci we are targeting for sequencing were previously identified Dockter *et al* (2013). We further evaluated target loci sequences of Wasatch penstemon (*P. cyananthus*) for specificity and uniformity with a database created from blue penstemon genome sequence reads. We on schedule to have all sequencing completed by the end of the calendar year.

Our two primary focuses for 2018 will be (1) analyzing our DNA sequencing data for genetic markers that will be used for population genetics; and (2) collecting phenotype data from our common gardens for statistical comparisons of accessions. These two datasets will be used to characterize blue penstemon's variation, and make recommendations for germplasm use in the Great Basin.

References

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

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

Dockter, R.B.; Elzinga, D.B.; Geary, B.; Maughan, P.J.; Johnson, L.A.; Tumbleson, D.; Franke, J.; Dockter, K.; Stevens, M.R. 2013. Developing molecular tools and insights into the *Penstemon* genome using genomic reduction and next-generation sequencing. BMC Genetics 14:66.

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

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

SOUTHWEST ENVIRONMENTAL INFORMATION NETWORK, SEINet – Arizona Chapter. 2016. Available: http//:swbiodiverstiy.org/seinet/inde.php October 29.

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

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

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

PLANT MATERIALS AND CULTURAL PRACTICES

Project Title: Plant Material Work at the Shrub Science Lab

Project Agreement No. 17-IA-11221632-180

Principal Investigators and Contact Information:

Scott Jensen, Botanist
Rocky Mountain Research Station
Grassland, Shrubland and Desert Ecosystem Program
735 N. 500 E., Provo, UT 84606-1865
801.356.5124, Fax 801.375.6968
sljensen@fs.fed.us

Project Description

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

This multiagency cooperative study assessing seed and ground treatments to improve forb establishment was initiated in 2015 then replicated with modification in 2016. The study is partitioned into two compartments, one focusing on two legume species under development by the Agricultural Research Service (ARS) Forage and Range Lab Legumes and a second focusing on a diverse group of native forbs under development by the United States Department of Agriculture (USDA) Rocky Mountain Research Station (RMRS) Shrub Sciences Lab. Data collection occurred in 2016 and 2017. Data are being analyzed for manuscript preparation.

Evaluation of Thickleaf Penstemon (Penstemon pachyphyllus) Seed Sources in Central Basin and Range Restoration Projects.

The Bureau of Land Management (BLM) Cedar City Field Office is implementing habitat improvement projects in Utah's Hamlin Valley. Treatment areas straddle multiple provisional seed zones and soil classifications, occur over a multi-year period and include bullhog and chaining treatments. Hamlin Valley sits within the geographic distribution of thickleaf penstemon and serves as an excellent opportunity to evaluate stock seed supplies in a restoration context. Pooled seed supplies developed according to provisional seed zone guidelines (Johnson et al. 2010, Bower et al. 2014) were assembled from wildland collections and G1 seed increased at Utah Department of Wildlife Resources (UDWR) Fountain Green farm. In 2016, 5 blocks were seeded in each combination of field variables totaling 90 experimental plots. In 2017, an additional 70 plots were established. At each plot three lots of thickleaf penstemon representing stock seed from three unique Provisional Seed Zones (PSZ) were planted. Establishment data will be collected in 2018 and 2019.

Tracking Thickleaf Penstemon Population Genetic Structure and Diversity from Native Populations through Initial Seed Increase, Commercial Production and Restoration Plantings.

Among our first species to complete the plant material development cycle, originating with wildland collection then species screening, seed increase, PSZ pooling, commercial production and restoration use is thickleaf penstemon. Completion of this cycle provides a valuable opportunity to evaluate genetic population structure and diversity throughout the process and quantitatively assess the theoretical benefits of genetically broad based stock seed supplies in a restoration context.

Stock seed supplies were assembled for three central basin and range (CBR) PSZ's from wildland collections (2009-2013) and G1 seed stocks (2012-2016). Commercial production fields were planted near Vale, Oregon in fall 2016 and restoration seedings were planted in 2016 and 2017 in Hamlin Valley, Utah. For this study seed from the same pooled supply was seeded in both commercial fields and restoration plantings. In the future, as commercial seed from these fields becomes available we anticipate evaluating generational structure and diversity effects from 2nd generation commercial seed and 3rd generation restoration plantings.

In 2017 leaf tissue for genetic analysis was collected from 30 of 31 wild thickleaf penstemon populations, 18 seed increase beds at Fountain Green, Utah, and 3 commercial production fields. During plot sampling in 2018 leaf tissue will be collected from Hamlin Valley restoration plantings.

This study is a cooperative effort between Chicago Botanical Garden (Andrea Kramer), UDWR GBRC (Melissa Landeen, Kevin Gunnell), USFS Region 4 (John Proctor), Quarter Circle J Seeds (Jerry Erstrom), Cedar City BLM (Dan Fletcher) and USFS RMRS Shrub Lab (Scott Jensen)

Testing Seed Weight Based Sagebrush Identification Techniques.

A sagebrush seed working group was organized in 2017 to address concerns related to sagebrush use in restoration. The group ranked further evaluation of Richardson et al.'s 2015 seed weight based sagebrush subspecies identification as highest priority. The purpose of this study is to test seed identification protocols with big sagebrush seed collected from sites representing a broad array of environmental variables and from plants of varied characteristics to verify seed weight is genetically rather than environmentally controlled and constant within subspecies. The study will also assess field employable identification techniques to classify big sagebrush subspecies.

A study plan and field sampling protocol was developed and refined through a working group review and comment process, review by Brigham Young University statistical and wildlife and wildlands program professors and field trials.

Several sites were sampled fall 2017. Samples are being processed.

Presentations

Jensen, S. L.; Anderson, Val Jo. 2017. The effect of seed characteristics and sowing depth on emergence of 20 Great Basin forbs. 2017 Nov; Provo, Utah.

Additional Products

- *Wildland seed collection*

Seed collection efforts in 2017 were focused in several areas: First, wildland collection of specific species currently in production beds but needing refreshing with G0 seed; Second, annual species proven in 2016 screening trials at Fountain Green; Third, octoploid populations of basin wildrye (*Leymus cinereus*) to create genecological based stock seed supplies. Forth; Colorado plateau ecoregion populations of thickleaf penstemon to compare level 3 ecoregion compatibility with Great Basin populations.

Species	Locations	Collections	Notes
Cleome lutea	1	1	
Cleome serrulata	3	3	
Helianthus annuus	7	7	
Heliomeris multiflora var. nevadensis	1	7	
Ipomopsis aggregata		2	
Leymus cinereus	5	20	15 Octoploid
Linum lewisii		4	
Lomatium nudicaule		6	
Penstemon pachyphyllus var. *congestus*	21	35	
Totals	38	85	

- *Seed Distributions for Commercial Production*

Seed produced from two annual species at Fountain Green, Utah was distributed to growers in Oregon and Utah in 2017.

Species	Common Name	Source	Quantity	State
Cleome serrulata	Rocky Mountain beeplant	10 - 15 Deg. F. / 6 – 12, CBR	5 lots, 22.5 lbs.	Oregon
Cleome serrulata	Rocky Mountain beeplant	10 - 15 Deg. F. / 6 – 12, CBR	5 lots, 2.5 lbs.	Utah
Helianthus annuus	common sunflower	15 - 20 Deg. F. / 6 - 12	6 lots, 8.8 lbs.	Utah

- *Internal Seed Increase*

In cooperation with the UDWR Great Basin Research Center (GBRC) additional increase / evaluation beds were planted. These include 9 experimental species, three annual species, several source additions to existing species seed zone increase efforts and new perennial species pooled zone increase efforts. See UDWR GBRC report for full details.

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

In cooperation with Nevada Fish and Wildlife Service (FWS) (Sarah Kulpa) and Ely BLM (Lara Derasery) stock seed supplies from the following sources were distributed to commercial producers in prior years. This table summarizes 2017 harvest yields.

Species	Source	Quantity
Agoseris grandiflora	20-25 Deg. F. / 3-6 CBR	67 lbs.
Argemone munita	15-20 Deg. F. / 6-12 CBR	5 lbs.
Cleome lutea	15-20 Deg. F. / 6-12 CBR	16 lbs.
Erigeron speciosus	15-20 Deg. F. / 3-6 CBR	99 lbs.
Heliomeris multiflora nevadensis	15-20 Deg. F. / 6-12 CBR	300 lbs.
Leymus cinereus	10-15 Deg. F. / 6-12 CBR	1370 lbs.
Leymus cinereus	15-20 Deg. F. / 3-6 CBR	450 lbs.
Leymus cinereus	15-20 Deg. F. / 6-12 CBR	1193 lbs.
Leymus cinereus	20-25 Deg. F. / 6-12 CBR	685 lbs.
Mentzelia albicaulis	20-25 Deg. F. / 6-12 CBR	2.5 lbs
Nicotiana attenuata	15-20 Deg.F / 3-6 CBR	99 lbs.
Nicotiana attenuata	15-20 Deg. F. / 6-12 CBR	11 lbs.
Sphaeralcea grossulariifolia	15-20 Deg. F. / 6-12 CBR	33 lbs.
Sphaeralcea grossulariifolia	15-20 Deg. F. / 6-12 CBR	1000 lbs.
Sphaeralcea munroana	10-15 Deg. F. / 6-12 CBR	23 lbs.
	Total	5353.5 lbs.

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

Johnson, G. R.; Stritch, L.; Olwell, P.; Lambert, S.; Horning, M.E.; Cronn, R. 2010. What are the best seed sources for ecosystem restoration on BLM and USFS lands? Native Plants Journal 11:117-131.

Project Title Great Basin Research Center Seed Increase

Project Agreement No. 16-JV-11221632-052

Principal Investigators and Contact Information

Melissa Landeen, GBRC Project Leader
Utah Division of Wildlife Resources
Great Basin Research Center
494 West 100 South,
Ephraim, UT 84627
435.283.4441, Fax 435.283.2034
mlandeen@utah.gov

Kevin Gunnell, GBRC Coordinator
Utah Division of Wildlife Resources
Great Basin Research Center
494 West 100 South,
Ephraim, UT 84627
435.283.4441, Fax 435.283.2034
kevingunnell@utah.gov

Project Description

The ongoing native seed increase project at the Utah Division of Wildlife Resources (UDWR) Great Basin Research Center (GBRC) uses wildland-collected seed to establish small-scale production plots. We then use seed harvested from the production plots to supply seed for commercial-scale seed production and to provide material for further research. We also use the seed increase plots to conduct research (both formal and informal) on propagation protocols, including techniques for increasing seed production. This work is being carried out by the GBRC in conjunction with the United States Forest Service (USFS) Rocky Mountain Research Station (RMRS) Provo Shrub Sciences Lab wildland seed collection project.

Introduction

One of the greatest limitations to native vegetation restoration efforts is a lack of seed material to meet the demands of large-scale restoration and ongoing research. The research at the GBRC emphasizes native forbs, which serve many purposes in wildland communities. Forbs are not only an essential component of sage-grouse (*Centrocercus urophasianus* and *C. minimus*) habitat and diet, but many are important for sustaining native pollinator populations (Crawford et al. 2004, Dumroese et al. 2016). In order for successful restoration of native vegetation in rangeland environments, land managers require seed in sufficient quantities at reasonable prices and a knowledge of the best practices for successful germination and establishment of the seed. The native plant research at the GBRC helps meet these needs through the increase of small-scale wildland collections of native species for release to larger-scale commercial production, or to researchers for further testing.

Objectives

1. Increase seed from wildland collections to support further research and increase distribution of native seed to commercial growers.
2. Keep detailed records of practices, plant growth, and production to assess methods to increase seed production of native species in agronomic settings.

Methods

In conjunction with the RMRS, we selected priority species and accessions of wildland collected seed to plant on the UDWR farm in Fountain Green, UT or the Snow College farm in Ephraim, UT for the purpose of seed increase. We either directly seeded into production beds or fields, or propagated seed in the greenhouse for transplanting, depending on the amount of seed available.

We maintained and harvested the production fields to maximize seed production of native species. When opportunities arose, we developed propagation protocols and conducted research on ways to increased establishment and production. We kept detailed records on growth traits and production techniques to further assess best practices for seed production.

Results and Discussion

In 2017 we had the opportunity to expand and increase the number of native plant species and accessions. In spring 2017, we established new plots of Palmer penstemon (*Penstemon palmeri;* 8 accessions transplanted from greenhouse), goosberryleaf globemallow (*Sphaeralcea grossularifolia*; 14 accessions – 7 seeded directly and 7 transplanted from greenhouse) and annual sunflower (5 accessions seeded directly). Several accessions were removed throughout the growing season due to disease or because they were not the intended species. In fall 2017, we established an additional 53 plots to augment production of three established species and begin seed increase for 16 other species (Table 1). All other existing perennial plots and production fields were maintained.

Table 1. Native species grown for increase in 2017.

Code	Species	# of Accessions	Location
ARMAF	*Arenaria macradenia*	1**	Ft. Green
ASFI	*Astragalus filipes*	1	Ephraim
CLLU2	*Cleome lutea*	5**	Ft. Green
CLSE	*Cleome serrulata*	6*	Ft. Green
CRAC2	*Crepis acuminata*	2**	Ft. Green
DASE3	*Dalea searlsiae*	1	Ephraim
ERLA6	*Eriophyllum lanatum*	1**	Ft. Green
ERSP	*Erigeron speciosis*	3**	Ft. Green
ERUM	*Eriogonum umbellatum*	2**	Ft. Green
HEAN	*Helianthus annuus*	5**	Ft. Green
HEMUN	*Heliomeris multiflora nevadensis*	5	Ft. Green
IPAG	*Ipomopsis aggregata*	12*	Ft. Green
LILE2	*Linum lewisii*	8	Ft. Green
LISU5	*Linum subteres*	1**	Ft. Green
LOGR	*Lomatium grayi*	1**	Ft. Green
LONU	*Lomatium nudicale*	3**	Ft. Green
LOTR	*Lomatium triternatum*	1**	Ft. Green
MACA	*Machaeranthera canescens*	1**	Ft. Green
MELA	*Mentzelia laevicaulis*	3**	Ft. Green
OENOT	*Oenothera*	1**	Ft. Green
PACKE	*Packera*	1**	Ft. Green
PEEA	*Penstemon eatonii*	4	Ft. Green
PEPA6	*Penstemon pachyphyllus*	18	Ft. Green
PEPA8	*Penstemon palmeri*	16*	Ft. Green
PHCRC	*Phacelia crenulata*	1**	Ft. Green
SPGR2	*Sphaeralcea grossularifolia*	15**	Ft. Green
STPII	*Stanleya pinnata*	2**	Ft. Green

*New increase plots of this species established in 2017.

**New species established in 2017.

In fall 2017 we successfully harvested seed from 18 accessions of thick leaf penstemon (*Penstemon pachyphyllus)*, five accessions of Nevada showy goldeneye (*Heliomeris multiflora nevadensis)*, eight accessions of Lewis flax (*Linum lewisii)*, five accessions of scarlet gilia, five accessions of annual sunflower, six accessions of Rocky Mountain bee plant, one germplasm ("Fanny") of Searls' prairie clover (*Dalea searlsiea)*, and one germplasm ("NBR1") of basalt milkvetch (*Astragalus filipes)*. Growth and harvest information are noted in Table 2. We also harvested seed from 14 accessions of goosberryleaf globemallow; however, we later discovered that six of the gooseberryleaf globemallow accessions were actually small-leaf globemallow (*Sphaeralcea parvifolia),* and that the harvested seed was therefore likely a hybrid of the two species. We removed the misidentified plants and discarded the seed.

Following the 2017 harvest, the project cleaned and distributed two pooled sources of scarlet gilia seed, six pooled sources of Rocky Mountain bee plant seed, and five pooled sources of annual sunflower seed to growers for commercial scale increase. The pooled sources all came from the 15-20 Deg. F/3-6 provisional seed zone (PSZ) for the Great Basin.

Table 2. 2017 Growth and harvest information for species grown for increase by the GBRC.

Species/Collection	Peak Bloom Date	Harvest Date(s)	No. of Plants	Cleaned Seed (g)
Astragalus filipes				
NBR1	-	7/16	-	22.20
Cleome serrulata				
Delta 2010	8/17	9/18	-	2880.31
Delta 2012	8/17	9/18	-	3515.34
North Ruby Valley	8/17	9/12	-	1474.18
Spring Valley	8/17	9/12	-	3515.34
Tippett	8/17	9/12	-	2540.12
West Spring Valley	8/17	9/12	-	3265.87
Dalea searlsiae				
‘Fanny’	-	7/13-9/11	686	1814.37
Helianthus annuus				
Exit 202	8/31	10/12	-	820.00
Filmore	9/11	10/12	-	780.00
Lookout Pass	8/31	10/12	-	880.00
Mona	9/11	10/12	-	560.00
Oak City	9/11	10/12	-	480.00
Heliomeris multiflora nevadensis				
Jackrabbit Mine	7/12	8/10–9/18	205	1115.30
Newcastle	7/5	8/10–9/18	126	356.30
Patterson Pass	7/26	8/10–9/18	115	449.70
Patterson Pass 2	7/5	8/10–9/18	104	294.70
Silverhorn Wash	7/26	8/10–9/18	90	347.30
Ipomopsis aggregata				
Chicken Rock	6/8	6/29-8/17	145	816.47
Soldier Canyon	6/8	6/29-8/17	240	1020.58
Old Iron Town	8/28	6/29-8/17	17	5.20
Windy Gap	6/8	6/29-8/17	22	17.80
Winecup	-	6/29-8/17	1	0.00
Linum lewisii				
Crystal Peak	6/8	6/22-8/16	308	1156.66
Halfway Hills	6/8	6/22-8/16	79	272.16
Jackrabbit Mine	6/8	6/22-8/16	97	1292.74

Table 2 continued. 2017 Growth and harvest information for species grown for increase by the GBRC.

Species/Collection	Peak Bloom Date	Harvest Date(s)	No. of Plants	Cleaned Seed (g)
Linum lewisii (continued)				
Long Hill	6/8	6/22-8/16	132	408.23
Majors Place	6/8	6/22-8/16	166	408.23
Patterson Pass	6/8	6/22-8/16	157	975.22
Rice Mountain	6/8	6/22-8/16	236	1700.97
Side Hill Pass	6/8	6/22-8/16	73	544.31
Penstemon pachyphyllus				
Applegarth Spring	6/8	7/31	214	69.90
Beaver/Millard Border	6/8	7/31	267	240.40
Cave Creek	6/8	7/31	252	267.00
Cave Lake	6/8	7/31	75	114.10
Cottonwood Wash	6/8	8/3	235	593.90
Eberhardt	6/8	7/31	227	62.20
Fisher's Wash	6/8	8/3	127	601.10
Gubler Canyon	6/8	7/31	298	351.10
Jockey Road	6/8	8/3	309	1437.40
Mount Zeppelin	6/8	7/31	103	322.00
N. Cave Lake Turn Off	6/8	7/31	18	37.00
Paris Creek	6/8	7/31	241	925.00
Rosebud Spring	6/8	7/31	192	440.00
Sand Spring	6/8	7/31	165	1034.00
Steptoe Creek	6/8	7/31	214	85.10
Treasure	6/8	7/31	215	188.60
Triple 7's	6/8	7/31	217	53.00
Upper Moonshine	6/8	7/31	216	406.60

Although we nearly doubled the number of species and increase plots on our farms in fall 2017, we do not expect to see an immediate drastic increase in seed production. While several of the newly established species are annual forbs, requiring only one growing season to produce seed, many others are perennial or biennial species, which require multiple years of growth before attaining reproductive maturity. We hope to see continual steady growth of the seed increase project in the coming years.

Management Applications

The objective of this project is to provide native plant materials to researchers and commercial growers in workable quantities, with the intent that materials will be increased to restoration scales. The Native Seed Increase project at the GBRC harvested over 40.8 kg of seed from eight different species in 2017. We distributed seed from three of those species to commercial growers for large-scale increase. Because the GBRC is a seed warehouse, in addition to being a research facility, we are in the position to buy back the seed produced from materials distributed to commercial growers through this project. In doing so, we are able to influence both the demand and supply of native plant materials, and create incentive for priority species to be produced in greater quantities. This cycle was demonstrated recently with the purchase of bulk quantities of Nevada showy goldeneye in 2016 and 2017, and thickleaf penstemon in 2016. Both species were initially increased through the project, distributed to a grower, purchased back through the GBRC seed warehouse, and distributed to large-scale restoration projects. We have also distributed seed from the project to researchers for further testing in restoration and laboratory settings, increasing our knowledge of their use in wildland settings.

Presentations

Gunnell, Kevin; Jensen, S. 2017. From the Wild to Farm and Back Again: A Strategy for Native Plant Material Development and Utilization. Presented at the National Native Seed Conference. 2017 February 12-16; Washington, D.C.

Gunnell, Kevin; Jensen, S. 2017. From the Wild to Farm and Back Again: A Strategy for Native Plant Material Development and Utilization. Presented at the Colorado Plateau Native Plant Program annual meeting. 2017 February 27 – March 1; Monticello, UT.

Gunnell, Kevin. 2017. Native forb increase and research at the GBRC: an update and summary. Presented at the Great Basin Native Plant Program Workgroup Meeting. 2017 November 8-9; Reno, NV.

Jensen, Scott; Gunnell, K. 2017. When plant distributions and administrative boundaries don't align, can people? Partnering across plant materials development programs. Presented at the Colorado Plateau Native Plant Program annual meeting; 2017 February 27 – March 1; Monticello, UT.

References

Crawford, John.A.; Olson, R.A.; West, N.E.; Mosley, J.C.; Schroeder, M.A.; Whitson, T.D.; Miller, R.F.; Gregg, M.A.; Boyd, C.S. 2004. Ecology and management of sage-grouse and sage-grouse habitat. Journal of Range Management 57:2-19.

Dumroese, R. Kasten; Luna, T.; Pinto, J.R.; Landis, T.D. 2016. Forbs: foundation for restoration of Monarch butterflies, other pollinators, and greater sage-grouse in the Western United States. Natural Areas Journal 36:499-501.

Project Title	Seed Production of Great Basin Native Forbs
Project No.	12-JV-11221632-066

Principal Investigators and Contact Information

Clinton C. Shock, Director/Professor
Oregon State University
Malheur Experiment Station
595 Onion Avenue
Ontario, OR 97914
541.889.2174, Fax 541.889.7831
clinton.shock@oregonstate.edu

Erik B. Feibert, Senior Faculty Research Assistant
Oregon State University
Malheur Experiment Station
595 Onion Avenue
Ontario, OR 97914
541.889.2174
erik.feibert@oregonstate.edu

Joel Felix, Assoc. Professor
Oregon State University
Malheur Experiment Station
595 Onion Avenue
Ontario, OR 97914
541.889.2174, Fax 541.889.7831
joel.felix@oregonstate.edu

Nancy Shaw, Research Botanist
USFS Rocky Mountain Research Station
322 E. Front Street, Suite 401
Boise, ID 83702
208.373.4360, Fax 208.373.4391
nancylshaw@fs.fed.us

Francis Kilkenny, Research Biologist
USFS Rocky Mountain Research Station
322 E. Front Street, Suite 401
Boise, ID 83702
208.373.4376, Fax 208.373.4391
ffkilkenny@fs.fed.us

Project Description

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

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

1. Irrigation Requirements for *Lomatium* Seed Production in a Semi-arid Environment

Clinton C. Shock, Erik B. G. Feibert, Alicia Rivera, and Lamont D. Saunders, Malheur Experiment Station, Oregon State University , Ontario, OR, 2017

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

Summary

Lomatium species are important botanical components in the rangelands of the Intermountain West. Relatively little is known about the cultural practices necessary to produce *Lomatium* seed for use in rangeland restoration activities. The seed yield response to four biweekly irrigations applying either 0, 1, or 2 inches of water (total of 0, 4, or 8 inches/season) was evaluated for four *Lomatium* species over multiple years starting in 2007. In order to try to improve the accuracy of estimated irrigation water requirements, seed yield responses to irrigation plus precipitation during the previous spring; winter and spring; and fall, winter, and spring were also evaluated. On average, over nine seed production seasons, fernleaf biscuitroot (*Lomatium dissectum*) seed yield was maximized by 7.7 to 9.5 inches of water applied plus spring precipitation depending on the seed source. On average, over 11 seed production seasons, Gray's biscuitroot (*L. grayi*) seed yield was maximized by 14.3 inches of water applied plus fall, winter, and spring precipitation. On average, over 11 seed production seasons, nineleaf biscuitroot (*L. triternatum*) seed yield was maximized by 12.4 inches of water applied plus spring precipitation. Over six seed production seasons, barestem biscuitroot (*L. nudicaule*) seed yield only responded to irrigation in 2017. In four seed production seasons, seed yield of Suksdorf's desertparsley (*L. suksdorfii*) responded to irrigation only 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 variation in spring rainfall and soil moisture results in highly unpredictable water stress at flowering, seed set, and seed development, which for other seed crops is known to compromise seed yield and quality.

Native wildflower plants are not well adapted to croplands and often are not competitive with crop weeds in cultivated fields, which could limit wildflower seed production. Supplemental water can be provided by sprinkler or furrow irrigation systems, but these irrigation systems risk further encouraging weeds. Sprinkler and furrow irrigation can lead to the loss of plant stand and seed production due to fungal pathogens. Burying drip tapes at 12-inch depth and avoiding wetting the soil surface could help to assure flowering and seed set without undue encouragement of weeds or opportunistic diseases. The trials reported here tested the effects of three low rates of irrigation on the seed yield of five *Lomatium* species (Table 1).

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

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

Species	Common names
Lomatium dissectum	fernleaf biscuitroot
Lomatium triternatum	nineleaf biscuitroot, nineleaf desertparsley
Lomatium grayi	Gray’s biscuitroot, Gray’s lomatium
Lomatium nudicaule	barestem biscuitroot, barestem lomatium
Lomatium suksdorfii	Suksdorf’s desertparsley

Materials and Methods

Plant Establishment

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

In late February 2005, drip tape (T-Tape TSX 515-16-340) was buried at 12-inch depth between two 30-inch rows of a Nyssa silt loam with a pH of 8.3 and 1.1% organic matter. The drip tape was buried in alternating inter-row spaces (5 ft apart). The flow rate for the drip tape was 0.34 gal/min/100 ft at 8 psi with emitters spaced 16 inches apart, resulting in a water application rate of 0.066 inch/hour.

On March 3, 2005, seed of the three species (fernleaf biscuitroot, Gray’s biscuitroot, and nineleaf biscuitroot) was planted in 30-inch rows using a custom-made plot grain drill with disc openers. All seed was planted at 20-30 seeds/ft of row at 0.5-inch depth. The trial was irrigated from March 4 to April 29 with a minisprinkler system (R10 Turbo Rotator, Nelson Irrigation Corp., Walla Walla, WA) for even stand establishment. Risers were spaced 25 ft apart along the flexible polyethylene hose laterals that were spaced 30 ft apart and the water application rate was 0.10 inch/hour. A total of 1.72 inches of water was applied with the minisprinkler system. Nineleaf biscuitroot and Gray’s biscuitroot started emerging on March 29. Beginning on June 24, the field was irrigated with the drip irrigation system. A total of 3.73 inches of water was applied with the drip system from June 24 to July 7. The field was not irrigated further in 2005.

Plant stands for nineleaf biscuitroot, and Gray's biscuitroot were uneven; fernleaf biscuitroot did not emerge. None of the species flowered in 2005. In early October 2005, more seed was received from the RMRS for replanting. The entire row lengths were replanted using the planter on October 26, 2005. In spring 2006, the plant stands were excellent.

On November 25, 2009 seed of barestem biscuitroot, Suksdorf's desertparsley, and three selections of fernleaf biscuitroot (LODI 38, LODI 41, and seed from near Riggins, ID) was planted in 30-inch rows using a custom-made plot grain drill with disc openers. All seed was planted on the soil surface at 20-30 seeds/ft of row. After planting, sawdust was applied in a narrow band over the seed row at 0.26 oz/ft of row (558 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 nonirrigated check, 1 inch of water applied per irrigation, and 2 inches of water applied per irrigation. Each treatment received four irrigations applied approximately every 2 weeks starting with flowering. The amount of water applied to each treatment was calculated by the length of time necessary to deliver 1 or 2 inches through the drip system. Irrigations were regulated with a controller and solenoid valves. After each irrigation, the amount of water applied was read on a water meter and recorded to ensure correct water applications.

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

Flowering, Harvesting, and Seed Cleaning

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

Cultural Practices in 2006

On October 27, 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). On November 9, Prowl at 1 lb ai/acre was broadcast on all plots for weed control.

Cultural Practices in 2008

On April 15, 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, 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, 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 containing 50 lb N/acre, 10 lb P/acre, and 0.3 lb iron (Fe)/acre was injected 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 containing 20 lb N/acre, 25 lb P/acre, and 0.3 lb Fe/acre was injected 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 containing 20 lb N/acre, 25 lb P/acre, and 0.3 lb Fe/acre was injected 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 containing 20 lb N/acre, 25 lb P/acre, and 0.3 lb Fe/acre was injected using a brief pulse of water through the drip irrigation system to all plots on April 15. On November 6, Prowl at 1 lb ai/acre and Roundup® at 24 oz/acre were broadcast on all plots for weed control.

Cultural Practices in 2016

Liquid fertilizer containing 20 lb N/acre, 25 lb P/acre, and 0.3 lb Fe/acre was injected using a brief pulse of water through the drip irrigation system to all plots on March 31. On October 27, Prowl H_2O at 1 lb ai/acre was broadcast on all plots for weed control.

Cultural Practices in 2017

On March 28, Prowl H_2O at 1 lb ai/acre and Poast at 0.75 lb ai/acre were broadcast on all plots for weed control. Liquid fertilizer containing 0.3 lb Fe/acre was injected using a brief pulse of water through the drip irrigation system to all plots on April 4.

Statistical Analysis

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

For each species, seed yields for each year were regressed separately against 1) applied water; 2) applied water plus spring precipitation; 3) applied water plus winter and spring precipitation; and 4) applied water plus fall, winter, and spring precipitation. Winter and spring precipitation occurred in the same year that yield was determined; fall precipitation occurred the prior year. Adding the seasonal precipitation to the irrigation response equation potentially could provide a closer estimate of the amount of water required for maximum seed yields of the *Lomatium* species. Regressions of seed yield each year were calculated on all the sequential seasonal amounts of precipitation and irrigation, but only some of the regressions are reported below. The period of precipitation plus applied water that had the lowest standard deviation for irrigation plus precipitation over the years was chosen as the most reliable independent variable for predicting seed yield. For species with few years where a yield response to irrigation existed, yield responses are reported as a function of water applied.

Results and Discussion

Spring precipitation in 2012, 2015, and 2016 was close to the average of 2.8 inches (Table 3). Spring precipitation in 2009-2011, and 2017 was higher, and spring precipitation in 2007, 2008, 2013, and 2014 was lower than average. The accumulated growing degree-days (50-86°F) from January through June in 2006, 2007, and 2013-2016 were higher than average (Table 2). The high accumulated growing degree-days in 2015 probably caused early harvest dates (Table 2).

Flowering and Seed Set

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

Seed Yields

Fernleaf Biscuitroot

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

Seed yields of fernleaf biscuitroot showed a quadratic response to irrigation rate plus spring precipitation from 2009 to 2011 and 2013 to 2015, and 2017 (Tables 4 and 6). In 2012, seed yields of fernleaf biscuitroot did not respond to irrigation. In 2016, seed yield increased linearly with increasing irrigation rate plus spring precipitation. Averaged over the 8 years, seed yield showed a quadratic response to irrigation rate plus spring precipitation and was estimated to be maximized at 999 lb/acre/year by spring precipitation plus irrigation of 9.5 inches.

Fernleaf Biscuitroot Riggins Selection
The Riggins selection fernleaf biscuitroot started flowering in 2013, but only in small amounts. Seed yields of this selection showed a quadratic response to irrigation rate plus spring precipitation in 2014 and 2016 (Tables 5 and 7). Seed yields were estimated to be maximized by 6.5 inches of applied water plus spring precipitation in 2014. Seed was inadvertently not harvested in 2015. In 2016, seed yields were estimated to be maximized by 7.5 inches of applied water plus spring precipitation. In 2017, seed yields were estimated to be maximized by 8 inches of applied water plus spring precipitation. Over years, seed yields were estimated to be maximized by 9.3 inches of applied water plus spring precipitation.

Fernleaf Biscuitroot Selections 38 and 41
Fernleaf biscuitroot 38 and 41started flowering in 2013, but only in small amounts. Seed yields of fernleaf biscuitroot 38 did not respond to irrigation in 2014-2017 (Tables 5 and 7) and seed yields of fernleaf biscuitroot 41 did not respond to irrigation in 2014 and 2016. In 2015 and 2017, seed yields of fernleaf biscuitroot 41 showed a quadratic response to irrigation rate (Tables 5 and 7). Seed yields of fernleaf biscuitroot 41 were estimated to be maximized by 8.1 inches of applied water plus spring precipitation in 2015 and by 10.4 inches of applied water plus spring precipitation in 2017. Over years, seed yields were estimated to be maximized by 7.7 inches of applied water plus spring precipitation.

Gray's Biscuitroot
Seed yields of Gray's biscuitroot showed a quadratic response to irrigation rate plus fall, winter, and spring precipitation in all years from 2007 through 2017, except in 2007, 2009, 2013, and 2017 (Tables 4 and 6). In 2007, 2009, and 2013, seed yield showed a positive linear response to water applied plus precipitation. In 2010, 2011, and 2017 seed yields were not responsive to irrigation. In 2010, seed yield was not responsive to irrigation, possibly because of the unusually wet spring of 2010. Rodent damage was a further complicating factor in 2010 that compromised seed yields. Extensive vole damage occurred over the 2009-2010 winter. The affected areas were transplanted with 3-year-old Gray's biscuitroot plants from an adjacent area in the spring of 2010. To reduce the habitat attractiveness to voles, all of the *Lomatium* plants were mowed after becoming dormant in early fall of 2010 and in each subsequent year. In 2011 and 2017, seed yield again did not respond to irrigation. The spring of 2011 was unusually cool and wet and the winter and spring of 2017 had higher than average precipitation. On average, seed yields of Gray's biscuitroot were maximized at 730 lb/acre by 14.3 inches of applied water plus fall, winter, and spring precipitation.

Nineleaf Biscuitroot
Seed yields of nineleaf biscuitroot showed a quadratic response to irrigation plus spring precipitation from 2008 through 2013 (Tables 4 and 6). In 2007, and 2014-2016, seed yield showed a positive linear response to water applied plus spring precipitation. In 2017, seed yields were not responsive to irrigation, probable due to heavy winter and spring precipitation. On average, seed yields of nineleaf biscuitroot were maximized at 1,213 lb/acre by 12.4 inches of applied water plus spring precipitation.

Barestem Biscuitroot

Seed yields did not respond to irrigation from 2012 to 2016 (Tables 4 and 6). In 2017, seed yields showed a quadratic response to irrigation rate. Seed yields in 2017 were 212 lb/acre with 8 inches of applied water.

Suksdorf's Desertparsley

Suksdorf's desertparsley started flowering in 2013, but only in small amounts. In the 4 years that seed was harvested, seed yields of Suksdorf's desertparsley responded to irrigation only in 2015 (Tables 5 and 7). In 2015, seed yield increased linearly with increasing water applied up to the highest amount of water applied, 8 inches.

Conclusions

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

Due to the arid environment, supplemental irrigation may often be required for successful flowering and seed set because soil water reserves may be exhausted before seed formation. The total irrigation requirements for these arid-land species were low and varied by species (Table 8). Barestem biscuitroot and Suksdorf's desertparsley did not respond to irrigation most years; natural rainfall was sufficient to maximize its seed production in the absence of weed competition. Fernleaf biscuitroot required approximately 6 inches of irrigation; Gray's biscuitroot and nineleaf biscuitroot responded quadratically to irrigation with the optimum varying by year. Accounting for precipitation improved the accuracy in the estimates of irrigation necessary for optimal seed production for Gray's biscuitroot, nineleaf biscuitroot, and fernleaf biscuitroot.

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.

Acknowledgements

This project was funded by the U.S. Forest Service(USFS) Great Basin Native Plant Project (GBNPP) , U.S. Bureau of Land Management (BLM), Oregon State University (OSU), Malheur County Education Service District, and supported by Formula Grant nos. 2017-31100-06041 and 2017-31200-06041 from the USDA National Institute of Food and Agriculture (NIFA).

Table 2. *Lomatium* flowering, irrigation, and seed harvest dates by species in 2006-2017, Malheur Experiment Station, Oregon State University (OSU), Ontario, OR. Continued on next page.

		Flowering			Irrigation		
Species	Year	Start	Peak	End	Start	End	Harvest
Fernleaf biscuitroot	2006	No flowering			19-May	30-Jun	
	2007	No flowering			5-Apr	24-Jun	
	2008	Very little flowering			10-Apr	29-May	
	2009	10-Apr		7-May	20-Apr	28-May	16-Jun
	2010	25-Apr		20-May	15-Apr	28-May	21-Jun
	2011	8-Apr	25-Apr	10-May	21-Apr	7-Jun	20-Jun
	2012	9-Apr	16-Apr	16-May	13-Apr	24-May	4-Jun
	2013	10-Apr		25-Apr	4-Apr	16-May	4-Jun
	2014	28-Mar		21-Apr	7-Apr	20-May	2-Jun
	2015	1-Apr		24-Apr	1-Apr	13-May	26-May (0 in), 1-Jun (4, 8 in)
	2016	25-Mar		24-Apr	31-Mar	9-May	26-May
	2017	7-Apr		8-May	19-Apr	6-Jun	6-Jun
Gray’s biscuitroot	2006	No flowering			19-May	30-Jun	
	2007	5-Apr		10-May	5-Apr	24-Jun	30-May, 29-Jun
	2008	25-Mar		15-May	10-Apr	29-May	30-May, 19-Jun
	2009	10-Mar		7-May	20-Apr	28-May	16-Jun
	2010	15-Mar		15-May	15-Apr	28-May	22-Jun
	2011	1-Apr	25-Apr	13-May	21-Apr	7-Jun	22-Jun
	2012	15-Mar	25-Apr	16-May	13-Apr	24-May	14-Jun
	2013	15-Mar		30-Apr	4-Apr	16-May	10-Jun
	2014	28-Mar		2-May	7-Apr	20-May	10-Jun
	2015	1-Mar		28-Apr	1-Apr	13-May	1-Jun
	2016	7-Mar		29-Apr	31-Mar	9-May	1-Jun
	2017	15-Mar		12-May	19-Apr	6-Jun	8-Jun
Nineleaf biscuitroot	2006	No flowering			19-May	30-Jun	
	2007	25-Apr		1-Jun	5-Apr	24-Jun	29-Jun, 16-Jul
	2008	25-Apr		5-Jun	10-Apr	29-May	3-Jul
	2009	10-Apr	7-May	1-Jun	20-Apr	28-May	26-Jun
	2010	25-Apr		15-Jun	15-Apr	28-May	22-Jul
	2011	30-Apr	23-May	15-Jun	21-Apr	7-Jun	26-Jul
	2012	12-Apr	17-May	6-Jun	13-Apr	24-May	21-Jun
	2013	18-Apr		10-May	4-Apr	16-May	4-Jun
	2014	7-Apr	29-Apr	2-May	7-Apr	20-May	4-Jun
	2015	10-Apr	28-Apr	20-May	1-Apr	13-May	7-Jun (0 in), 15-Jun (4, 8 in)
	2016	11-Apr	28-Apr	20-May	31-Mar	9-May	15-Jun
	2017	24-Apr	15-May	30-May	19-Apr	6-Jun	27-Jun

Table 2. Continued. *Lomatium* flowering, irrigation, and seed harvest dates by species in 2006-2017, Malheur Experiment Station, Oregon State University (OSU), Ontario, OR.

		Flowering			Irrigation		
Species	Year	Start	Peak	End	Start	End	Harvest
Barestem biscuitroot	2011	No flowering					
	2012	12-Apr	1-May	30-May	18-Apr	30-May	22-Jun
	2013	11-Apr		20-May	12-Apr	22-May	10-Jun
	2014	7-Apr		13-May	7-Apr	20-May	16-Jun
	2015	25-Mar		5-May	1-Apr	13-May	8-Jun
	2016	5-Apr		5-May	11-Apr	23-May	6-Jun
	2017	12-Apr		15-May	19-Apr	6-Jun	19-Jun
Suksdorf’s desertparsley	2013	18-Apr		23-May			
	2014	15-Apr		20-May	7-Apr	20-May	30-Jun
	2015	3-Apr	27-Apr	10-May	1-Apr	13-May	23-Jun
	2016	5-Apr	27-Apr	31-May	11-Apr	23-May	28-Jun
	2017	17-Apr		2-Jun	19-Apr	6-Jun	19-Jun

Table 3. Precipitation and growing degree-days at the Malheur Experiment Station, Oregon State University (OSU), Ontario, OR, 2006-2017.

	Precipitation (inch)			Growing degree-days (50 – 86°F)
Year	Spring	Winter + spring	Fall + winter + spring	Jan – June
2006	3.4	10.1	14.5	1273
2007	1.9	3.8	6.2	1406
2008	1.4	3.2	6.7	1087
2009	4.1	6.7	8.9	1207
2010	4.3	8.4	11.7	971
2011	4.8	9.3	14.5	856
2012	2.6	6.1	8.4	1228
2013	0.9	2.4	5.3	1319
2014	1.7	5.1	8.1	1333
2015	3.2	5.9	10.4	1610
2016	2.2	5.0	10.1	1458
2017	4.0	9.7	12.7	1196
12-year average:	2.9	6.3	9.8	23-year average: 1207

Table 4. Seed yield response to irrigation rate (inches/season) for four *Lomatium* species in 2006 through 2017. Malheur Experiment Station, Oregon State University (OSU), Ontario, OR.

		Irrigation Rate						Irrigation Rate			
Species	Year	0 inches	4 inches	8 inches	LSD (0.05)	Species	Year	0 inches	4 inches	8 inches	LSD (0.05)
Fernleaf biscuitroot		--------- lb/acre -----				Gray's biscuitroot		---------- lb/acre ----------			
	2006	---- no flowering ----					2006	---- no flowering ----			
	2007	---- no flowering ----					2007	36.1	88.3	131.9	77.7[b]
	2008	- very little flowering -					2008	393.3	1287	1444.9	141.0
	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	672.0
	2015	591.2	1094.7	1376.0	348.7		2015	186.4	576.7	297.6	213.9
	2016	1039.4	1612.7	1745.4	564.2		2016	483.7	644.2	322.9	218.7
	2017	488.2	713.1	674.4	220.5[b]		2017	333.5	259.5	246.3	NS
	9-year average	474.7	923.3	968.5	137.1		12-year average	438.4	718.9	621.6	210.5

		Irrigation Rate						Irrigation Rate			
Species	Year	0 inches	4 inches	8 inches	LSD (0.05)	Species	Year	0 inches	4 inches	8 inches	LSD (0.05)
Barestem biscuitroot		---------- lb/acre ----------				Nineleaf biscuitroot		---------- lb/acre ----------			
							2006	---- no flowering ----			
							2007	2.3	17.5	26.7	16.9[b]
							2008	195.3	1060.9	1386.9	410.0
							2009	181.6	780.1	676.1	177.0
	2010	---- no flowering ----					2010	1637.2	2829.6	3194.6	309.4
	2011	---- no flowering ----					2011	1982.9	2624.5	2028.1	502.3[b]
	2012	53.8	123.8	61.1	NS		2012	238.7	603	733.2	323.9
	2013	357.6	499.1	544.0	NS		2013	153.7	734.4	1050.9	425.0
	2014	701.3	655.6	590.9	NS		2014	240.6	897.1	1496.7	157.0
	2015	430.6	406.1	309.3	NS		2015	403.2	440.8	954.9	446.6
	2016	363.0	403.7	332.5	NS		2016	395.0	475.7	638.4	175.7
	2017	53.7	159.7	212.0	49.7		2017	932.8	948.9	1266.2	216.8
	6-year average	326.7	374.7	341.6	NS		11-year average	578.5	1037.5	1211.2	128.2

[a] LSD (0.10)

Table 5. Seed yield response to irrigation rate (inches/season) for two *Lomatium* species in 2014-2017. Malheur Experiment Station, Oregon State University (OSU), Ontario, OR.

		Irrigation Rate			
Species	Year	0 inches	4 inches	8 inches	LSD (0.05)
		---------- lb/acre ----------			
Fernleaf biscuitroot 'Riggins'	2014	276.8	497.7	398.4	163
	2016	299.1	679.5	592.4	247.4
	2017	315.1	405.1	440.0	87.4
3-year average		297.0	527.4	476.9	141.8
Fernleaf biscuitroot '38'	2014	281.9	356.4	227.1	NS
	2015	865.1	820.9	774.6	NS
	2016	474.8	634.5	620.0	70.3
	2017	398.8	575.0	553.2	NS
4-year average		508.4	596.7	523.7	NS
Fernleaf biscuitroot '41'	2014	222.2	262.4	149.8	NS
	2015	152.2	561.9	407.4	181.4
	2016	238.1	297.7	302.0	NS
	2017	214.9	363.0	377.5	71.0
4-year average		206.9	371.2	309.2	124.8
Suksdorf's desertparsley	2014	162.6	180.0	139.8	NS
	2015	829.6	1103.9	1832.0	750.2
	2016	692.6	898.8	467.5	NS
	2017	1315.5	1736.6	1315.5	NS
4-year average		1025.7	979.8	1025.7	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 2006-2017, and 9- to 11-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 Exp. Station, Oregon State Univ., Ontario, OR.

Fernleaf biscuitroot

Year	intercept	linear	quadratic	R^2	*P*	Maximum yield	Water applied plus spring precipitation for maximum yield	Spring precipitation
						lb/acre	inches/season	inch
2009	-922.0	307.9	-16.9	0.60	0.05	478	9.1	4.1
2010	-178.3	128.3	-5.9	0.51	0.05	514	10.8	4.3
2011	-1669.6	618.7	-31.4	0.86	0.001	1380	9.9	4.8
2012	293.9	43.4	-2.8	0.07	NS			2.6
2013	407.0	148.1	-7.0	0.68	0.01	1186	10.5	0.9
2014	9.7	211.4	-7.4	0.83	0.001	1524	14.3	1.7
2015	24.5	198.4	-6.9	0.78	0.01	1441	14.3	3.2
2016	916.9	88.2		0.42	0.05	1623	10.2	2.2
2017	134.7	139.9	-8.2	0.40	0.10	730	8.5	4.0
Average	-146.8	240.2	-12.6	0.91	0.001	999	9.5	2.9

Gray's biscuitroot

Year	intercept	linear	quadratic	R^2	*P*	Maximum yield	Water applied plus fall, winter, and spring precipitation for maximum yield	Spring, winter, fall precipitation
						lb/acre	inches/season	inch
2007	-36.6	12.0		0.26	0.10	59	14.2	6.19
2008	-2721.1	621.3	-23.0	0.93	0.001	1475	13.5	6.65
2009	17.8	40.8		0.38	0.05	344	16.8	8.8
2010	-2431.4	495.9	-17.1	0.22	NS			11.7
2011	-1335.1	234.7	-7.1	0.07	NS			14.5
2012	-778.8	172.8	-6.2	0.66	0.01	418	13.8	8.4
2013	344.3	55.0		0.25	0.10	1075	13.3	5.3
2014	-4502.3	890.8	-33.2	0.64	0.05	1477	13.4	8.1
2015	-3980.4	617.7	-20.9	0.71	0.01	579	14.8	10.4
2016	-2046.2	403.1	-15.1	0.66	0.01	651	13.4	9.1
2017	461.9	-10.9		0.22	NS			12.7
Average	-1690.8	337.9	-11.8	0.55	0.05	730	14.3	9.8

Nineleaf biscuitroot

Year	intercept	linear	quadratic	R^2	*P*	Maximum yield	Water applied plus spring precipitation for maximum yield	Spring precipitation
						lb/acre	inches/season	inch
2007	-2.6	3.1		0.52	0.01	28	9.9	1.92
2008	-245.1	332.1	-16.9	0.77	0.01	1390	9.8	1.43
2009	-1148.3	416.1	-22.0	0.83	0.001	824	9.5	4.1
2010	-586.2	625.4	-25.9	0.83	0.001	3196	12.1	4.3
2011	-400.3	684.1	-38.7	0.45	0.10	2623	8.8	4.8
2012	-123.6	158.4	-7.3	0.52	0.05	734	10.8	2.6
2013	-3.8	192.2	-8.3	0.68	0.01	1115	11.6	0.9
2014	-22.7	157.4		0.97	0.001	1509	9.7	1.7
2015	101.8	69.0		0.51	0.01	875	11.2	3.2
2016	313.9	30.4		0.29	0.10	624	10.2	2.2
2017	717.1	41.7		0.20	NS	1217	12.0	4.0
Average	-159.2	221.2	-8.9	0.81	0.001	1213	12.4	2.9

Table 7. Regression analysis for seed yield response to irrigation rate (inches/season) in 2012-2017 for barestem biscuitroot, Suksdorf's desertparsley, and three selections of fernleaf biscuitroot planted in 2009. For the quadratic equations, the amount of irrigation that resulted in maximum yield was calculated using the formula: -b/2c, where b is the linear parameter and c is the quadratic parameter. Malheur Experiment Station, Oregon State University (OSU), Ontario, OR.

Barestem biscuitroot

Year	intercept	linear	quadratic	R^2	*P*	Maximum yield	Water applied for maximum yield
						lb/acre	inches/season
2012	53.8	34.1	-4.1	0.18	NS		
2013	357.6	47.5	-3.0	0.11	NS		
2014	704.5	-13.8		0.08	NS		
2015	430.6	2.9	-2.3	0.15	NS		
2016	363.0	24.1	-3.5	0.07	NS		
2017	53.7	33.2	-1.7	0.75	0.01	218	9.9
Average	399.2	-1.2		0.01	NS		

Suksdorf's desertparsley

Year	intercept	linear	quadratic	R^2	*P*	Maximum yield	Water applied for maximum yield
						lb/acre	inches/season
2014	162.6	11.5	-1.8	0.01	NS		
2015	753.9	125.3		0.43	0.05	1756	8.0
2016	692.6	131.2	-19.9	0.17	NS		
2017	750.7	422.4	-44.0	0.39	NS		
Average	608.9	133.4	-10.2	0.28	NS		

Fernleaf biscuitroot 'Riggins'

Year	intercept	linear	quadratic	R^2	*P*	Maximum yield	Water applied plus spring precipitation for maximum yield	Spring precipitation
						lb/acre	inches/season	inch
2014	82.1	129.9	-10.0	0.57	0.05	503	6.5	1.7
2016	-113.8	218.4	-14.6	0.63	0.05	703	7.5	2.2
2017	262.3	15.6		0.37	0.05	387	8.0	4.0
Average	-209.5	162.4	-8.8	0.65	0.01	542	9.3	2.8

Fernleaf biscuitroot '38'

Year	intercept	linear	quadratic	R^2	*P*	Maximum yield	Water applied for maximum yield	Spring precipitation
						lb/acre	inches/season	inch
2014	281.9	44.1	-6.4	0.11	NS			1.7
2015	865.4	-11.3		0.01	NS			3.2
2016	474.8	61.7	-5.4	0.32	NS			2.2
2017	398.8	68.8	-6.2	0.38	NS			4.0
Average	508.4	42.2	-5.0	0.1	NS			2.8

Fernleaf biscuitroot '41'

Year	intercept	linear	quadratic	R^2	*P*	Maximum yield	Water applied plus spring precipitation for maximum yield	Spring precipitation
						lb/acre	inches/season	inch
2014	222.2	29.1	-4.8	0.13	NS			1.7
2015	-587.4	286.5	-17.6	0.67	0.01	576	8.1	3.2
2016	181.3	29.4	-1.7	0.18	NS			2.2
2017	-64.2	86.9	-4.2	0.70	0.01	388	10.4	4.0
Average	-41.3	108.7	-7.1	0.49	0.05	377	7.7	2.8

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

Species	Optimum amount of irrigation plus precipitation	Critical precipitation period	Years to first seed set	Life span
	inches		from fall planting	years
Fernleaf biscuitroot	7.7-9.5[a]	spring	4	9+
Gray’s biscuitroot	14.3	fall, winter, and spring	2	9+
Barestem biscuitroot	no response in 5 out of 6 years, 8 inches in 2017		3	4+
Nineleaf biscuitroot	12.4	spring	2	9+
Suksdorf’s desertparsley	no response in 2014, 2016, and 2017, 8 inches irrigation in 2015	undetermined	5	5+

[a]The amount of recommended irrigation p

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

Clinton C. Shock, Erik B. G. Feibert, Alicia Rivera, and Lamont D. Saunders, Malheur Experiment Station, Oregon State University (OSU), Ontario, OR, 2017

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

Summary

Native buckwheats (*Eriogonum* spp.) are important perennials in the Intermountain West. Buckwheat seed is desired for rangeland restoration activities, but little cultural practice information is available for seed production of native buckwheat. The seed yield of sulphur-flower buckwheat (*Eriogonum umbellatum*) and parsnipflower buckwheat (*E. heracleoides*) were evaluated over multiple years in response to four biweekly irrigations applying either 0, 1, or 2 inches of water (total of 0, 4, or 8 inches/season). Seed yield of sulphur-flower buckwheat responded to irrigation plus spring precipitation in 10 of the 11 years, with 5 to 11 inches of water applied plus spring precipitation maximizing yields, depending on year. Averaged over 11 years, seed yield of sulphur-flower buckwheat showed a quadratic response to irrigation rate plus spring precipitation and was estimated to be maximized at 232 lb/acre/year by irrigation plus spring precipitation of 9.4 inches. Over six seasons, seed yield of parsnipflower buckwheat was responsive to irrigation only in 2013, a dry year when seed yield was maximized by 4.9 inches of applied water. Averaged over 6 years, seed yield of parsnipflower buckwheat showed a quadratic response to irrigation rate with the highest yield achieved with 5 inches of water applied.

Introduction

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

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

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

Materials and Methods

Plant Establishment

Seed of sulphur-flower buckwheat was received in late November in 2004 from the RMRS (Boise, ID). The plan was to plant the seed in the fall of 2004, but due to excessive rainfall in October, the ground preparation was not completed and planting was postponed to early 2005. To try to ensure germination, the seed was submitted to cold stratification. The seed was soaked overnight in distilled water on January 26, 2005, after which the water was drained and the seed soaked for 20 min in a 10% by volume solution of 13% bleach in distilled water. The water was drained and the seed was placed in thin layers in plastic containers. The plastic containers had lids with holes drilled in them to allow air movement. These containers were placed in a cooler set at approximately 34°F. Every few days the seed was mixed and, if necessary, distilled water added to maintain seed moisture.

In late February 2005, drip tape (T-Tape TSX 515-16-340) was buried at 12-inch depth between two 30-inch rows of a Nyssa silt loam with a pH of 8.3 and 1.1% organic matter. The drip tape was buried in alternating inter-row spaces (5 ft apart). The flow rate for the drip tape was 0.34 gal/min/100 ft at 8 psi with emitters spaced 16 inches apart, resulting in a water application rate of 0.066 inch/hour.

On March 3, 2005, seed of sulphur-flower buckwheat 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 (R10 Turbo Rotator, Nelson Irrigation Corp., Walla Walla, WA) from March 4 to April 29 for even stand establishment. Risers were spaced 25 ft apart along the flexible polyethylene hose laterals that were spaced 30 ft apart and the water application rate was 0.10 inch/hour. A total of 1.72 inches of water was applied with the minisprinkler system. Sulphur-flower buckwheat started emerging on March 29. Starting June 24, the field was irrigated with the drip system. A total of 3.73 inches of water was applied with the drip system from June 24 to July 7. The field was not irrigated further in 2005.

Plant stands for sulphur-flower buckwheat were uneven, and it did not flower in 2005. In early October 2005, more seed was received from the RMRS for replanting. The empty lengths of 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 parsnipflower buckwheat. On November 25, 2009 seed of parsnipflower buckwheat was planted in 30-inch rows using a custom-made small-plot grain drill with disc openers. All seed was planted on the soil surface at 20-30 seeds/ft of row. After planting, sawdust was applied in a narrow band over the seed row at 0.26 oz/ft of row (558 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 parsnipflower buckwheat emerged, the row cover was removed in April 2010. The irrigation treatments were not applied to parsnipflower buckwheat in 2010, and stands were not adequate for yield estimates. Gaps in the rows were replanted by hand on November 5, 2010. The replanted seed was covered with a thin layer of a mixture of 50% sawdust and 50% hydro-seeding mulch (Hydrostraw LLC, Manteno, IL) by volume. The mulch mixture was sprayed with water using a backpack sprayer.

Irrigation for Seed Production

The planted strips were divided into plots 30 ft long (sulphur-flower buckwheat in April 2006 and parsnipflower buckwheat in April 2011). Each plot contained four rows of each species. The experimental designs were randomized complete blocks with four replicates. The three treatments were a non-irrigated check, 1 inch of water applied per irrigation, and 2 inches of water applied per irrigation. Each treatment received four irrigations that were applied approximately every 2 weeks starting at bud formation and flowering. The amount of water applied to each treatment was calculated by the length of time necessary to deliver 1 or 2 inches through the drip system. Irrigations were regulated with a controller and solenoid valves. Irrigation dates are found in Table 1.

Flowering, Harvesting, and Seed Cleaning

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

Cultural Practices 2006

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

Cultural Practices 2007

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

Cultural Practices 2008

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

Cultural Practices 2009

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

Cultural Practices 2010

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

Cultural Practices 2011

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

Cultural Practices 2012

November 7, Prowl at 1 lb ai/acre was broadcast on all plots of both species. In addition to herbicides, hand weeding was used as necessary to control weeds.

Cultural Practices 2013

On April 3, Select Max® at 32 oz/acre was broadcast for grass weed control on all plots of sulphur-flower buckwheat. In addition to herbicides, hand weeding was used as necessary to control weeds.

Cultural Practices 2014

On February 26, Prowl at 1 lb ai/acre and Select Max at 32 oz/acre were broadcast on all plots of both species. In addition to herbicides, hand weeding was used as necessary to control weeds.

Cultural Practices 2015

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

Cultural Practices 2016

On October 27, Prowl at 1 lb ai/acre was broadcast on all plots of sulphur-flower buckwheat and parsnipflower buckwheat. In addition to herbicides, hand weeding was used as necessary to control weeds.

Cultural Practices 2017

On April 21, Prowl at 1 lb ai/acre and Poast® at 30 oz/acre were broadcast on all plots of parsnipflower buckwheat. In addition to herbicides, hand weeding was used as necessary to control weeds.

Statistical Analysis

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

For each species, seed yields for each year were regressed separately against 1) applied water; 2) applied water plus spring precipitation; 3) applied water plus winter and spring precipitation; and 4) applied water plus fall, winter, and spring precipitation. Winter and spring precipitation occurred in the same year that yield was determined; fall precipitation occurred the prior year. Adding the seasonal precipitation to the irrigation response equation would have the potential to provide a closer estimate of the amount of water required for maximum seed yields of the *Eriogonum* species. Regressions of seed yield each year were calculated on all the sequential seasonal amounts of precipitation and irrigation, but only some of the regressions are reported below. The period of precipitation plus applied water that had the lowest standard deviation for irrigation plus precipitation over the years was chosen as the most reliable independent variable for predicting seed yield.

Results and Discussion

Spring precipitation in 2009, 2012, and 2014 was close to the average of 5.8 inches (Table 2). Spring precipitation in 2009, 2010, 2011, and 2017 was higher than the average and spring precipitation in 2007, 2008, 2013, and 2014 was lower than the average of 2.9 inches. The accumulated growing degree-days (50-86°F) from January through June in 2007, and 2013-2016 were higher than average (Table 2). Both buckwheats flowered and were harvested earlier in 2013-2016 than in 2011-2012 (Table 1), consistent with more early season growing degree-days (Table 2).

Seed Yields

Sulfur-flower Buckwheat

Seed yield of sulphur-flower buckwheat exhibited a positive linear response to irrigation rate in 2006 (Tables 3 and 4). In 2007-2009, and 2012-2016 seed yield showed a quadratic response to irrigation rate. In 2010 and 2017, there was no significant difference in yield between the irrigation treatments. In 2011, seed yield was highest with no irrigation. The 2010 and 2011 seasons had unusually cool and wet weather (Table 2). The accumulated spring plus winter precipitation in 2010, 2011, and 2017 was higher than average. The negative effect of irrigation on seed yield in 2011 might have been compounded by the presence of rust. Irrigation could have exacerbated the rust and resulted in lower yields.

Averaged over 12 years, seed yield showed a quadratic response to irrigation rate plus spring precipitation and was estimated to be maximized at 221 lb/acre/year by irrigation plus spring precipitation of 9.4 inches.

Parsnipflower Buckwheat

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

In 2013, seed yields showed a quadratic response to irrigation with a maximum seed yield at 4.9 inches of water applied. Seed yields did not respond to irrigation in 2011, 2012, 2014, 2015, 2016, and 2017 (Tables 3 and 4). Averaged over 7 years, seed yield of parsnipflower buckwheat showed a quadratic response to irrigation rate with the highest yield achieved with 5 inches of water applied.

Conclusions

The total irrigation requirements for these arid-land species were low and varied by species. Parsnipflower buckwheat responded to irrigation only in 2013, a drier than average year. In the other years, natural rainfall was sufficient to maximize seed production in the absence of weed competition. Seed yield of sulphur-flower buckwheat responded to irrigation plus spring precipitation in 10 of the 12 years, with irrigation plus spring precipitation of 9.4 inches maximizing yields. Buckwheat flowering and harvests have been earlier in 2013-2016 than in previous years, probably due to warmer weather.

Acknowledgements

This project was funded by the U.S. Forest Service (USFS) Great Basin Native Plant Project (GBNPP), U.S. Bureau of Land Management (BLM), Oregon State University (OSU), Malheur County Education Service District, and supported by Formula Grant nos. 2017-31100-06041 and 2017-31200-06041 from the USDA National Institute of Food and Agriculture (NIFA).

Table 1. Sulphur-flower buckwheat and parsnipflower buckwheat flowering, irrigation, and seed harvest dates by species in 2006-2017, Malheur Experiment Station, Oregon State University (OSU), Ontario, OR.

		Flowering dates			Irrigation dates		
Species	Year	Start	Peak	End	Start	End	Harvest
Sulphur-flower buckwheat	2006	19-May		20-Jul	19-May	30-Jun	3-Aug
	2007	25-May		25-Jul	2-May	24-Jun	31-Jul
	2008	5-Jun	19-Jun	20-Jul	15-May	24-Jun	24-Jul
	2009	31-May		15-Jul	19-May	24-Jun	28-Jul
	2010	4-Jun	15-Jun	15-Jul	28-May	8-Jul	27-Jul
	2011	8-Jun	30-Jun	20-Jul	20-May	5-Jul	1-Aug
	2012	30-May	20-Jun	4-Jul	30-May	11-Jul	24-Jul
	2013	8-May	27-May	27-Jun	8-May	19-Jun	9-Jul
	2014	20-May	4-Jun	1-Jul	13-May	24-Jun	10-Jul
	2015	13-May	26-May	25-Jun	29-Apr	10-Jun	2-Jul
	2016	16-May	26-May	25-Jun	27-Apr	7-Jun	1-Jul
	2017	25-May	7-Jun	10-Jul	23-May	6-Jul	26-Jul
Parsnipflower buckwheat	2011	26-May	10-Jun	8-Jul	27-May	6-Jul	1-Aug
	2012	23-May	30-May	25-Jun	11-May	21-Jun	16-Jul
	2013	29-Apr	13-May	10-Jun	24-Apr	5-Jun	1-Jul
	2014	1-May	20-May	12-Jun	29-Apr	10-Jun	3-Jul
	2015	24-Apr	5-May	17-Jun	15-Apr	27-May	24-Jun
	2016	26-Apr	6-May	16-Jun	18-Apr	31-May	23-Jun
	2017	10-May		30-Jun	2-May	20-Jun	26-Jul

Table 2. Precipitation and growing degree-days at the Malheur Experiment Station, Ontario, OR, 2006-2017.

	Precipitation (inch)			Growing degree-days (50 – 86°F)
Year	Spring	spring + winter	spring + winter + fall	Jan–June
2006	3.4	10.1	14.5	1273
2007	1.9	3.8	6.2	1406
2008	1.4	3.2	6.7	1087
2009	4.1	6.7	8.9	1207
2010	4.3	8.4	11.7	971
2011	4.8	9.3	14.5	856
2012	2.6	6.1	8.4	1228
2013	0.9	2.4	5.3	1319
2014	1.7	5.1	8.1	1333
2015	3.2	5.9	10.4	1610
2016	2.2	5.0	10.1	1458
2017	4.0	9.7	12.7	1196
12-year average:	2.9	6.3	9.8	23-year average: 1207

Table 3. Sulphur-flower buckwheat and parsnipflower buckwheat seed yield in response to irrigation rate (inches/season) in 2006 through 2017. Malheur Experiment Station, Oregon State University (OSU), Ontario, OR.

		Irrigation rate			
Species	Year	0 inches	4 inches	8 inches	LSD (0.05)
		------------------ lb/acre ----------------			
Sulphur-flower buckwheat	2006	155.3	214.4	371.6	92.9
	2007	79.6	164.8	193.8	79.8
	2008	121.3	221.5	245.2	51.7
	2009	132.3	223	240.1	67.4
	2010	252.9	260.3	208.8	NS[a]
	2011	248.7	136.9	121	90.9
	2012	61.2	153.2	185.4	84.4
	2013	113.2	230.1	219.8	77.5
	2014	257	441.8	402.7	82.9
	2015	136.4	124.4	90.7	NS
	2016	183.4	204.3	140.8	NS
	2017	115.6	116.4	96.5	NS
	Average	157.3	216.5	205.7	24.2
Parsnipflower buckwheat	2011	55.2	71.6	49	NS[a]
	2012	252.3	316.8	266.4	NS
	2013	287.4	516.9	431.7	103.2
	2014	297.6	345.2	270.8	NS
	2015	83.6	148.2	122.3	NS
	2016	421.6	486.9	437.2	NS
	2017	221.9	319.1	284.6	62.5
	Average	212.9	312.2	280.1	59.4

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

Table 4. Regression analysis for sulphur-flower buckwheat and parsnipflower buckwheat seed yield (y) in response to irrigation (x) (inches/season) using the equation $y = a + b \bullet x + c \bullet x^2$. 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 (OSU), Ontario, OR.

Sulphur-flower buckwheat

Year	intercept	linear	quadratic	R^2	*P*	Maximum yield	Water applied plus spring precipitation for maximum yield	Spring precipitation
						lb/acre	inches/season	inch
2006	66.6	22.9		0.52	0.05	328.0	11.4	3.4
2007	18.7	35.0	-1.8	0.69	0.05	193.8	10.0	1.9
2008	66.9	41.4	-2.4	0.73	0.01	246.6	8.7	1.4
2009	-35.6	50.6	-2.3	0.6	0.05	242.7	11.0	4.1
2010	178.5	25.2	-1.8	0.08	NS[a]			4.3
2011	308.9	-16.0		0.58	0.01	232.7	4.8	4.8
2012	-30.7	40.2	-1.9	0.65	0.01	185.4	10.7	2.6
2013	71.9	51.9	-4.0	0.62	0.05	241.3	6.5	0.9
2014	107.7	98.4	-7.0	0.76	0.01	453.7	7.0	1.7
2015	-35.7	70.4	-5.3	0.55	0.10	199.4	6.7	3.2
2016	96.3	48.9	-4.4	0.47	0.10	233.5	5.6	2.2
2017	94.2	7.9	-0.6	0.16	NS			4.0
Average	29.1	41.0	-2.2	0.73	0.01	220.7	9.4	2.9

Parsnipflower buckwheat

Year	intercept	linear	quadratic	R^2	*P*	Maximum yield	Water applied for maximum yield
						lb/acre	inches/season
2011	61.7	-0.8		0.01	NS		
2012	271.5	1.8		0.01	NS		
2013	287.4	96.7	-9.8	0.64	0.05	525.1	4.9
2014	297.6	27.2	-3.8	0.08	NS		
2015	83.6	27.5	-2.8	0.29	NS		
2016	421.6	30.7	-3.6	0.06	NS		
2017	221.9	40.7	-4.1	0.38	NS		
Average	212.9	41.2	-4.1	0.63	0.05	316.5	5.0

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

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

Clinton C. Shock, Erik B. G. Feibert, Alicia Rivera, and Lamont D. Saunders, Malheur Experiment Station, Oregon State University (OSU), Ontario, OR, 2017

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

Summary

Penstemon is an important wildflower genus in the Great Basin of the United States. Seed of *Penstemon* species is desired for rangeland restoration activities, but little cultural practice information is known for seed production of native *Penstemons*. The seed yield response of five *Penstemon* species to four biweekly irrigations applying either 0, 1, or 2 inches of water (a total of 0, 4, or 8 inches of water/season) was evaluated over multiple years. Sharpleaf penstemon (*Penstemon acuminatus*) seed yields were maximized by 4-8 inches of water applied per season in warmer, drier years and did not respond to irrigation in cooler, wetter years. In 7 years of testing, blue penstemon (*P. cyaneus*) responded to irrigation only in 2013, a dry year with 4 inches of water applied maximizing yields. In 7 years of testing, thickleaf beardtongue (*P. pachyphyllus*) seed yields responded to irrigation only in 2013 with 8 inches of water applied maximizing yields. In 7 years of testing, seed yields of scabland penstemon (*P. deustus*) responded to irrigation only in 2015, with highest yields resulting from 5.4 inches of water applied. From 2006 to 2017, royal penstemon (*P. speciosus*) showed a quadratic response to irrigation in 7 out of the 11 years. Royal penstemon showed either no response or a negative response to irrigation in three years with higher than average spring precipitation. Averaged over the 12 years of testing, royal penstemon seed yields were maximized by 8.8 inches of water applied plus spring precipitation.

Introduction

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

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

Native wildflower plants are not well adapted to croplands; they often do not compete with crop weeds in cultivated fields, and this could limit wildflower seed production. Both sprinkler and furrow irrigation could provide supplemental water for seed production, but these irrigation systems risk further encouraging weeds. Also, sprinkler and furrow irrigation can lead to the loss of plant stand and seed production due to fungal pathogens. By burying drip tapes at 12-inch depth and avoiding wetting the soil surface, we designed experiments to assure flowering and seed set without undue encouragement of weeds or opportunistic diseases. The trials reported here tested the effects of three low rates of irrigation on the seed yield of five species of *Penstemon* native to the Intermountain West (Table 1).

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

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

Materials and Methods

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

Seed of sharpleaf penstemon, scabland penstemon, and royal penstemon was received in late November in 2004 from the RMRS (Boise, ID). The plan was to plant the seed in the fall of 2004, but due to excessive rainfall in October, the ground preparation was not completed and planting was postponed to early 2005. To try to ensure germination, the seed was submitted to cold stratification. The seed was soaked overnight in distilled water on January 26, 2005, after which the water was drained and the seed soaked for 20 min in a 10% by volume solution of 13% bleach in distilled water. The water was drained and the seed was placed in thin layers in plastic containers. The plastic containers had lids with holes drilled in them to allow air movement. These containers were placed in a cooler set at approximately 34°F. Every few days the seed was mixed and, if necessary, distilled water added to maintain seed moisture.

In late February 2005, drip tape (T-Tape TSX 515-16-340) was buried at 12-inch depth between two 30-inch rows of a Nyssa silt loam with a pH of 8.3 and 1.1% organic matter. The drip tape was buried in alternating inter-row spaces (5 ft apart). The flow rate for the drip tape was 0.34 gal/min/100 ft at 8 psi with emitters spaced 16 inches apart, resulting in a water application rate of 0.066 inch/hour.

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

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

Cultural Practices in 2006

On October 27, 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

Sharpleaf penstemon and royal penstemon were sprayed with Aza-Direct® at 0.0062 lb ai/acre on May 14 and 29 for lygus bug control. Irrigations for each species were initiated and terminated on different dates (Table 2). On November 9, Prowl at 1 lb ai/acre was broadcast on all plots for weed control.

Cultural Practices in 2008

On April 15, 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 sharpleaf penstemon and royal penstemon on May 20 for lygus bug control. Irrigations for each species were initiated and terminated on different dates (Table 2). Due to substantial stand loss, all plots of scabland penstemon were disked out.

Cultural Practices in 2009

On March 18, Prowl at 1 lb ai/acre and Volunteer® at 8 oz/acre were broadcast on all plots for weed control. On December 4, 2009, Prowl at 1 lb ai/acre was broadcast for weed control on all plots.

Cultural Practices in 2010

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

Cultural Practices in 2011

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

Cultural Practices in 2013

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

Cultural Practices in 2014

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

Cultural Practices in 2015

On April 20, Orthene at 8 oz/acre was broadcast to all plots of royal penstemon for lygus bug control. Stand of royal penstemon was poor in 2015 due to die-off, especially in the plots with the highest irrigation rate. On November 2, seed of royal penstemon was planted on the soil surface at 30 seeds/ft of row. Following planting, the beds were covered with row cover. The row cover (N-sulate, DeWitt Co., Inc., Sikeston, MO) covered four rows (two beds) and was applied with a mechanical plastic mulch layer.

Cultural Practices in 2016

On March 2, Poast® at 30 oz/acre was broadcast on all plots for grass control. On October 27, Prowl at 1 lb ai/acre was broadcast on all plots for weed 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 royal penstemon have regenerated by natural reseeding, but replanting was required in 2015. Prowl was not applied after 2011 to encourage natural reseeding.

While natural reseeding might be advantageous for maintaining stands for irrigation research, it might be disadvantageous for seed production, because of changes in the genetic composition of the stand over time.

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

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

Cultural Practices in 2010

After the newly planted wildflowers had emerged, the row cover was removed in April. The irrigation treatments were not applied to these wildflowers in 2010. Stands of blue penstemon and thickleaf beardtongue were not adequate for yield estimates.

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

Cultural Practices in 2011

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

Cultural Practices in 2012

Many areas of the wildflower seed production were suffering from severe iron deficiency early in the spring of 2012. On April 13, 50 lb nitrogen/acre, 10 lb P/acre, and 0.3 lb Fe/acre was applied to all plots as liquid fertilizer injected through the drip tape. On April 23, 0.3 lb Fe/acre was applied to all plots as liquid fertilizer injected through the drip tape.

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

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

Cultural Practices in 2014
On April 29, 0.3 lb Fe/acre was applied through the drip tape to all plots.
Seed of scabland penstemon was harvested with a small plot combine. Seed of the other species was harvested manually.

Cultural Practices in 2015
Seed of scabland penstemon was harvested with a small plot combine. Seed of the other species was harvested manually.
Stands of scabland penstemon and royal penstemon were poor at the end of 2015 due to die-off. On November 5, seed of scabland penstemon and royal penstemon was planted on the soil surface at 30 seeds/ft of row. Following planting, the beds were covered with row cover. The row cover (N-sulate) covered four rows (two beds) and was applied with a mechanical plastic mulch layer.
Stands of blue penstemon and thickleaf beardtongue are currently poor, but might regenerate from natural reseeding. While natural reseeding might be advantageous for maintaining stands for irrigation research, natural reseeding might be disadvantageous for seed production, because of changes in the genetic composition of the stand over time. Weeds were controlled each year by handweeding.

Cultural Practices in 2016
On October 27, Prowl at 1 lb ai/acre was broadcast on all plots for weed control.

Irrigation for Seed Production
In April 2006, each planted strip of sharpleaf penstemon, scabland penstemon, and royal penstemon was divided into plots 30 ft long. Each plot contained four rows of each species. The experimental designs were randomized complete blocks with four replicates. The three treatments were a nonirrigated check, 1 inch of water applied per irrigation, and 2 inches of water applied per irrigation. Each treatment received four irrigations that were applied approximately every 2 weeks starting with bud formation and flowering. The amount of water applied to each treatment was calculated by the length of time necessary to deliver 1 or 2 inches through the drip system. Irrigations were regulated with a controller and solenoid valves. After each irrigation, the amount of water applied was read on a water meter and recorded to ensure correct water applications.
In March of 2007, the drip-irrigation system was modified to allow separate irrigation of the species due to different timings of flowering. Scabland penstemon and royal penstemon were irrigated together, but separately from sharpleaf penstemon.
Irrigation dates are found in Table 2. In 2007, irrigation treatments were inadvertently continued after the fourth irrigation. Irrigation treatments for all species were continued until the last irrigation on June 24, 2007.

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

Flowering, Harvesting, and Seed Cleaning

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

All species were harvested with a Wintersteiger small plot combine. Scabland penstemon seed pods were too hard to be opened in the combine; the unthreshed seed was precleaned in a small clipper seed cleaner and then seed pods were broken manually by rubbing the pods on a ribbed rubber mat. The seed was then cleaned again in the small clipper seed cleaner. The other species were threshed in the combine and the seed was further cleaned using a small clipper seed cleaner. Seed of blue penstemon, thickleaf beardtongue, and royal penstemon were harvested by hand when stands became too poor for combining.

Statistical Analysis

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

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

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

Results and Discussion

Precipitation showed large year to year variation over the 12 years of irrigation trials (Table 3). The accumulated growing degree-days (50-86°F) from January through June in 2006, 2007, and 2013-2016 were higher than average (Table 3).

Flowering and Seed Set

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

Seed Yields

Royal Penstemon

In 2006-2009, 2012, 2014, and 2015, seed yield of royal penstemon showed a quadratic response to irrigation rate plus spring precipitation (Tables 4 and 5). Seed yields were maximized by 7.7, 6.1, 6.4, 8.3, 6.5, 6.9, and 8.2 inches of water applied plus spring precipitation in 2006, 2007, 2008, 2009, 2012, 2014, and 2015, respectively. In 2011 and 2017 there was no difference in seed yield between treatments. In 2010, seed yields were highest with no irrigation and 4.3 inches of spring precipitation. In 2013, seed yield increased with increasing water application, up to 8.9 inches, the highest amount tested (includes 0.9 inches of spring precipitation). Seed yield was low in 2007 due to lygus bug damage, as discussed previously. Seed yield in 2009 was low due to stand loss from root rot. The plant stand recovered somewhat in 2010 and 2011, due in part to natural reseeding, especially in the non-irrigated plots. The replanting of royal penstemon in the fall of 2015 resulted in a good stand in 2016. The new stand of royal penstemon did not flower in 2016.

Sharpleaf Penstemon

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

Blue Penstemon

From 2011 to 2017, seed yields were only responsive to irrigation in 2013 (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.

Scabland Penstemon

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

Thickleaf Beardtongue

From 2011 to 2017, seed yields only responded to irrigation in 2013 (Tables 4 and 5). In 2013, seed yields increased with increasing irrigation up to the greatest level of 8 inches.

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 was occasionally required for successful flowering and seed set. The total irrigation requirements for these semi-arid-land species were low and varied by species and years. In 4 years of testing, sharpleaf penstemon showed a quadratic response to irrigation in 2007 and 2008 and a negative response to irrigation in 2009. The years 2007 and 2008 had lower than average spring precipitation. From 2011 to 2017, blue penstemon and thickleaf beardtongue only responded to irrigation in 2013, which had the lowest spring precipitation of the seven years. From 2006 to 2017, royal penstemon showed a quadratic response to irrigation in 7 out of the 11 years. Similar to thickleaf beardtongue and blue penstemon, royal penstemon showed a positive linear response to irrigation in 2013. Royal penstemon showed either no response or a negative response to irrigation in three years with higher than average spring precipitation.

Acknowledgements

This project was funded by the U.S. Forest Service (USFS) Great Basin Native Plant Project (GBNPP), U.S. Bureau of Land Management (BLM), Oregon State University (OSU), Malheur County Education Service District, and was supported by Formula Grant nos. 2017-31100-06041 and 2017-31200-06041 from the USDA National Institute of Food and Agriculture (NIFA).

Table 2. *Penstemon* flowering, irrigation, and seed harvest dates by species in 2006-2017, Malheur Experiment Station, Oregon State University (OSU), Ontario, OR.

		Flowering dates			Irrigation dates		
Species	Year	Start	Peak	End	Start	End	Harvest
Sharpleaf penstemon	2006	2-May	10-May	19-May	19-May	30-Jun	7-Jul
	2007	19-Apr		25-May	19-Apr	24-Jun	9-Jul
	2008	29-Apr		5-Jun	29-Apr	11-Jun	11-Jul
	2009	2-May		10-Jun	8-May	12-Jun	10-Jul
Blue penstemon	2011	23-May	15-Jun	8-Jul	13-May	23-Jun	18-Jul
	2012	16-May	30-May	10-Jun	27-Apr	7-Jun	27-Jun
	2013	3-May	21-May	5-Jun	24-Apr	5-Jun	11-Jul
	2014	5-May	13-May	8-Jun	29-Apr	10-Jun	14-Jul
	2015	5-May		12-Jun	21-Apr	3-Jun	13-Jul
	2016	29-Apr		15-Jun	18-Apr	31-May	8-Jul
	2017	8-May	15-May	7-Jun	2-May	20-Jun	17-Jul
Scabland penstemon	2006	10-May	19-May	30-May	19-May	30-Jun	4-Aug
	2007	5-May	25-May	25-Jun	19-Apr	24-Jun	
	2008	5-May		20-Jun	18-Apr	31-May	
	2011	23-May	20-Jun	14-Jul	13-May	23-Jun	16-Aug
	2012	16-May	30-May	4-Jul	27-Apr	7-Jun	7-Aug
	2013	3-May	18-May	15-Jun	24-Apr	5-Jun	
	2014	10-May	20-May	19-Jun	29-Apr	10-Jun	21-Jul
	2015	1-May		10-Jun	21-Apr	3-Jun	23-Jul
	2016	no flowering			18-Apr	31-May	
	2017	15-May	7-Jun	30-Jun	2-May	20-Jun	1-Aug
Thickleaf beardtongue	2011	10-May	30-May	20-Jun	13-May	23-Jun	15-Jul
	2012	23-Apr	2-May	10-Jun	27-Apr	7-Jun	26-Jun
	2013	26-Apr		21-May	24-Apr	5-Jun	8-Jul
	2014	22-Apr	5-May	4-Jun	29-Apr	10-Jun	13-Jul
	2015	24-Apr	5-May	26-May	21-Apr	3-Jun	10-Jul
	2016	18-Apr		13-May	18-Apr	31-May	22-Jun
	2017	1-May	15-May	7-Jun	2-May	20-Jun	29-Jun
Royal penstemon	2006	10-May	19-May	30-May	19-May	30-Jun	13-Jul
	2007	5-May	25-May	25-Jun	19-Apr	24-Jun	23-Jul
	2008	5-May		20-Jun	29-Apr	11-Jun	17-Jul
	2009	14-May		20-Jun	19-May	24-Jun	10-Jul
	2010	14-May		20-Jun	12-May	22-Jun	22-Jul
	2011	25-May	30-May	30-Jun	20-May	5-Jul	29-Jul
	2012	2-May	20-May	25-Jun	2-May	13-Jun	13-Jul
	2013	2-May	10-May	20-Jun	2-May	12-Jun	11-Jul
	2014	29-Apr	13-May	9-Jun	29-Apr	10-Jun	11-Jul
	2015	28-Apr	5-May	5-Jun	21-Apr	3-Jun	30-Jun
	2016	no flowering					
	2017	8-May	15-May	7-Jun	2-May	20-Jun	17-Jul

Table 3. Early season precipitation and growing degree-days at the Malheur Experiment Station, Oregon State University (OSU), Ontario, OR, 2006-2017.

	Precipitation (inch)			Growing degree-days (50 – 86°F)
Year	Spring	Winter + spring	Fall + winter + spring	Jan–June
2006	3.4	10.1	14.5	1273
2007	1.9	3.8	6.2	1406
2008	1.4	3.2	6.7	1087
2009	4.1	6.7	8.9	1207
2010	4.3	8.4	11.7	971
2011	4.8	9.3	14.5	856
2012	2.6	6.1	8.4	1228
2013	0.9	2.4	5.3	1319
2014	1.7	5.1	8.1	1333
2015	3.2	5.9	10.4	1610
2016	2.2	5.0	10.1	1458
2017	4.0	9.7	12.7	1196
12-year average:	2.9	6.3	9.8	23-year average: 1207

Table 4. Native wildflower seed yield in response to irrigation rate (inches/season) in 2006 through 2017. Malheur Experiment Station, Oregon State University (OSU), Ontario, OR.

Species	Year	0 inches	4 inches	8 inches	LSD (0.05)
		------------- lb/acre ---------------			
Sharpleaf penstemon[a]	2006	538.4	611.1	544	NS
	2007	19.3	50.1	19.1	25.5[b]
	2008	56.2	150.7	187.1	79
	2009	20.7	12.5	11.6	NS
	2010	-- Stand disked out --			
Blue penstemon	2011	857.2	821.4	909.4	NS
	2012	343.3	474.6	581.1	NS
	2013	221.7	399.4	229.2	74.4
	2014	213.9	219.8	215.1	NS
	2015	148.4	122.5	216.8	NS
	2016	36.0	84.1	79.6	NS
	2017	117.7	196.6	173.1	NS
	Average	276.9	326.5	343.5	NS
Scabland penstemon[c]	2006	1246.4	1200.8	1068.6	NS
	2007	120.3	187.7	148.3	NS
	2008	-- Stand disked out --			
	2011	637.6	477.8	452.6	NS
	2012	308.7	291.8	299.7	NS
	2013	--- no flowering ---			
	2014	356.4	504.8	463.2	NS
	2015	20.0	76.9	67.0	43.7[b]
	2017	205.4	258.8	247.6	NS
	Average	314.5	323.0	305.6	NS
Thickleaf beardtongue	2011	569.9	337.6	482.2	NS
	2012	280.5	215	253.7	NS
	2013	159.4	196.8	249.7	83.6
	2014	291.7	238.6	282.1	NS
	2015	89.5	73.5	93.3	NS
	2016	142.7	186.3	169.7	NS
	2017	111.2	108.1	99.1	NS
	Average	235.0	193.7	232.8	NS
Royal penstemon [a]	2006	163.5	346.2	213.6	134.3
	2007	2.5	9.3	5.3	4.7[b]
	2008	94	367	276.5	179.6
	2009	6.8	16.1	9	6.0[b]
	2010	147.2	74.3	69.7	NS
	2011	371.1	328.2	348.6	NS
	2012	103.8	141.1	99.1	NS
	2013	8.7	80.7	138.6	63.7
	2014	76.9	265.6	215.1	76.7
	2015	105.4	207.3	173.7	50.3
	2016	--- no flowering ---			
	2017	88.6	117.1	82.3	NS
	Average	106.4	174.8	147.1	33.9

[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. Regression analysis for native wildflower seed yield (y) in response to irrigation (x) (inches/season) using the equation $y = a + b \cdot x + c \cdot x^2$ in 2006-2017, and 4- to 11-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 (OSU), Ontario, OR. (Continued on next page.)

Sharpleaf penstemon

Year	Intercept	linear	quadratic	R^2	*P*	Maximum yield	Water applied for maximum yield
2006	538.4	35.6	-4.4	0.03	NS[a]		
2007	19.3	15.4	-1.9	0.44	0.10	50.5	4.1
2008	56.2	30.9	-1.8	0.63	0.05	188.8	8.6
2009	19.5	-1.1		0.28	0.10	11.4	8.0
Average	165.6	17.1	-1.8	0.1	NS		

Blue penstemon

Year	intercept	linear	quadratic	R^2	*P*	Maximum yield	Water applied for maximum yield
						lb/acre	inches/season
2011	836.6	6.5		0.01	NS		
2012	347.4	29.7		0.21	NS		
2013	221.7	87.9	-10.9	0.63	0.05	398.9	4
2014	215.7	0.1		0.01	NS		
2015	128.4	8.5		0.09	NS		
2016	36.0	18.6	-1.6	0.29	NS		
2017	117.7	32.5	-3.2	0.19	NS		
Average	282.3	8.3		0.36	0.05	348.9	8

Scabland penstemon

Year	intercept	linear	quadratic	R^2	*P*	Maximum yield	Water applied for maximum yield
						lb/acre	inches/season
2006	1260.9	-22.2		0.05	NS		
2007	120.3	30.2	-3.3	0.19	NS		
2011	615.2	-23.1		0.35	0.05	615.2	0
2012	304.6	-1.1		0.01	NS		
2014	356.4	60.8	-5.9	0.26	NS		
2015	20.0	22.6	-2.1	0.42	0.10	81.0	5.4
2017	205.4	21.4	-2.0	0.08	NS		
Average	314.5	5.4	-0.8	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) Regression analysis for native wildflower seed yield in response to irrigation rate (inches/season) in 2006-2017, and 4- to 11-year averages. Malheur Experiment Station, Oregon State University (OSU), Ontario, OR.

Thickleaf beardtongue Year	intercept	linear	quadratic	R^2	P	Maximum 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	247.2	8.0
2014	275.6	-1.2		0.01	NS		
2015	83.6	0.5		0.01	NS		
2016	142.7	18.4	-1.9	0.07	NS		
2017	112.2	-1.5		0.02	NS		
Average	221.6	-0.3		0.0004	NS		

Royal penstemon Year	intercept	linear	quadratic	R^2	P	Maximum yield	Water applied plus spring precipitation for maximum yield	Spring precipitation
						lb/acre	inches/season	inch
2006	-238.2	151.9	-9.9	0.66	0.05	347.2	7.7	3.4
2007	-5.1	4.7	-0.4	0.48	0.10	9.3	6.1	1.9
2008	-91.7	146.1	-11.4	0.56	0.05	378.4	6.4	1.4
2009	-19.5	8.6	-0.5	0.54	0.05	16.2	8.3	4.1
2010	177.8	-9.7		0.28	0.10	135.8	4.3	4.3
2011	374.0	-2.8		0.01	NS			4.8
2012	6.5	46.7	-3.6	0.54	0.05	158.8	6.5	2.6
2013	-2.8	16.2		0.77	0.001	141.0	8.9	0.9
2014	-78.8	102.9	-7.5	0.62	0.05	275.5	6.9	1.7
2015	-75.1	69.7	-4.2	0.64	0.05	211.6	8.2	3.2
2017	-2.4	30.8	-2.0	0.27	NS			4.0
Average	-56.6	53.0	-3.0	0.60	0.05	177.0	8.8	2.9

[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 (OSU), Ontario, OR.

Species	Optimum amount of irrigation for seed production	Year of first seed set	Approximate life span
	inches/season	from fall planting	years
Sharpleaf penstemon	0 in wetter years, 4 in warm, dry years	1	3
Scabland penstemon	response to irrigation in 1 out of 7 years	2	3
Blue penstemon	no response in 6 out of 7 years, 4 inches in 2013 (drier year)	1	3
Thickleaf beardtongue	no response in 6 out of 7 years, 8 inches in 2013 (drier year)	1-2	3
Royal penstemon	0 in cool, wet years, 4-8 in warm, dry years	1-2	3

4. Irrigation Requirements for Seed Production of Various Native Wildflower Species

Clinton C. Shock, Erik B. G. Feibert, Alicia Rivera, and Lamont D. Saunders, Malheur Experiment Station, Oregon State University (OSU), Ontario, OR, 2017

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

Introduction

Commercial seed production of native wildflowers is necessary to provide the quantity of seed needed for restoration of Intermountain West rangelands. Native wildflower plants may not be well adapted to croplands. Native plants are often not competitive with crop weeds in cultivated fields, and this poor competitiveness with weeds could limit wildflower seed production. Both sprinkler and furrow irrigation could provide supplemental water for seed production, but these irrigation systems risk further encouraging weeds. Also, sprinkler and furrow irrigation can lead to the loss of plant stand and seed production due to fungal pathogens. By burying drip tape at a 12-inch depth and avoiding wetting the soil surface, we designed experiments to assure flowering and seed set without undue encouragement of weeds or opportunistic diseases. The trials reported here tested effects of three low rates of irrigation on seed yield of 14 native wildflower species (Table 1).

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

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

[a] Planted in the fall of 2011.

[b] Recently classified as *Cymopterus nivalis* S. Watson "snowline springparsley". Planted in the fall of 2009.

Materials and Methods

Plant Establishment

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

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

Starting in March following fall planting, the row cover was removed. Immediately following the removal of the row cover, bird netting was placed over the seedlings on No. 9 galvanized wire hoops to prevent bird feeding on young seedlings and new shoots. During seedling emergence, wild bird seed was placed several hundred 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/acre was applied to all plots of Hayden’s cymopterus and limestone hawksbeard as liquid fertilizer injected through the drip tape.

Cultural Practices in 2013

On July 26, all plots of hoary tansyaster (*Machaeranthera canescens)* were sprayed with Capture® at 19 oz/acre (0.3 lb ai/acre) for aphid control. On October 31, seed of threadleaf phacelia (*Phacelia linearis)* was planted as previously described.

Due to poor stand, seed of Douglas’ dustymaiden (*Chaenactis douglasii*) was replanted on November 1, as previously described. Stand of coyote tobacco (*Nicotiana attenuata)* was extremely poor and seed was unavailable for replanting.

Cultural Practices in 2014

Stand of Douglas’ dustymaiden, which was replanted in the fall of 2013, was poor and did not allow evaluation of irrigation responses.

On November 11, threadleaf phacelia, coyote tobacco, and manyflower thelypody *(Thelypodium milleflorum)* were replanted as previously described. Lengths of row with missing stand in plots of Douglas’ dustymaiden were replanted by hand and row cover was not applied to the replanting.

Cultural Practices in 2015

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

Cultural Practices in 2016

On November 22, coyote tobacco, threadleaf phacelia, and manyflower thelypody were replanted as previously described.

Irrigation for Seed Production

In March of 2010 for Hayden's cymopterus, and March of 2013 for the other species, the planted strip of each wildflower species was divided into 12 30-ft-long plots. Each plot contained four rows of each species. The experimental design for each species was a randomized complete block with four replicates. The three treatments were a nonirrigated check, 1 inch of water per irrigation, and 2 inches of water per irrigation. Each treatment received four irrigations that were applied approximately every 2 weeks starting at bud formation and flowering. The amount of water applied to each treatment was calculated by the length of time necessary to deliver 1 or 2 inches through the drip system. Irrigations were regulated with a controller and solenoid valves. The drip-irrigation system was designed to allow separate irrigation of each species due to different timings of flowering and seed formation. All species were irrigated separately except the two *Phacelia* spp. and the two *Ligusticum* spp. Flowering, irrigation, and harvest dates were recorded (Table 2) with the exception of coyote tobacco, which did not germinate in 2014 and the *Ligusticum* spp., which did not flower.

Harvest

All species were harvested manually in 2013. Due to a long flowering duration, seed of nakedstem sunray, Douglas' dustymaiden, and limestone hawksbeard required multiple harvests. Seed of nakedstem sunray was harvested manually once a week. Seed of Douglas' dustymaiden and limestone hawksbeard was harvested weekly with a leaf blower in vacuum mode. In 2016, the duration of flowering for limestone hawksbeard was much shorter and uniform in timing between irrigation treatments. In 2016 and 2017, seed of limestone hawksbeard was harvested by mowing and bagging just prior to the seed heads opening. A seed sample from each plot of limestone hawksbeard in 2016 was cleaned manually to determine the proportion of pure seed. A sample of light yellow (immature) seed and dark brown (mature) seed of limestone hawksbeard was analyzed for viability (tetrazolium). In 2016, seed of Douglas' dustymaiden was harvested manually once a week.

Hoary tansyaster seed was harvested by cutting and windrowing the plants. After drying for 2 days the hoary tansyaster plants were beaten on plastic tubs to separate the seed heads from the stalks. Silverleaf phacelia (*Phacelia hastata*) was harvested with a small-plot combine in 2014 and 2015. In 2016 and 2017, silverleaf phacelia was harvested manually due to the low stature of the plants. Showy goldeneye (*Heliomeris multiflora*) was harvested with a small plot combine in 2015 and 2016. The duration of flowering for showy goldeneye tends to increase with increasing irrigation. In 2013 and 2014, the duration of flowering in the wetter plots of showy goldeneye was much longer than in the drier plots, making a single mechanical harvest unfeasible. In 2015, the duration of flowering in the wetter plots of showy goldeneye was shorter, enabling mechanical harvest. In 2016, plots of the driest treatment were harvested manually before the other plots, which were harvested mechanically on July 8. All plots of showy goldeneye were harvested with a small plot combine in 2017.

Seed of all species was cleaned manually.

Statistical Analysis

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

Results and Discussion

Precipitation in the winter and spring in 2013 was lower and in 2017 was higher than the 5-year average (Table 3). Precipitation in the other years was close to the average. The accumulation of growing degree-days (50-86°F) was higher than average in 2013-2016 (Table 3).

Common Yarrow

Seed yields of common yarrow showed a quadratic response to irrigation in 2017 with a maximum seed yield of 220 lb/acre at 6.2 inches of water applied (Tables 4 and 5).

Manyflower Thelypody

Seed yield of manyflower thelypody did not respond to irrigation in 2014 or 2016 (Tables 4 and 5). Highest seed yields averaged 225 lb/acre over the two years.

Limestone Hawksbeard

Limestone hawksbeard flowered and produced seed for the first time in 2015, the third year after fall planting in 2011. The uniform and short flowering of limestone hawksbeard in 2016 allowed the seed from all plots to be harvested once. A single mechanical harvest is more efficient, but some of the seed could be immature because harvest needed to occur just before seed heads opened. In 2016, 77% of the seed harvested was mature and had a viability of 57%. The other 23% of the harvested seed was immature and had a viability of 5%. This suggests that the single harvest as conducted in this trial resulted in adequate seed quality. Limestone hawksbeard seed yields increased with increasing irrigation rate up to the highest rate of 8 inches in 2015. In 2016 and 2017, seed yields of limestone hawksbeard did not respond to irrigation. Seed yields increased each year from 2015 to 2017 with highest seed yields of 349 lb/acre in 2017.

Hayden's Cymopterus

Hayden's cymopterus did not flower in either 2010 or 2011, and flowered very little in 2012. Hayden's cymopterus seed yields did not respond to irrigation in 2013 and 2016. In 2014, seed yields increased with increasing irrigation rate up to the highest rate of 8 inches. In 2015, seed yields showed a quadratic response to irrigation with a maximum seed yield at 4.2 inches of water applied. In 2017, seed yields were highest with no irrigation. Highest seed yields averaged 1146 lb/acre over the 5 years.

Showy Goldeneye

Showy goldeneye seed yield increased with increasing irrigation rate up to the highest rate of 8 inches in 2013-2015; showy goldeneye seed yield did not respond to irrigation in 2016 and 2017. Highest seed yields averaged 149 lb/acre over the 5 years.

Scarlet gilia

Scarlet gilia flowered very little in 2013, then flowered and set seed in 2014. The stand of scarlet gilia died over the winter of 2014-2015, which indicated a biennial growth habit. Scarlet gilia seed yields were highest with 4 inches of water applied in 2014 and 2017. Highest seed yields averaged 262 lb/acre over the 2 years.

Douglas' Dustymaiden

Stands of Douglas' dustymaiden were poor in 2013 and 2014, and did not permit evaluation of irrigation responses. After replanting in the fall of 2013 and 2014, adequate stand of Douglas' dustymaiden was established, allowing evaluations of irrigation responses in 2015, 2016, and 2017. Douglas' dustymaiden seed yields did not respond to irrigation in 2015, 2016, and 2017. Highest seed yields averaged 288 lb/acre over the 3 years.

Nakedstem Sunray

Nakedstem sunray seed yield was very low and did not respond to irrigation in 2013. In 2014, seed yield showed a quadratic response to irrigation with a maximum seed yield at 5.4 inches of water applied. Extensive die-off of nakedstem sunray occurred over the winter of 2014-2015, and was more severe in the plots receiving the highest amount of irrigation. Seed yields of nakedstem sunray were substantially reduced in 2015 and were highest without irrigation. In 2016, seed yield showed a quadratic response to irrigation with a maximum seed yield at 5.8 inches of water applied. In 2017, seed yields were highest without irrigation. The replanting done in the fall of 2015 was successful, but stands continue to decline especially in the irrigated plots. Highest seed yields averaged 25 lb/acre over the 4 years.

Hoary Tansyaster

Hoary tansyaster seed yields showed a quadratic response to irrigation with a maximum seed yield at 2.4 inches of water applied in 2013. In 2014, 2015, and averaged over the 3 years, seed yields of hoary tansyaster did not respond to irrigation. Highest seed yields averaged 240 lb/acre over the 3 years. Partial die-off of hoary tansyaster over the winter of 2015-2016 resulted in stand too uneven for an irrigation trial in 2016 and 2017. Natural reseeding occurred over the winter of 2016-2017, but the young plants did not flower in 2017.

Coyote Tobacco

Seed yields of coyote tobacco showed a quadratic response to irrigation in 2016 with a maximum seed yield of 151 lb/acre at 4.6 inches of water applied. In 2015 and 2017, stands of coyote tobacco were uneven and did not permit evaluation of irrigation responses.

Silverleaf Phacelia

Irrigation responses for silverleaf phacelia were evaluated for two sets of plots: the 3-year-old stand planted in 2012 and a new stand originating in 2015 from volunteer seed. 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 silverleaf phacelia did not respond to irrigation, possibly due to loss of stand in this weak perennial. The original stand of silverleaf phacelia, planted in the fall of 2012, was extremely poor in 2016 and seed was not harvested. Seed yields of silverleaf phacelia (started in the fall of 2014) increased with increasing irrigation rate up to the highest rate of 8 inches in 2015. In 2016, seed yields of silverleaf phacelia, showed a quadratic response to irrigation with a maximum seed yield at 4 inches of water applied. In 2017, seed yields of silverleaf phacelia did not respond to irrigation. Averaged over the three years, seed yields of silverleaf phacelia, showed a quadratic response to irrigation with a maximum seed yield of 163 lb/acre and 62 lb/acre at 6.6 and 5 inches of water applied for the 2012 and 2014 stands, respectively. The two stands of silverleaf phacelia showed a pattern of increased seed yields in the second year and then a decline in the third year.

Threadleaf Phacelia

Seed yields of threadleaf phacelia showed a quadratic response to irrigation in 2013 with a maximum seed yield at 6.2 inches of water applied. In 2014, seed yields of threadleaf phacelia did not respond to irrigation. Highest seed yields averaged 240 lb/acre over the 2 years. Stand of threadleaf phacelia was poor at the end of 2014 and the area was replanted in the fall. Stand of replanted threadleaf phacelia was very poor in 2015. Threadleaf phacelia was replanted in the fall of 2016 in a different location in the field, but stand in the spring of 2016 was extremely poor.

Stands of Porter's licorice-root (*Ligusticum porteri*) and Canby's licorice-root *(L. canbyi)* were poor and uneven and did not permit evaluation of irrigation responses.

Acknowledgements

This project was funded by the U.S. Forest Service (USFS) Great Basin Native Plant Project (GBNPP), U.S. Bureau of Land Management (BLM), Oregon State University (OSU), Malheur County Education Service District, and supported by Formula Grant nos. 2017-31100-06041 and 2017-31200-06041 from the USDA National Institute of Food and Agriculture (NIFA).

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

	Flowering dates			Irrigation dates		
Year	Start	Peak	End	Start	End	Harvest
Achillea millefolium, common yarrow						
2017	26-Apr	7-Jun	12-Jul	2-May	20-Jun	26-Jul
Chaenactis douglasii, Douglas' dustymaiden						
2013	23-May	30-Jun	15-Jul	22-May	3-Jul	2-Jul, 22-Jul
2014	20-May		15-Jul	13-May	24-Jun	poor stand
2015	5-May		10-Jul	5-May	17-Jun	weekly, 8-Jun to 15-Jul
2016	23-May		22-Jul	23-May	8-Jul	weekly, 17-Jun to 7-Jul
2017	25-May	7-Jun	19-Jul	9-May	20-Jun	weekly, 16-Jun to 6-Jul
Machaeranthera canescens, hoary tansyaster						
2013	13-Aug		1-Oct	17-Jul	28-Aug	2-Oct
2014	20-Aug	17-Sep	5-Oct	22-Jul	2-Sep	6-Oct
2015	10-Aug	17-Sep	1-Oct	11-Aug	22-Sep	6-Oct, 15-Oct
2016	17-Aug	20-Sep	10-Oct			partial winter die-off
2017	29-Aug		20-Oct			
Phacelia hastata, silverleaf phacelia						
2013	17-May		30-Jul	22-May	3-Jul	30-Jul (0 in), 7-Aug, 19-Aug (8 in)
2014	5-May		10-Jul	29-Apr	10-Jun	14-Jul
2015 (1st year)	28-Apr	26-May	7-Aug	20-May	30-Jun	6-Aug
2015 (3rd year)	28-Apr	26-May	7-Aug	29-Apr	10-Jun	7-Jul (0 in), 21-Jul (4, 8 in)
2016	28-Apr		17-Jun	27-Apr	7-Jun	23-Jun
2017	8-May	7-Jun		2-May	20-Jun	25-Jul
Phacelia linearis, 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					
Enceliopsis nudicaulis, nakedstem sunray						
2013	30-Jun		15-Sep	3-Jul	14-Aug	weekly, 8-Aug to 30-Aug
2014	5-May	1-Jul	30-Jul	6-May	17-Jun	weekly, 14-Jul to 30-Aug
2015	28-Apr	13-May	5-Aug	29-Apr	10-Jun	weekly, 2-Jun to 15-Aug
2016	20-Apr		30-Jul	3-May	14-Jun	weekly, 27-Apr to 29-Jul
2017	11-May	7-Jun	20-Aug	23-May	6-Jul	
Heliomeris multiflora, showy goldeneye						
2013	15-Jul		30-Aug	5-Jun	17-Jun	8-Aug, 15-Aug, 28-Aug
2014	20-May	20-Jun	30-Aug	13-May	24-Jun	weekly, 15-Jul to 15-Aug
2015	5-May	26-May	10-Jul	5-May	17-Jun	13-Jul
2016	5-May	15-Jun	30-Sep	9-May	22-Jun	8-Jul
2017	12-May	7-Jun	30-Jul	9-May	20-Jun	17-Jul
Cymopterus bipinnatus, Hayden's cymopterus						
2013	5-Apr		15-May	12-Apr	22-May	10-Jun
2014	7-Apr		29-Apr	7-Apr	20-May	16-Jun
2015	25-Mar		24-Apr	1-Apr	13-May	8-Jun
2016	15-Mar		25-Apr	31-Mar	9-May	7-Jun
2017	27-Mar		1-May	19-Apr	6-Jun	16-Jun
Ipomopsis aggregata, scarlet gilia						
2013	31-Jul	very little flowering		31-Jul	11-Sep	
2014	22-Apr	13-May	30-Jul	23-Apr	3-Jun	20-Jun
2015		winter die-off				
2016	no flowering			7-Jun	22-Jul	
2017	1-May	15-May	27-Jun	2-May	20-Jun	23-Jun

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

	Flowering dates			Irrigation dates		
Year	Start	Peak	End	Start	End	Harvest
Thelypodium milleflorum, manyflower thelypody						
2013	No flowering					
2014	22-Apr	5-May	10-Jun	23-Apr	3-Jun	2-Jul
2015	No flowering					
2016	11-Apr	6-May	8-Jun	11-Apr	23-May	21-Jun
2017	No flowering					
Crepis intermedia, limestone hawksbeard						
2015	28-Apr	5-May	1-Jun	21-Apr	3-Jun	weekly, 1-Jun to 2-Jul
2016	29-Apr		25-May	27-Apr	7-Jun	26-May
2017	15-May		7-Jun	9-May	20-Jun	8-Jun
Nicotiana attenuata, coyote tobacco						
2016	16-May		31-Jul	16-May	22-Jun	weekly, 21-Jun to 29-Jul
2017	1-May		15-Aug			

Table 3. Precipitation and growing degree-days at the Malheur Experiment Station, Ontario, OR, 2013-2017.

	Precipitation (inch)			Growing degree-days (50 – 86°F)
Year	Spring	Winter + spring	Fall + winter + spring	Jan–June
2013	0.9	2.4	5.3	1319
2014	1.7	5.1	8.1	1333
2015	3.2	5.9	10.4	1610
2016	2.2	5.0	10.1	1458
2017	4.0	9.7	12.7	1196
5-year average:	2.4	5.6	9.3	23-year average: 1207

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

		Irrigation rate			
Species	Year	0 inches	4 inches	8 inches	LSD (0.05)
		--------------- lb/acre --------------			
Douglas's dustymaiden	2015	132.1	137.6	183.3	NS[a]
	2016	29.1	16.0	27.2	NS
	2017	707.1	711.1	627.3	NS
	Average	289.5	288.2	279.2	NS
Limestone hawksbeard	2015	75.5	75.8	153.7	58.1
	2016	91.9	113.1	85.6	NS
	2017	331.6	348.5	315.8	NS
	Average	166.3	179.1	192.0	NS
Hayden's cymopterus	2013	194.2	274.5	350.6	NS
	2014	1236.2	1934	2768.5	844.7
	2015	312.3	749.0	374.9	240.7
	2016	1501.4	2120.6	1799.0	546.6[b]
	2017	245.4	178.6	95.8	NS
	Average	732.1	1145.7	1035.3	195.6
Nakedstem sunray	2013	2.3	6.8	5.9	NS
	2014	1.5	34.6	29.1	20.7
	2015	15.7	3.2	4.4	7.3
	2016	10.5	47.6	45.9	34.9
	2017	105.0	43.2	25.0	59.6
	Average	27.0	27.6	22.1	NS
Showy goldeneye	2013	28.7	57.6	96.9	NS
	2014	154.6	200.9	271.7	107.3[b]
	2015	81.7	115.6	188.2	58.2
	2016	92.3	89.2	98.0	NS
	2017	87.8	75.9	89.9	NS
	Average	89.0	106.7	148.9	27.5
Scarlet gilia	2014	47.1	60.9	63.6	9.0
	2017	241.0	315.8	188.8	74.5
	Average	180.3	261.7	145.1	97.2
Hoary tansyaster	2013	206.1	215	124.3	73.6
	2014	946.1	1210.2	1026.3	NS
	2015	304.1	402.6	459.1	NS
	Average	163.0	240.3	233.3	NS
Coyote tobacco	2016	49.4	151.0	95.8	81.4
Silverleaf phacelia (planted fall 2012)	2013	35.3	102.7	91.2	35.7
	2014	87.7	305.7	366.4	130.3
	2015	78.8	79.3	65.0	NS
	Average	67.3	162.6	174.2	34.5
Silverleaf phacelia (planted fall 2014)	2015	0.0	21.4	50.4	13.7
	2016	82.5	125.2	83.1	26.8
	2017	20.3	23.2	23.2	NS
	Average	34.3	61.7	52.2	20.7
Threadleaf phacelia	2013	121.4	306.2	314.2	96
	2014	131.9	172.9	127.2	NS
	Average	126.7	239.5	220.7	87.2
Manyflower thelypody	2014	200.5	246.2	205.6	NS
	2016	121.9	110.0	63.3	NS
	Average	171.7	224.6	152.6	NS
Common yarrow	2017	59.2	213.3	220.4	99.8

[a] Not significant. [b] LSD (0.10).

Table 5. Regression analysis for native wildflower seed yield (y) in response to irrigation (x) (inches/season) using the equation $y = a + b \bullet x + c \bullet x^2$. 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 (OSU), Ontario, OR. Continued on next page.

Species	Year	intercept	linear	quadratic	R^2	P	Maximum yield	Water applied for maximum yield
							lb/acre	inches/season
Douglas' dustymaiden	2015	125.4	6.4		0.08	NS[a]		
	2016	25.1	-0.2		0.01	NS		
	2017	707.1	12.0	-2.7	0.09	NS		
	Average	289.5	0.7	-0.2	0.01	NS		
Limestone hawksbeard	2015	58.6	12.7		0.32	0.10	160	8.0
	2016	91.9	11.4	-1.5	0.25	NS		
	2017	331.6	10.4	-1.5	0.03	NS		
	Average	166.3	3.2		0.05	NS		
Hayden's cymopterus	2013	194.9	19.6		0.07	NS		
	2014	1214.6	190.6		0.41	0.05	2739	8.0
	2015	312.3	210.5	-25.3	0.46	0.10	750	4.2
	2016	1501.4	272.4	-29.4	0.34	NS		
	2017	308.1	-24.4		0.38	0.10	308	0.0
	Average	732.1	168.9	-16.4	0.51	0.05	1168	5.2
Nakedstem sunray	2013	3.1	0.4		0.16	NS		
	2014	1.5	13.1	-1.2	0.6	0.05	37.1	5.4
	2015	13.4	-1.4		0.29	0.10	13.4	0.0
	2016	10.5	14.1	-1.2	0.57	0.05	51.6	5.8
	2017	99.1	-10.0		0.44	0.05	99.1	0.0
	Average	27.0	0.9	-0.2	0.04	NS		
Showy goldeneye	2013	27	8.5		0.38	0.05	95	8
	2014	150.5	14.6		0.27	0.10	267	8
	2015	75.2	13.3		0.48	0.05	182	8
	2016	90.7	0.7		0.01	NS		
	2017	83.5	0.3		0.01	NS		
	Average	84.9	7.5		0.49	0.05	145	8
Scarlet gilia	2014	48.5	2.1		0.23	NS		
	2017	241.0	43.9	-6.3	0.52	0.05	317.5	3.5
	Average	180.3	45.1	-6.2	0.24	NS		
Hoary tansyaster	2013	206.1	14.7	-3.1	0.54	0.05	224	2.4
	2014	946.1	122	-14	0.13	NS		
	2015	311.1	19.4		0.02	NS		
	Average	163.0	29.9	-2.6	0.03	NS		
Coyote tobacco	2016	49.4	45.0	-4.9	0.50	0.05	153	4.6
Silverleaf phacelia (planted fall 2012)	2013	35.3	26.7	-2.5	0.66	0.01	107	5.3
	2014	87.7	74.2	-4.9	0.76	0.01	369	7.6
	2015	78.8	2.0	-0.5	0.04	NS		
	Average	67.3	34.3	-2.6	0.9	0.001	180	6.6

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

Table 5. **(cont.)** 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 (OSU), Ontario, OR.

Species	Year	intercept	linear	quadratic	R^2	P	Maximum yield	Water applied for maximum yield
							lb/acre	inches/season
Silverleaf phacelia	2015	-1.3	6.3		0.88	0.001	49	8
(planted fall 2014)	2016	82.5	21.3	-2.6	0.72	0.01	125.2	4.0
	2017	20.3	1.1	-0.1	0.04	NS		
	Average	34.3	11.5	-1.2	0.56	0.05	62.8	5.0
Threadleaf phacelia	2013	121.4	68.3	-5.5	0.69	0.01	333	6.2
	2014	131.9	21.1	-2.7	0.11	NS		
	Average	126.7	44.7	-4.1	0.48	0.1	249	5.5
Manyflower thelypody	2014	200.5	22.2	-2.7	0.12	NS		
	2016	121.9	1.4	-1.1	0.35	NS		
	Average	171.7	28.8	-3.9	0.20	NS		
Common yarrow	2017	59.2	56.9	-4.6	0.75	0.01	235	6.2

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

Clinton C. Shock, Erik B. G. Feibert, Alicia Rivera, and Lamont D. Saunders, Malheur Experiment Station, Oregon State University (OSU), Ontario, OR, 2017

Douglas A. Johnson and B. Shaun Bushman, USDA-ARS Forage and Range Research Lab, Logan, UT

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

Summary

Legumes are important components of rangeland vegetation in the Intermountain West due to their supply of protein to wildlife and livestock and contribution of nitrogen to rangeland productivity. Seed of selected native legumes is needed for rangeland restoration, but cultural practices for native legume production are largely unknown. The seed yield response of three native legume species to irrigation was evaluated starting in 2011. Four biweekly irrigations applying either 0, 1, or 2 inches of water (a total of 0, 4, or 8 inches/season) were tested. Over the 7-year period of study, Searls' prairie clover (*Dalea searlsiae*) seed yield was maximized by 13-17 inches of water applied plus fall, winter, and spring precipitation per season. Western prairie clover (*Dalea ornata*) seed yield was maximized by 13-16 inches of water applied plus fall, winter, and spring precipitation per season. Seed yield of basalt milkvetch (*Astragalus filipes*) did not respond to irrigation.

Introduction

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

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

Native wildflower plants are not well adapted to croplands; they are often not competitive with crop weeds in cultivated fields, and this could limit wildflower seed production. Both sprinkler and furrow irrigation can provide supplemental water for seed production, but these irrigation systems risk further encouraging weeds. Also, sprinkler and furrow irrigation can lead to the loss of plant stand and seed production due to fungal pathogens. By burying drip tapes at 12-inch depth and avoiding wetting the soil surface, we designed experiments to assure flowering and seed set without undue encouragement of weeds or opportunistic diseases. The trials reported here tested the effects of three low rates of irrigation on the seed yield of three native wildflower legume species (Table 1) planted in 2009.

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

Species	Common names	Growth habit
Dalea searlsiae	Searls' prairie clover	Perennial
Dalea ornata	Western prairie clover, Blue Mountain prairie clover	Perennial
Astragalus filipes	Basalt milkvetch	Perennial

Materials and Methods

Plant Establishment

Each of three species was planted in four rows 30 inches apart in a 10-ft-wide strip about 450 ft long on Nyssa silt loam at the Malheur Experiment Station, Ontario, Oregon. The soil had a pH of 8.3 and 1.1% organic matter. In October 2009, two drip tapes 5 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 disc openers. All seed was planted on the soil surface at 20-30 seeds/ft of row. After planting, sawdust was applied in a narrow band over the seed row at 0.26 oz/ft of row (558 lb/acre). Following planting and sawdust application, the beds were covered with row cover (N-sulate, DeWitt Co., Inc., Sikeston, MO), which covered four rows (two beds) and was applied with a mechanical plastic mulch layer. The field was irrigated for 24 hours on December 2, 2009 due to very dry soil conditions.

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

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

Irrigation for Seed Production

In April 2011, each strip of each wildflower species was divided into 12 30-ft plots. Each plot contained four rows of each species. The experimental design for each species was a randomized complete block with four replicates. The three treatments were a non-irrigated check, 1 inch of water applied per irrigation, and 2 inches of water applied per irrigation. Each treatment received four irrigations applied approximately every 2 weeks starting at bud formation and flowering. The amount of water applied to each treatment was calculated by the length of time necessary to deliver 1 or 2 inches through the drip system. Irrigations were regulated with a controller and solenoid valves.

The drip-irrigation system was designed to allow separate irrigation of the species due to different timings of flowering and seed formation. The irrigation treatments of the two *Dalea* spp. were applied together. The basalt milkvetch was irrigated separately to correspond to the timing of its flowering and seed set. Flowering, irrigation, and harvest dates were recorded (Table 2).

Weed Control

On October 27, 2016, Prowl at 1 lb ai/acre was broadcast on all plots of both species for weed control. On April 21, 2017, Prowl at 1 lb ai/acre and Poast® at 30 oz/acre were broadcast on all plots of both species.

Seed Beetle Control

Harvested seed pods of western prairie clover, Searls' prairie clover, and basalt milkvetch were extensively damaged from feeding by seed weevils in 2013 and 2014, indicating that control measures during and after flowering would be necessary to maintain seed yields. On May 21, 2015, Capture® 2EC at 6.4 oz/acre (0.1 lb ai/acre) and Rimon® at 12 oz/acre (0.08 lb ai/acre) were broadcast in the evening to minimize harm to pollinators. On May 28, 2015, Rimon at 12 oz/acre was broadcast in the evening to minimize harm to pollinators. Seed beetles were not observed during flowering in 2016 and 2017.

Statistical Analysis

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

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

Adding the seasonal precipitation to the irrigation response equation would have the potential to provide a closer estimate of the amount of water required for maximum seed yields. Regressions of seed yield each year were calculated on all the sequential seasonal amounts of precipitation and irrigation, but only some of the regressions are reported below. The period of precipitation plus applied water that had the lowest standard deviation for irrigation plus precipitation over the years was chosen as the most reliable independent variable for predicting seed yield. For basalt milkvetch, seed yield was not responsive to irrigation, so seed yield responses only to water applied are reported without trying to find the optimal amount of irrigation plus seasonal precipitation.

Results and Discussion

Precipitation from January through June was close to average in 2012, and 2014-2016, higher than average in 2011 and 2017, and lower than average in 2013 (Table 3). The accumulation of growing degree-days (50-86°F) was increasingly higher than average from 2012 to 2016, close to average in 2017, and was below average in 2011 (Table 3). Flowering and seed harvest were early in 2015 and 2016, probably due to warmer weather and greater accumulation of growing degree-days.

Searls' Prairie Clover

In 2012 and 2014-2016, seed yields showed a quadratic response to irrigation plus fall, winter, and spring precipitation (Table 5). Maximum seed yields were achieved with 15, 17, 17, and 15.4 inches of water applied plus fall, winter, and spring precipitation in 2012, 2014, 2015, and 2016, respectively. In 2013, seed yields were very low due to seed weevils. In 2011, seed yields were highest with no irrigation plus 14.5 inches of fall, winter, and spring precipitation. In 2017, seed yields were not responsive to irrigation. Averaged over the seven years, maximum seed yields were 227 lb/acre achieved with 16.1 inches of water applied plus fall, winter, and spring precipitation.

Blue Mountain or Western Prairie Clover

Seed yields showed a quadratic response to irrigation in 2012-2016 with a maximum seed yield at 16.1, 13.3, 14.9, 14.9, and 14.6 inches of water applied plus fall, winter, and spring precipitation, respectively (Tables 4 and 5). Seed yields in 2011 were highest with no irrigation plus 14.5 inches of fall, winter, and spring precipitation. In 2017, seed yields were not responsive to irrigation. Averaged over the seven years, maximum seed yields were 350 lb/acre achieved with 15.3 inches of water applied plus fall, winter, and spring precipitation.

Both Searls' prairie clover and western prairie clover showed either a negative response or no response to irrigation in 2011 and 2017, years with higher than average fall, winter, and spring precipitation.

Basalt Milkvetch

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

Acknowledgements

This project was funded by the U.S. Forest Service (USFS) Great Basin Native Plant Project (GBNPP), U.S. Bureau of Land Management (BLM), Oregon State University (OSU), Malheur County Education Service District, and was supported by Formula Grant nos. 2017-31100-06041 and 2017-31200-06041 from the USDA National Institute of Food and Agriculture (NIFA).

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

		Flowering			Irrigation		
Species	Year	Start	Peak	End	Start	End	Harvest
Searls' prairie clover							
	2011	8-Jun	20-Jun	20-Jul	27-May	6-Jul	21-Jul
	2012	23-May	10-Jun	30-Jun	11-May	21-Jun	10-Jul
	2013	13-May		15-Jun	8-May	19-Jun	29-Jun
	2014	15-May	4-Jun	24-Jun	6-May	17-Jun	1-Jul
	2015	13-May	26-May	16-Jun	5-May	17-Jun	22-Jun
	2016	11-May	28-May	10-Jun	3-May	14-Jun	16-Jun
	2017	23-May	7-Jun	30-Jun	23-May	6-Jul	3-Jul
Western prairie clover							
	2011	8-Jun	20-Jun	20-Jul	27-May	6-Jul	22-Jul
	2012	23-May	10-Jun	30-Jun	11-May	21-Jun	11-Jul
	2013	13-May	21-May	15-Jun	8-May	19-Jun	28-Jun
	2014	15-May	4-Jun	24-Jun	6-May	17-Jun	1-Jul
	2015	5-May	26-May	22-Jun	5-May	17-Jun	25-Jun
	2016	3-May	26-May	10-Jun	3-May	14-Jun	13-Jun
	2017	23-May	7-Jun	29-Jun	23-May	6-Jul	5-Jul
Basalt milkvetch							
	2011	20-May	26-May	30-Jun	13-May	23-Jun	18-Jul
	2012	28-Apr	23-May	19-Jun	11-May	21-Jun	5-Jul
	2013	3-May	10-May	25-May	8-May	19-Jun	28-Jun
	2014	5-May	13-May	28-May	29-Apr	10-Jun	24-Jun
	2015	17-Apr	13-May	1-Jun	21-Apr	3-Jun	16-Jun

Table 3. Early season precipitation and growing degree-days at the Malheur Experiment Station, Ontario, OR, 2006-2017.

	Precipitation (inch)			Growing degree-days (50 – 86°F)
Year	Spring	Winter + spring	Fall + winter + spring	Jan–June
2006	3.4	10.1	14.5	1273
2007	1.9	3.8	6.2	1406
2008	1.4	3.2	6.7	1087
2009	4.1	6.7	8.9	1207
2010	4.3	8.4	11.7	971
2011	4.8	9.3	14.5	856
2012	2.6	6.1	8.4	1228
2013	0.9	2.4	5.3	1319
2014	1.7	5.1	8.1	1333
2015	3.2	5.9	10.4	1610
2016	2.2	5.0	10.1	1458
2017	4.0	9.7	12.7	1196
12-year average:	2.9	6.3	9.8	23-year average: 1207

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

Species	Year	0 inches	4 inches	8 inches	LSD (0.05)
		--------------- lb/acre ----------------			
Searls' prairie clover					
	2011	262.7	231.2	196.3	50.1
	2012	175.5	288.8	303.0	93.6
	2013	14.8	31.7	44.4	6.1
	2014	60.0	181.4	232.2	72.9
	2015	221.2	330.7	344.2	68.3
	2016	148.7	238.8	222.3	56.0
	2017	222.2	223.6	206.2	NS
	Average	157.9	218.0	221.2	13.4
Western prairie clover					
	2011	451.9	410.8	351.7	NS[a]
	2012	145.1	365.1	431.4	189.3
	2013	28.6	104.6	130.4	38.8
	2014	119.4	422.9	476.3	144.1
	2015	212.9	396.7	267.2	109.6
	2016	246.3	307.9	312.4	NS
	2017	328.2	347.0	270.1	NS
	Average	219.6	339.9	323.1	49.9
Basalt milkvetch					
	2011	87	98.4	74	NS
	2012	22.7	12.6	16.1	NS
	2013	8.5	9.8	6.1	2.7[b]
	2014	56.6	79.3	71.9	NS
	2015	17.8	12.5	11.6	NS
	Average	38.5	35.2	36.0	NS

[a] NS = not significant, [b] LSD (0.10)

Table 5. Regression analysis for native wildflower seed yield (y) in response to irrigation (x) (inches/season) plus fall, winter, and spring precipitation using the equation $y = a + b \bullet x + c \bullet x^2$. 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 (OSU), Ontario, OR.

Searls' prairie clover

Year	intercept	linear	quadratic	R^2	*P*	Maximum yield	Water applied plus precipitation for max. yield	Precipitation, fall, winter, spring
						(lb•acre^{-1})	(inches/season)	(inches)
2011	383.3	-8.3		0.49	0.05	263.3	14.5	14.5
2012	-384.4	92.7	-3.1	0.62	0.05	309.3	15.0	8.4
2013	-4.1	3.7		0.54	0.01	45.1	13.3	5.3
2014	-400.8	74.8	-2.2	0.79	0.001	234.0	17.0	8.1
2015	-515.3	101.9	-3.0	0.56	0.05	350.4	17.0	10.4
2016	-548.3	102.8	-3.3	0.56	0.05	245.2	15.4	10.1
2017	92.1	17.7	-0.6	0.04	NS[a]			12.7
Average	-232.0	57.1	-1.8	0.60	0.05	226.8	16.1	9.8

Western prairie clover

Year	intercept	linear	quadratic	R^2	*P*	Maximum yield	Water applied plus precipitation for max. yield	Precipitation, fall, winter, spring
						(lb•acre^{-1})	(inches/season)	(inches)
2011	635.9	-12.5		0.11	NS	454.9	14.5	14.5
2012	-815.6	154.8	-4.8	0.65	0.01	431.8	16.1	8.4
2013	-149.4	41.9	-1.6	0.88	0.001	130.4	13.4	9.4
2014	-1258.9	233.6	-7.8	0.87	0.001	486.6	14.9	8.1
2015	-1597.0	267.3	-8.9	0.64	0.05	399.0	14.9	10.4
2016	-1096.9	203.5	-6.9	0.55	0.10	393.0	14.6	10.1
2017	-368.8	92.9	-3.0	0.13	NS			12.7
Average	-659.0	131.5	-4.3	0.83	0.001	349.7	15.3	9.8

[a] Not significant. There was no statistically significant trend in seed yield in response to the amount of irri

6. Native Beeplant (*Cleome* spp.) Seed Production in Response to Irrigation in a Semi-arid Environment

Clinton C. Shock, Erik B. G. Feibert, Alicia Rivera, and Lamont D. Saunders, Malheur Experiment Station, Oregon State University (OSU), Ontario, OR, 2017

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

Summary

Beeplants (*Cleome* spp.) are annual native range species in the Intermountain West. Beeplant is visited by many classes of pollinators and are thought to be supportive of a wide range of pollinators. Beeplant seed is desired for rangeland restoration activities, but little cultural practice information is known for its seed production. The seed yield response of Rocky Mountain beeplant (*Cleome serrulata*) and yellow beeplant (*Cleome lutea*) to irrigation was studied. Four biweekly irrigations applying either 0, 1, or 2 inches of water (total of 0, 4 inches, or 8 inches/season) was evaluated over multiple years. Beeplant stands were established through fall plantings each year and were maintained without weed competition. Rocky Mountain beeplant seed yield was maximized by 8 inches of water applied per season in 2011, but did not respond to irrigation in the following years. Yellow beeplant seed yield was highest with no irrigation in 2016. Yellow beeplant seed yield did not respond to irrigation in 2012, 2014, or 2015. Yellow beeplant stands were lost to flea beetles in 2013 and to poor emergence in 2017. Flea beetle control is essential for seed production when flea beetles occur.

Introduction

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

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

Native wildflower plants are not well adapted to croplands; they do not compete well with crop weeds in cultivated fields, which could also limit their seed production. Both sprinkler and furrow irrigation could provide supplemental water for seed production, but these irrigation systems risk further encouraging weeds. Also, sprinkler and furrow irrigation can lead to the loss of plant stand and seed production due to fungal pathogens. By burying drip tapes at 12-inch depth and avoiding wetting the soil surface, we designed experiments to assure flowering and seed set without undue encouragement of weeds or opportunistic diseases. The trials reported here tested the effects of three low rates of irrigation on the seed yield of Rocky Mountain beeplant and yellow beeplant.

Materials and Methods

Plant Establishment

Each species was planted in separate strips containing four rows 30 inches apart (a 10-ft wide strip) and about 450 ft long on Nyssa silt loam at the Malheur Experiment Station, Ontario, Oregon. The soil had a pH of 8.3 and 1.1% organic matter. In October 2010, two drip tapes 5 ft apart (T-Tape TSX 515-16-340) were buried at 12-inch depth to irrigate the four rows in the plot. Each drip tape irrigated two rows of plants. The flow rate for the drip tape was 0.34 gal/min/100 ft at 8 psi with emitters spaced 16 inches apart, resulting in a water application rate of 0.066 inch/hour.

Starting in 2010, seed of Rocky Mountain beeplant was planted each year in 30-inch rows using a custom-made plot grain drill with disc openers in mid-November. All seed was planted on the soil surface at 20-30 seeds/ft of row in the same location each year. After planting, sawdust was applied in a narrow band over the seed row at 0.26 oz/ft of row (558 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 yellow beeplant was also planted each year. After the newly planted wildflowers had emerged, the row cover was removed in April each year.

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

Flea Beetle Control

Flea beetles were observed feeding on leaves of Rocky Mountain beeplant and yellow beeplant in April of 2012. On April 29, 2012, all plots of Rocky Mountain beeplant and yellow beeplant were sprayed with Capture® at 5 oz/acre to control flea beetles. On June 11, 2012, Rocky Mountain beeplant 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 and resulted in full stand loss. Flea beetles were not observed on either *Cleome* species in 2014.

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

On March 18, 2016, after removal of the row cover, all plots of Rocky Mountain beeplant and yellow beeplant were sprayed with Radiant® at 8 oz/acre and on April 6, all plots were sprayed with Capture at 5 oz/acre to control flea beetles. On June 30, all plots of Rocky Mountain beeplant were sprayed with Sivanto® at 14 oz/acre to control flea beetles.

The following insecticides were applied to both species for flea beetle control in 2017: April 11, Radiant® at 8 oz/acre, May 4, Capture at 5 oz/acre, July 14, Capture at 5 oz/acre and Rimon at 12 oz/acre, July 25 and August 4, Rimon at 12 oz/acre.

Weeds were controlled by hand weeding as necessary.

Irrigation for Seed Production

In April 2011, each strip of each wildflower species was divided into 12 30-ft plots. Each plot contained four rows of each species. The experimental design for each species was a randomized complete block with four replicates. The three treatments were a nonirrigated check, 1 inch of water applied per irrigation, and 2 inches of water applied per irrigation. Each treatment received four irrigations that were applied approximately every 2 weeks starting with bud formation and flowering. The amount of water applied to each treatment was calculated by the length of time necessary to deliver 1 or 2 inches through the drip system. Irrigations were regulated with a controller and solenoid valves.

The drip-irrigation system was designed to allow separate irrigation of each species due to different timings of flowering and seed formation. Flowering, irrigation, and harvest dates were recorded (Table 1). In 2014, after the four bi-weekly irrigations ended, Rocky Mountain beeplant and yellow beeplant 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 nitrogen/acre, 30 lb phosphorus/acre, and 0.2 lb iron/acre were applied through the drip tape to all *Cleome* plots.

Flowering and Harvest

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

Table 1. Rocky Mountain beeplant and yellow beeplant flowering, irrigation, and seed harvest dates by species. Malheur Experiment Station, Oregon State University (OSU), Ontario, OR.

		Flowering dates			Irrigation dates		
Species	Year	Start	Peak	End	Start	End	Harvest
Rocky Mountain beeplant	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
	2016	23-May		20-Sep	16-May	29-Jun	28 Jun to 15 Aug
	2017	7-Jun		29-Sep	6-Jun	15-Sep	7-31, 10-4
Yellow beeplant	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
	2016	13-Apr	13-May	25-Jul	18-Apr	31-May	14 Jun to 22 Jul
	2017	5-May		10-Aug			

Results and Discussion

Spring precipitation in 2012 and 2016 was close to the average of 2.9 inches (Table 2). Spring precipitation in 2013 and 2014 was lower than the average and spring precipitation in 2011 and 2017 was higher than the average. The total growing degree-days (50-86°F) in June and July in 2012-2017 were higher than average (Table 2) and were associated with early flowering and seed harvest.

Rocky Mountain Beeplant

In 2011, seed yields increased with increasing irrigation up to the highest tested of 8 inches (Tables 3 and 4). Seed yields did not respond to irrigation the other years. There was no plant stand in 2013 due to early, severe flea beetle damage. The additional irrigations starting on

August 12, 2014 did result in an extension/resumption of flowering, but seed harvested in mid-October was not mature. Flowering in 2015, 2016, and 2017 continued through the end of September, but as in 2014, seed set in September of 2015 and 2016 did not mature. Seed set in September of 2017 matured and was harvested. Seed set and seed production were extremely poor in 2016. Continued flea beetle infestations could have caused the poor seed set. A more intensive control program than the three insecticide applications in 2016 might have been necessary. Birds were also observed feeding on seed pods and might also have been responsible for the low seed yields. A total of five insecticide applications were made in 2017. Seed yields in 2017 were higher than in 2016 and similar to 2014 and 2015. The year 2011 that had the highest seed yield also had the lowest June and July growing degree days, suggesting the possibility of a negative effect of higher temperatures on sustained flowering and seed set.

Yellow Beeplant or Yellow Spiderflower

Seed yields did not respond to irrigation in 2012, 2014, or 2015 (Tables 3 and 4). In 2016 seed yields were highest with no irrigation. There was no plant stand in 2013. Early attention to flea beetle control is essential for yellow beeplant seed production. The additional irrigations starting on August 12, 2014 did not result in an extension or resumption of flowering. In 2017, emergence was poor and uneven not allowing an evaluation of irrigation responses.

Acknowledgements

This project was funded by the U.S. Forest Service (USFS), U.S. Bureau of Land Management (BLM), Oregon State University (OSU), Malheur County Education Service District, and supported by Formula Grant nos. 2017-31100-06041 and 2017-31200-06041 from the USDA National Institute of Food and Agriculture (NIFA).

Table 2. Early season precipitation and growing degree-days at the Malheur Experiment Station, Oregon State University (OSU), Ontario, OR, 2011-2017.

	Precipitation (inch)			Growing degree-days (50 – 86°F)
Year	Spring	Winter +spring	Fall + winter + spring	June + July
2011	4.8	9.3	14.5	1099
2012	2.6	6.1	8.4	1235
2013	0.9	2.4	5.3	1294
2014	1.7	5.1	8.1	1323
2015	3.2	5.9	10.4	1390
2016	2.2	5.0	10.1	1256
2017	4.0	9.7	12.7	1300
12-year average:	2.9	6.3	9.8	23-year average: 1213

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

		Irrigation rate			
Species	Year	0 inches	4 inches	8 inches	LSD (0.05)
Rocky Mountain beeplant	2011	446.5	499.3	593.6	100.9[b]
	2012	184.3	162.9	194.7	NS[a]
	2013		No stand		
	2014	66.3	80	91.3	NS
	2015	54.0	41.0	37.9	NS
	2016	0.8	2.1	1.6	NS
	2017	46.5	52.3	34.8	NS
	Average	114.5	120.0	136.4	NS
Yellow beeplant	2012	111.7	83.7	111.4	NS
	2013	No stand			
	2014	207.1	221.7	181.7	NS
	2015	136.9	80.5	113.0	NS
	2016	65.6	48.9	35.0	18.7
	2017		poor stand		
	Average	130.3	108.7	110.3	NS

[a] LSD (0.10).

[b] Not significant: There was no statistically significant trend in seed yield in response to the amount of irrigation.

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

Rocky Mountain beeplant

Year	intercept	linear	quadratic	R^2	*P*	Maximum yield	Water applied for maximum yield
						lb/acre	inches/season
2011	439.6	18.4		0.35	0.05	586.7	8
2012	175.4	1.3		0.01	NS[a]		
2014	66.7	3.1		0.16	NS		
2015	52.4	-2.0		0.08	NS		
2016	0.8	0.6	-0.1	0.19	NS		
2017	46.5	4.4	-0.7	0.11	NS		
Average	112.6	2.7		0.32	0.1	134.6	8

Yellow beeplant

Year	intercept	linear	quadratic	R^2	*P*	Maximum yield	Water applied for maximum yield
						lb/acre	inches/season
2012	102.4	-0.031		0.01	NS		
2014	207.1	10.4	-1.7	0.2	NS		
2015	122.0	-3.0		0.08	NS		
2016	65.2	-3.8		0.45	0.05	65.2	0.0
Average	126.5	-2.5		0.04	NS		

[a] Not significant.

7. Direct Surface Seeding Systems for the Establishment of Native Plants in 2016 and 2017

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

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

Introduction

Seed of native plants is needed to restore rangelands of the Intermountain West. Reliable commercial seed production is needed to make seed readily available. Direct seeding of native range plants in the Intermountain West is often problematic. Fall planting is helpful in establishing stands for many of these native species to overcome physiological dormancy through cold stratification. Fall planting alone may be insufficient for adequate stands for seed production, and it may be necessary to combine fall planting with other techniques.

Previous trials to address poor stand examined seed pelleting, planting depth, and soil anticrustant with four fall-planted species (Shock et al. 2010). Planting at depth with soil anticrustant improved emergence compared to surface planting whereas seed pelleting did not improve emergence. Planting at 0.125-inch depth resulted in higher emergence than either surface planting or planting at 0.25-inch depth for three of the four species. Emergence for one species was too poor for any conclusions to be made. Despite these positive results, emergence was extremely poor for all species tested. Soil crusting, loss of soil moisture, and bird damage could have contributed to the poor emergence.

In established native perennial fields at the Malheur Experiment Station and in rangelands, we observed prolific emergence from seed naturally falling on the soil surface and subsequently covered by thin layers of normally occurring organic debris. Building on this observation, we developed and tested planting systems, focusing on surface-planted seed (Table 1, Shock et al. 2012-2014). Treatments included row cover, sawdust, sand, and seed treatments. Row cover can act as a protective barrier against soil desiccation and bird damage. Sawdust was intended to mimic the protective effect of organic debris. Sand could help hold the seed in place. Seed treatment could protect the emerging seed from fungal pathogens that might cause seed decomposition or seedling damping off. Trials did not test all possible combinations of treatments, but focused on combinations likely to result in adequate stand establishment based on previous observations.

Materials and Methods

In 2016 and 2017, 14 species for which stand establishment has been problematic were included and an additional species (royal penstemon; *Penstemon speciosus*) was chosen as a check, because it has reliably produced adequate stands at Ontario. Seed weights for all species were determined. In November each year, a portion of the seed was treated with a liquid mix of the fungicides Thiram and Captan (10 g Thiram, 10 g Captan in 0.5 L of water). Seed weights of the treated seeds were determined after treatment. The seed weights of untreated and treated seed were used to make seed packets containing approximately 300 seeds each. The seed packets were assigned to one of seven treatments (Table 1). The trials were planted manually on November 23, 2015 and on December 1, 2016. The experimental had randomized complete block designs with six replicates. Treatments were planted on beds 30-inch wide by 5-ft long. The seed was placed on the soil surface in two rows on each bed.

The four factors (row cover, sawdust, sand, and mulch) were applied in combined systems after planting. Sawdust was applied in a narrow band over the seeded row at 0.26 oz/ft of row (558 lb/acre). For the treatment systems receiving both sawdust and sand, 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) and was applied with a mechanical plastic mulch layer. Mouse bait packs were scattered under the row covers. For the hydroseeding mulch treatments, 10 lb of hydro seeding paper mulch (Premium Hydroseeding Mulch, Applegate Mulch, http://applegatemulch.com) was mixed in 50 gal of water in a jet agitated 50-gal hydroseeder (Turbo Turf Technologies, Beaver Falls, PA). The mulch was applied with the hydroseeder in a thin 3-cm band over the seed row. In early April each year, the row cover was removed and the trial was sprayed with Poast® at 24 oz/acre for control of grass weeds. The trial was hand weeded. Emergence counts were recorded in all plots on May 2, 2016 and May 4, 2017.

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

Results and Discussion

2016 Results

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

Adding seed treatment to sawdust plus row cover only improved stand of threadleaf phacelia and royal penstemon and reduced stands of cleftleaf wildheliotrope, showy goldeneye, and scarlet gilia. Adding sand to sawdust, seed treatment, plus row cover combination improved stand for silverleaf phacelia, threadleaf phacelia, showy goldeneye, coyote tobacco, and yellow beeplant. Hydroseed mulch with seed treatment resulted in lower stand than row cover with seed treatment for hoary tansyaster, silverleaf phacelia, cleftleaf wildheliotrope, showy goldeneye, coyote tobacco, manyflower thelypody, royal penstemon , western prairie clover, Searls' prairie clover, common yarrow, and yellow beeplant. For Douglas' dustymaiden, threadleaf phacelia, yellow beeplant, and scarlet gilia, there was no difference in stand between hydroseed mulch with seed treatment and row cover with seed treatment. However, for scarlet gilia, seed treatment was detrimental and all systems with seed treatment resulted in low stand, negating an evaluation of hydroseed mulch for this species.

2017 Results

The row cover with sawdust plus seed treatment resulted in higher stands than no row cover (bare ground) with sawdust and seed treatment only for western prairie clover and Searls' prairie clover (Table 4). Sawdust added to the row cover plus seed treatment did not improve stand of any species and reduced stand of coyote tobacco and common yarrow.

Adding seed treatment to sawdust plus row cover only improved stand of hoary tansyaster and Douglas' dustymaiden and reduced stands of cleftleaf wildheliotrope, yellow beeplant, Rocky

Mountain beeplant, and scarlet gilia. Adding sand to sawdust, seed treatment, plus row cover combination did not improve stand of any species. Hydroseed mulch with seed treatment resulted in lower stand than row cover with seed treatment for cleftleaf wildheliotrope, coyote tobacco, and western prairie clover. For the other species there was no difference in stand between Hydroseed mulch with seed treatment and row cover with seed treatment. However, for scarlet gilia, seed treatment was detrimental and all systems with seed treatment resulted in low stand, negating an evaluation of hydroseed mulch for this species.

Discussion

The differences in stand between the two years were small for the treatments that included row cover. Plant stands for the treatments that did not include row cover were higher in 2017 than in 2016. Snow cover over the winter of 2016/2017 was deeper and longer lasting than in 2015/2016. In the winter of 2015/2016 the ground was covered by snow for 44 days. In the winter of 2016/2017 the ground was covered by snow for 89 days. The longer snow cover in 2017 probably was a factor in the higher stands without row cover.

Seed treatment, sawdust, and sand were factors that had inconsistent results for most species over the two years. Some species showed consistent results over the two years for seed treatment and sawdust. Seed treatment resulted in lower stands for scarlet gilia and cleftleaf wildheliotrope both years. Sawdust reduced stands of coyote tobacco and common yarrow both years.

Acknowledgements

This project was funded by the U.S. Forest Service (USFS) Great Basin Native Plant Project (GBNPP), U.S. Bureau of Land Management (BLM), Oregon State University (OSU), Malheur County Education Service District, and supported by Formula Grant nos. 2017-31100-06041 and 2017-31200-06041 from the USDA National Institute of Food and Agriculture (NIFA).

Table 1. Planting systems evaluated for emergence of 15 native plant species. Malheur Experiment Station, Oregon State University (OSU), Ontario, OR, 2017.

#	Row cover	Seed treatment[a]	Sawdust	Sand	Mulch
1	yes	yes	yes	no	no
2	yes	yes	no	no	no
3	yes	no	yes	no	no
4	yes	yes	yes	yes	no
5	no	yes	yes	no	no
6	no	yes	no	no	yes
7	no	no	no	no	no

[a] Mixture of Captan and Thiram fungicides for prevention of seed decomposition and seedling damping off.

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

Species	Common name	Preplant untreated seed weight	Tetrazolium test	
			2016	2017
		seeds/g	%	
Chaenactis douglasii	Douglas' dustymaiden	682	72	29
Machaeranthera canescens	hoary tansyaster	1,590	70	83
Phacelia hastata	silverleaf phacelia	1,098	98	95
Phacelia crenulata	cleftleaf wildheliotrope	918	87	89
Phacelia linearis	threadleaf phacelia	4,091	98	98
Heliomeris multiflora	showy goldeneye	1,800	76	76
Nicotiana attenuata	coyote tobacco	8,333	90	93
Thelypodium milleflorum	manyflower thelypody	3,629	97	96
Ipomopsis aggregata	scarlet gilia	616	81	79
Penstemon speciosus	royal penstemon	662	85	86
Dalea ornata	western prairie clover	341	84	83
Dalea searlsiae	Searls’ prairie clover	274	81	51
Achillea millefolium	common yarrow	12,162	37	45
Cleome lutea	yellow beeplant	214	87	85
Cleome serrulata	Rocky Mountain beeplant	134	90	97

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

Species	Row cover, seed treatment, sawdust	Row cover, seed treatment	Row cover, sawdust	Row cover, seed treatment, sawdust, sand	Seed treatment, sawdust	Mulch, seed treatment	Untreated check	Average	LSD (0.05)
	----------	----------	----------	----------	% Stand	----------	----------	----------	
Douglas's dustymaiden	22.3	16.3	24.2	23.2	10.7	14.2	5.3	16.6	7.8
Hoary tansyaster	28.9	26.0	25.2	38.7	14.8	16.2	16.0	23.7	9.7
Silverleaf phacelia	23.2	28.3	21.8	31.7	11.1	3.6	8.5	18.3	7.4
Threadleaf phacelia	6.2	1.8	2.3	11.7	4.5	2.7	1.8	4.4	2.9
Showy goldeneye	33.1	31.0	44.9	41.2	6.7	1.2	2.3	22.9	7.5
Coyote tobacco	6.5	21.7	15.2	10.1	0.1	0.1	0.4	7.7	10.9
Manyflower thelypody	10.9	15.3	9.8	14.4	9.3	6.1	5.2	10.1	4.6
Scarlet gilia	2.6	1.8	22.9	4.1	0.6	0.2	2.7	5.0	7.1
Royal penstemon	23.4	11.4	15.9	26.3	3.7	0.5	0.5	11.7	5.7
Western prairie clover	4.0	6.4	4.8	4.0	0.4	0.1	0.0	2.8	4.2*
Searls' prairie clover	2.8	2.3	1.0	3.0	0.3	0.1	0.1	1.4	2.0
Common yarrow	27.9	51.1	25.7	18.2	10.5	8.0	9.3	21.5	15.5
Yellow beeplant	19.0	14.4	18.2	28.9	11.9	6.3	6.1	15.0	7.4
Rocky Mountain beeplant	7.2	2.6	7.0	7.7	4.6	1.4	1.5	4.6	2.5
Cleftleaf wildheliotrope	15.5	13.9	30.5	17.1	2.3	1.9	0.8	11.7	4.6
Average	15.6	16.3	18.0	18.7	6.1	4.2	4.0	11.8	

Table 4. Plant stands of 15 native plant species on May 4, 2017 in response to seven planting systems used in November 2016. Stand for each species was corrected to the percent of viable seed based on the tetrazolium test. To evaluate factors, the following treatment comparisons were used: Row cover, treatments 1 and 5; Seed treatment, treatments 1 and 3; Sawdust, treatments 1 and 2; Sand, treatments 1 and 4. Oregon State University (OSU), Malheur Experiment Station, Ontario, OR.

Species	Row cover, seed treatment, sawdust	Row cover, seed treatment	Row cover, sawdust	Row cover, seed treatment, sawdust, sand	Seed treatment, sawdust	Mulch, seed treatment	Untreated check	Average	LSD (0.05)
	--- % Stand ---								
Douglas’ dustymaiden	26.2	21.5	13.5	25.3	26.2	24.4	12.9	21.4	6.5
Hoary tansyaster	77.7	77.4	13.7	73.4	67.7	59.4	18.6	55.4	28.9
Silverleaf phacelia	9.5	13.7	12.3	15.2	11.8	11.8	12.7	12.4	NS
Threadleaf phacelia	13.7	10.7	13.3	12.1	10.7	11.5	11.2	11.9	NS
Showy goldeneye	7.7	8.7	16.2	10.2	8.2	11.3	12.4	10.7	NS
Coyote tobacco	12.5	35.8	10.2	21.1	9.9	6.3	8.4	14.9	12.6
Manyflower thelypody	6.3	6.1	10.2	5.3	9.3	8.7	11.2	8.2	NS
Scarlet gilia	0.6	4.9	18.6	0.3	0.2	3.5	12.5	5.8	9.4
Royal penstemon	10.8	7.6	13.0	20.2	12.7	10.3	11.2	12.3	NS
Western prairie clover	11.0	9.6	10.3	11.6	6.0	2.1	3.6	7.8	4.0
Searls’ prairie clover	3.2	2.1	2.6	3.8	1.1	1.1	1.2	2.1	1.8*
Common yarrow	30.6	49.0	36.4	27.4	31.1	38.6	46.0	37.0	11.5
Yellow beeplant	18.1	19.0	26.1	24.6	22.5	21.2	32.5	23.4	7.8*
Rocky Mountain beeplant	8.4	8.6	24.4	8.2	10.5	9.6	36.9	15.2	6.3
Cleftleaf wildheliotrope	5.2	11.5	15.0	8.7	5.7	3.9	13.3	9.0	6.5
Average	16.1	19.1	15.7	17.8	15.6	14.9	16.3	16.5	

<u>Management Applications and/or Seed Production Guidelines</u>

Irrigation water requirements for native wildflower seed production

Clint Shock and Erik Feibert, 24 January 2018

Wildflower species irrigated with drip systems at the Malheur Experiment Station, Oregon State University (OSU), Ontario, OR. Continued on next page

Species	Common names	Years of research	Flowering dates*	Irrigation water needs		Years to first harvest	Stand life	Seed yield
				range	average			
				-- inches/year --			years	lb/ac per harvest
Eriogonum umbellatum	Sulphur-flower buckwheat	12	late May to July	0-8	5	1	11+	100-350
Eriogonum heracleoides	Parsnipflowered buckwheat	7	May to June	0-4	5	2	6+	50-400
Penstemon acuminatus	Sharpleaf penstemon	4	late April to early June	0-4	0	2	3	100-600
Penstemon deustus	Scabland penstemon	7	May to early July	0-4	0	1	2	200-600
Penstemon speciosus	Royal penstemon	11	May to June	0-5	4	2	3	25-350
Penstemon cyaneus	Blue penstemon	7	May to June	0-8	0	1	3	200-800
Penstemon pachyphyllus	Thickleaf beardtongue	7	late April to early June	0-8	0	2	3	200-500
Lomatium dissectum	Fernleaf biscuitroot	9	April to early May	0-12	7	4	9+	300-1200
Lomatium triternatum	Nineleaf biscuitroot	11	April to early June	4-8	8	2	10+	700-2000
Lomatium grayi	Gray's biscuitroot	11	late March to early May	0-8	5	2	10+	300-1200
Lomatium nudicaule	Barestem desert parsley	6	April to May	0	0	3	5+	500-600
Lomatium suksdorfii	Suksdorf's desertparsley	4	mid April to late May	0-8	0	4	8+	400-1800
Cymopterus bipinnatus	Hayden's cymopterus	5	April to May	0-8	5	3	5+	300-2500
Sphaeralcea parvifolia	Smallflower globemallow	5	May to June	0	0	1	4-5	100-500
Sphaeralcea grossulariifolia	Gooseberryleaf globemallow	5	May to June	0	0	1	4-5	150-400
Sphaeralcea coccinea	Scarlet globemallow	5	May to June	0	0	1	4-5	100-300

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

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

Species	Common names	Years of research	Flowering dates*	Irrigation water needs range	Irrigation water needs average	Years to first harvest	Stand life	Seed yield
				-- inches/year --			years	lb/ac per harvest
Dalea searlsiae	Searls' prairie clover	7	May to June	0-9	6	2	6+	150-300
Dalea ornata	Western prairie clover	7	May to June	0-8	5	2	6+	150-450
Astragalus filipes	Basalt milkvetch	5	late April to June	0	0	2	4+	10-100
Cleome serrulata	Rocky Mountain beeplant	6	June to August	0-8	8	1	1	100-500
Cleome lutea	Yellow beeplant	4	May to July	0-4	0	1	1	100-200
Machaeranthera canescens	hoary tansyaster	3	Mid-Aug to late Sept.	0-2	0	1	3	200-400
Phacelia hastata	silverleaf phacelia	3	May to July	0-8	7	1	3+	100-300
Phacelia linearis	threadleaf phacelia	2	early May to late June	0-6	5	1	2	150-300
Enceliopsis nudicaulis	nakedstem sunray	5	May to August	0-6	5	1	2	Oct-35
Heliomeris multiflora	showy goldeneye	5	late May to August	0-8	8	1	4+	50-250
Chaenactis douglasii	Douglas' dustymaiden	3	late May to mid July	0	0	2	3+	100-700
Crepis intermedia	limestone hawksbeard	3	late April to early June	0-8	0	3	3+	100-350
Ipomopsis aggregata	scarlet gilia	2	late April to mid July	4	4	2	2	50-300
Nicotiana attenuata	coyote tobacco	1	early May to early August	4.6		1	1	50-150
Thelypodium milleflorum	manyflower thelypody	2	mid April to early June	0	0	2	2	100-250
Achillea millefolium	common yarrow	1	late April to mid July	6.2		2	2+	200

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.

Acknowledgements

This project was funded by the U.S. Forest Service (USFS), U.S. Bureau of Land Management (BLM), Oregon State University (OSU), Malheur County Education Service District, and supported by Formula Grant no. 2017-31100-06041 and Formula Grant no. 2017-31200-06041 from the USDA National Institute of Food and Agriculture (NIFA).

Presentations

Feibert, E.B.G.; Shock, C.C.; Rivera, A.; Saunders, L.D.; Shaw, N.; Kilkenny, F.F. 2017. Irrigation Requirements for Intermountain West Rangeland Legume Seed Production. American Society of Horticultural Sciences, Waikoloa, HI. 19 September. https://ashs.confex.com/ashs/2017/webprogramarchives/Paper26340.html

Shaw, N., Shock, C.C.; Feibert, E.B.G.; Rivera, A.; Saunders, L.D.; Kilkenny, F.F. 2017. Irrigation Requirements for Seed Production of Eriogonum Species for Use in Intermountain West Rangeland Restoration. American Society of Horticultural Sciences, Waikoloa, HI. 22 September. https://ashs.confex.com/ashs/2017/webprogramarchives/Paper26336.html

Shock, C.C., Feibert, E.B.G.; Shaw, N.L. 2017 Ecological restoration hurdles to use rarely cultivated plants; developing reliable seed production technology. Society for Ecological Restoration, Iguassu Falls, Parana, Brazil, 31 August.

Field days

- *Native Wildflower Seed Production Field Day*, Malheur Experiment Station, Oregon State University (OSU), Ontario, Oregon, 18 May 2017
- “Planting native wildflower seeds”, Erik Feibert and Clint Shock
- “Wildflower sequence of flowering”, Clint Shock and Erik Feibert
- “Plants supporting pollinators”, Clint Shock and Erik Feibert
- “Irrigation needs to produce seed of native wildflowers”, Clint Shock and Erik Feibert
- “Seed harvests and expected seed yields”, Erik Feibert and Clint Shock
- “Drip irrigation systems”, Erik Feibert and Clint Shock
- *Summer Farm Festival and Malheur Experiment Station Field Day*, Malheur Experiment Station, Oregon State University (OSU), Ontario, Oregon, 12 July 2017.
- Alternative crops. This tour will highlighted quinoa and wildflower seed production. Erik Feibert and Clint Shock.

Publications

Refereed Journal Articles

Shock, C.C.; Feibert, E.B.G.; Rivera, A.; Saunders, L.D.; Shaw, N.; Kilkenny, F.F. 2017. Irrigation Requirements for Seed Production of Two *Eriogonum* Species in a Semiarid Environment. HortScience 52: 1188-1194.

Annual Reports

Shock, C.C.; Feibert, E.B.G.; Rivera, A.; Saunders, L.D.; Kilkenny, F.F.; Shaw, N. 2017. Direct surface seeding systems for the establishment of native plants in 2016. p 123-130 In Shock C.C. (Ed.) Oregon State University (OSU) Agricultural Experiment Station, Malheur Experiment Station Annual Report 2016, Department of Crop and Soil Science Ext/CrS 157.

Shock, C.C.; Feibert, E.B.G.; Rivera, A.; Saunders, L.D.; Shaw, N.; Kilkenny, F.F. 2017. Native beeplant seed production in response to irrigation in a semi-arid environment. p 140-144 In Shock C.C. (Ed.) Oregon State University (OSU) Agricultural Experiment Station, Malheur Experiment Station Annual Report 2016, Department of Crop and Soil Science Ext/CrS 157.

Shock, C.C.; Feibert, E.B.G.; Rivera, A.; Saunders, L.D.; Shaw, N.; Kilkenny, F.F. 2017. Irrigation requirements for native buckwheat seed production in a semi-arid environment. p 145-152 In Shock C.C. (Ed.) Oregon State University (OSU) Agricultural Experiment Station, Malheur Experiment Station Annual Report 2016, Department of Crop and Soil Science Ext/CrS 157.

Shock, C.C.; Feibert, E.B.G.; Rivera, A.; Saunders, L.D.; Johnson, D.; Bushman, S.; Shaw, N.; Kilkenny, F. 2017. Prairie clover and basalt milkvetch seed production in response to irrigation. p 153-159 In Shock C.C. (Ed.) Oregon State University (OSU) Agricultural Experiment Station, Malheur Experiment Station Annual Report 2016, Department of Crop and Soil Science Ext/CrS 157.

Shock, C.C.; Feibert, E.B.G.; Rivera, A.; Saunders, L.D.; Shaw, N.; Kilkenny, F.F. 2017. Irrigation requirements for seed production of five *Lomatium* species in a semi-arid environment. p 160-173 In Shock C.C. (Ed.) Oregon State University (OSU) Agricultural Experiment Station, Malheur Experiment Station Annual Report 2016, Department of Crop and Soil Science Ext/CrS 157.

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 18 May 2017.
- 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

References

Shock, C.C.; Feibert, E.B.G.; Parris, C.; Saunders, L.D.; Shaw, N. 2012. Direct surface seeding strategies for establishment of Intermountain West native plants for seed production. Oregon State University (OSU) Malheur Experiment Station Annual Report 2011, Ext/CrS 141:130-135.

Shock, C.C.; Feibert, E.B.G.; Saunders, L.D.; Shaw, N. 2010. Emergence of native plant seeds in response to seed pelleting, planting depth, scarification, and soil anti-crusting treatment. Oregon State University (OSU) Malheur Experiment Station Annual Report 2009, Ext/CrS 131:218-222.

Shock, C.C., Feibert, E.B.G.; Saunders, L.D.; Johnson, D.; Bushman, S. 2013. Direct surface seeding strategies for establishment of two native legumes of the Intermountain West. Oregon State University (OSU) Malheur Experiment Station Annual Report 2012, Ext/CrS 144:132-137.

Shock, C.C., Feibert, E.B.G.; Saunders, L.D.; Shaw, N. 2014. Direct surface seeding systems for successful establishment of native wildflowers. Oregon State University (OSU) Malheur Experiment Station Annual Report 2013, Ext/CrS 149:159-165.

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

RESTORATION STRATEGIES

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

Project Agreement No. 15-IA-11221632-205

Principal Investigators and Contact Information

Kirk W. Davies, Rangeland Scientist
Agricultural Research Service
67826-A Hwy 205, Burns, OR 97720
541.573.4074, Fax 541.573.3042
kirk.davies@oregonstate.edu

Project Description

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

Introduction

We are evaluating sagebrush restoration success with five methods across an elevation gradient using a randomized block design. Treatments were randomly assigned within block (site) and include: 1) natural recovery (control), 2) broadcast seeding sagebrush, 3) broadcast seeding sagebrush followed by roller-packing, 4) broadcast seeding sagebrush seed pillows, and 5) planting sagebrush seedlings. All sagebrush used in the study were big sagebrush *(Artemisia tridentata)*. However, subspecies (Wyoming or mountain) of big sagebrush varied based on the potential natural community type. Wyoming (*Artemisia tridentata* ssp. *wyomingensis*) and mountain (*Artemisia tridentata* ssp. *vaseyana*) big sagebrush were seeded and planted on sites where Wyoming or mountain big sagebrush was dominant prior to burning, respectively. Treatments were applied along five transects that span an elevation gradient from 1219 to 2134 m (4000 to 7000 ft). Along each elevation gradient, treatments were applied at approximately 1219, 1372, 1524, 1676, 1829, 1981, and 2134 m (4000, 4500, 5000, 5500, 6000, 6500, and 7000 ft) elevation. At each elevation on each transect, treatments were randomly assigned to five 5 X 10 m plots with a 2 m buffer between treatment plots in each year. Total number of blocks was 35 (5 elevation transects X 7 elevations per transect = 35 blocks) and total number of treatment plots was 350 (5 treatments X 2 years X 35 blocks = 350 plots). All sagebrush seeding treatments were applied at a rate of 1.1 kg pure live seed per hectare in the fall. Roller-packing was applied by pulling a small roller-packer by hand across the plot after seeding. Seed pillows were a mixture that promotes survival, growth, and establishment of sagebrush (exact formulation is not reported because of proprietary rights). Seeds and seed pillows were broadcasted using a non-automated centrifugal flinger fertilizer spreader. Sagebrush seedlings were hand planted at a density of 1 seedling per m^2. Sagebrush seedlings were grown to a pre-planting height of approximately 15 cm by planting five sagebrush seeds in seedling cone containers in a greenhouse. Cone containers were 3.8 cm diameter at the top and 21 cm tall. Sagebrush seedlings were thinned to one individual per cone container. Sagebrush seedlings were planted in the spring by digging a hole approximately 21 cm deep, placing the seedling in the hole, and pressing the soil around the roots of the seedlings.

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 m^2 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 m^2 quadrats. Density will be measured by species by counting all plants rooted inside the 0.2 m^2 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 determined from nearby weather stations.

Expected Results and Discussion

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

Management Applications

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

Presentations

K.W. Davies. 2017. Sagebrush restoration across a large elevation gradient. Great Basin Native Plant Project. Reno, NV. November 2017.

K.W. Davies. 2017. Native plant restoration in sagebrush communities: challenges and opportunities. High Desert Museum. Natural History Pub Event. Bend, OR. November 2017.

K.W. Davies. 2017. Restoring sagebrush after wildfires and prescribed burning. Northwest Basin and Range Ecosystem Symposium. Lakeview, OR. February 2017.

Hulet, A. and K.W. Davies. 2017. Restoring sagebrush after mega-fires: success of different restoration methods across an elevation gradient. Society for Range Management National Meetings. St. George, UT. February 2017.

Publications

Davies, K.W., C.S. Boyd, M.D. Madsen, J. Kerby and A. Hulet. (IN PRESS). Evaluating a seed technology for sagebrush restoration efforts across an elevation gradient: support for bet hedging. Rangeland Ecology & Management

Additional Products

None

References

N/A

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

Project Agreement No. 15-IA-11221632-211

Principal Investigators and Contact Information

Kristin Hulvey, Assistant Professor
Department of Wildland Resources
Utah State University
Logan, UT 84322-5230
435.797.5522, Fax 435.797.3796
kris.hulvey@usu.edu

Thomas A. Monaco, Ecologist
USDA-Agricultural Research Service
Forage and Range Research Lab
Utah State University
Logan, UT 84322-6300
435.797.7231, Fax 435.797.3075
tom.monaco@ars.usda.gov

Douglas A. Johnson, Plant Physiologist (retired)
USDA-Agricultural Research Service
Forage and Range Research Lab
Utah State University
Logan, UT 84322-6300
435.797.3067, Fax 435.797.3075
doug.johnson@ars.usda.gov

Other collaborators

Derek Tilley - Natural Resources Conservation Service (NRCS), Scott Jensen – United States Forest Service (USFS), Matt Madsen – Brigham Young University (BYU), Adam Fund (Utah State University), Erica David (Perth, Australia), Jim Cane (ARS)

Project Description

Introduction

Public land management agencies (Bureau of Land Management (BLM), Forest Service (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.

Objectives

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

Methods

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

Field studies were first established during November 2015 (Yr-1 plots) with three primary treatments (HFFS, N-sulate fabric, and Control) in a randomized complete block design with four replications at two sites in Utah (Spanish Fork, Clarkston) and one site in Idaho (Virginia). The two Utah sites are located on cultivated land, and the Idaho site was recently placed into the Conservation Reserve Program (CRP) to control erosion and enhance pollinator and sage-grouse habitat. During November 2015, 33 rows of two forb species (basalt milkvetch, western prairie clover) treated with 14 specific seed coatings (Table 1) seeded into 1.5-m (5 ft) long rows at a rate of 82 PLS m^2 in each of the three main site treatments (HFFS, N-sulate, and Control) with a four-row Hege cone seeder (Figure 1). The remaining 1.5-m (5 ft) portion in each of the 33 rows in each treatment combination was seeded to 10 forb species native to the Intermountain West with three seed treatments provided for each species compared to two check species, including small burnet (*Sanguisorba minor*) and sainfoin (*Onobrychis viciifolia*) (Table 2).

In 2016, we repeated the study, maintaining Yr-1 plots so we could monitor plant survival into the second year, but establishing a second set of randomize plots containing our three main treatments (HFFS snow fencing, plant protection fabric, and control) (Yr-2 plots). The Idaho site was moved to Downey, ID, due to logistical difficulties in maintaining the site from the previous year. We altered the Legume study seed treatments (Table 3) and Diversity study species (Table 4), but collected the same germination, emergence and establishment data as the previous year. In year 2, we also collected soil water data in each treatment at all study sites using a hand-held TDR probe to provide a mechanistic understanding of the effects of our main treatments on water availability.

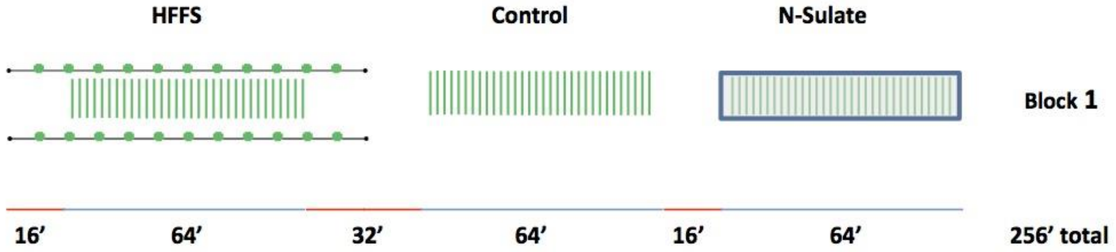


Figure 1. Plot layout for one block indicating the seeded rows in each main site treatment.

Organza mesh bags containing 25 seeds of each of the species with specific seed treatments were placed alongside the three main site treatments and covered with soil at each site for retrieval in March, April, and June of 2016 and March and April of 2017 to determine seed treatment effects on germination. Seedling emergence and phenological development were determined for seedlings in the seeded rows at each site on a monthly basis beginning in March and ending July of each year.

Results

2016-17 Legume Study

As in 2015, the effects of snow fencing and plant protection fabric varied significantly for each life stage and site in 2016. Snow fencing increased soil water availability at one site (Clarkston), and while this did not increase germination or emergence, increased soil water may have reduced seedling mortality at this site late in the growing season. Plant protection fabric increased soil water at Downey and Clarkston, but not Spanish Fork. Increased soil water did not lead to increases in germination at any site, but may have contributed to increased emergence at Downey. No increases in emergence were found at Clarkston. Decreases in emergence in plant protection plots were found at Spanish Fork when compared to controls.

Scarifying seed led to a significant increase in germination at one of our three sites (Downey), but not at either of the other two sites. Scarification did not increase emergence or end of the year survival at any site, Seed coatings did not further increase in germination at Downey, but did increase germination at both Clarkston and Spanish Fork. All seed coatings increased seedling emergence compared to unscarified and acid scarified seeds. One seed coating (scarified + FarMore fungicide + hydrophobic coating + plasticizer) increased milkvetch survival compared to unscarified seed at two sites (Downey, Spanish Fork).

Diverse Species Study

These data have not been analyzed yet.

Management Applications

Results were shared in the 2017 Natural Resources Conservation Service Aberdeen Plant Materials Center Progress Report. This project will provide land managers with information to diversify their rangeland revegetation projects.

Presentations

Results were disseminated via two presentations at national conferences by A. Fund (graduate student) including:

Fund, A., Hulvey, K., Johnson, D., Tilley, D., Jensen, S., Madsen, M. "Enhancing native forb establishment in the Great Basin using snow fences, N-sulate fabric, and seed coatings" National Native Seed Conference, Washington, DC, 2017 (talk).

Fund, A., Hulvey, K., Johnson, D., Tilley, D., Jensen, S., Madsen, M. "Novels techniques for enhancing native forb germination and establishment on Great Basin Rangelands" Society for Range Management Annual Meeting, St. George, UT, 2017 (talk).

Results were also disseminated at two regional conference by A. Fund and collaborator Scott Jensen (US Forest Service).

S. Jensen, Fund, K. Hulvey, A., D. Johnson, M. Madsen, T. Monaco, D. Tilley. Update on Possible Techniques to Improve Forb Seedling Establishment for Diversifying Sagebrush Steppe Communities. Great Basin Native Plant Project Annual Meeting, Reno, NV 2017 (talk).

Fund, A., D. Johnson, J. Cane, D. Tilley, S. Jensen, M. Madsen, K. Hulvey, T. Monaco, and E. David. Forb Islands: Possible Techniques to Improve Forb Seedling Establishment for Diversifying Sagebrush Steppe Communities. Society for Ecological Restoration, Great Basin Chapter & Great Basin Native Plant Project Annual Meeting, Boise, ID, 2016 (talk).

Publications

We are in the ***final prep stage*** of two publications to academic journals.

Fund, AJ, KB Hulvey, SL Jensen, DA Johnson, MD Madsen, TA Monaco, DJ Tilley, E David, BJ Teller. Evaluating novels techniques for native forb restoration in the Great Basin. Rangeland Ecology and Management. Estimated submission date: Feb 9, 2018

Fund, AJ, KB Hulvey, SL Jensen, DA Johnson, MD Madsen, TA Monaco, DJ Tilley, E David, BJ Teller. Evaluating snow fences and plant protection fabric as effective techniques for native forb restoration in the Great Basin. Rangeland Ecology and Management. Estimated submission date: May 30, 2018.

References

Cane, J. H. 2008. Pollinating bees crucial to farming wildflower seed for U.S. habitat restoration. In: R.R. James and T.L. Pitts-Singer (eds.), Bees in Agricultural Ecosystems. New York: Oxford Univ. Press: 48-64.

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

Cane, J. H.; Love, B.; Swoboda, K.A. 2013. Breeding biology and bee guild of Douglas' dustymaiden, *Chaenactis douglasii* (Asteraceae, Helenieae). Western North American Naturalist 72: 563-568.

Cane, J. H.; Weber, M.; Miller, S. 2012. Breeding biologies, pollinators, and seed beetles of two prairie-clovers, *Dalea ornata* and *Dalea searlsiae* (Fabaceae: Amorpheae), from the Intermountain West, USA. Western North American Naturalist 72: 16-20.

David, E. 2013. Innovative snow harvesting technology increases vegetation establishment success in native sagebrush ecosystem restoration. Plant and Soil 373: 843-856.

Jensen, S. 2009. The quest for natives: cultural practices, species screening and private growers. Ogden, UT; Department of Agriculture, Forest Service, Intermountain Research Station. Great Basin Native Plant Selection and Increase Project Annual Report: 12-18.

Madsen, M. D.; Hulet, A. 2015. Primed seed matrix composition and method of making extruded seed pellets. U.S. Patent Application No. 62/111,451.

Madsen, M. D.; Svejcar, T. J. 2013. Development and application of "seed pillow" technology for overcoming the limiting factors controlling rangeland reseeding success. U.S. Patent Application No. 14/039,873.

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

Watrous, K. W.; Cane, J. H. 2011. Breeding biology of the threadstalk milkvetch, *Astragalus filipes* (Fabaceae), with a review of the genus. American Midland Naturalist 165: 225-240.

Wisdom, M. J.; Rowland, M. M.; Wales, B. C.; Hemstrom, M. A.; Hann, W. J.; Raphael, M. G.; Holthausen, R. S.; Gravenmier, R. A.; Rich, T. D. 2002. Modeled effects of sagebrush-steppe restoration on greater sage-grouse in the interior Columbia Basin, USA. Conservation Biology 16: 1223-1231.

Table 1. List of seed coatings used in 2015 Legume study

Seed Treatment	Justification
Unscarified	Control
Acid scarified (AS)	Breaks physical seed dormancy
AS + Polymer coating	Control for seed coatings
AS + Obvius® fungicide	Soil fungal pathogen protection
AS + Farmore® fungicide	Soil fungal pathogen protection
AS + Captan® fungicide	Soil fungal pathogen protection
AS + Hydrophobic Rate 1	Delay germination
AS + Hydrophobic Rate 2	Delay germination
AS + Obvius® fungicide + Hydrophobic Rate 1	Soil fungal pathogen protection, delay germination
AS + Farmore® fungicide + Hydrophobic Rate 1	Soil fungal pathogen protection, delay germination
AS + Captan® fungicide + Hydrophobic Rate 1	Soil fungal pathogen protection, delay germination
AS + Obvius® fungicide + Hydrophobic Rate 2	Soil fungal pathogen protection, delay germination
AS + Farmore® fungicide + Hydrophobic Rate 2	Soil fungal pathogen protection, delay germination
AS + Captan® fungicide + Hydrophobic Rate 2	Soil fungal pathogen protection, delay germination

Table 2. List of species and seed coatings used in 2015 Diversity study

Species	Common names	Seed Treatments
Agoseris grandiflora	Bigflowerr agoseris	Untreated, Obvius® fungicide, Farmore® fungicide
Eriogonum heracleoides	Parsnipflower buckwheat	Untreated, Obvius® fungicide, Leach
Heliomeris multiflora var. *nevadensis*	Nevada goldeneye	Untreated, Obvius® fungicide, Farmore® fungicide
Ipomopsis aggregata	Scarlet gilia	Untreated, Obvius® fungicide, Heat
Lupinus argenteus	Silvery lupine	Untreated, Scarification, Obvius® fungicide
Lupinus prunophilus	Hairy bigleaf lupine	Untreated, Scarification, Obvius® fungicide
Onobrychis viciifolia	Sainfoin	Untreated
Penstemon pachyphyllus	Thickleaf beardtongue	Untreated, Obvius® fungicide, C
Penstemon speciosus	Royal penstemon	Untreated, Obvius® fungicide, Gibberellic acid
Sanguisorba minor	Small burnet	Untreated
Sphaeralcea coccinea	Scarlet globemallow	Untreated, Obvius® fungicide, Farmore® fungicide

Table 3. List of seed coatings used 2016 Legume study

Seed Treatment	Justification
Unscarified	Control
Acid scarified	Breaks physical seed dormancy
Acid scarified + Farmore® fungicide	Soil fungal pathogen protection
Acid scarified + Hydrophobic coating	Delay germination
Acid scarified + Hydrophobic coating + Plasticizer coating	Delay germination, increase durability of coating
Acid scarified + Farmore® + Hydrophobic coating	Soil fungal pathogen protection, delay germination
Acid scarified + Farmore® + Hydrophobic coating + Plasticizer coating	Soil fungal pathogen protection, delay germination, increase durability of coating

Table 4. List of species used in 2016 Diversity study

Species	Common names	Seed Treatments
Lupinus argenteus	Silvery lupine	Control, Scarified
Lupinus prunophilus	Hairy bigleaf lupine	Control, Scarified
Lupinus sericeus	silky lupine	Control, Scarified
Penstemon pachyphyllus	Thickleaf beardtongue	Control, Primed
Lomatium nudicaule	Barestem biscuitroot	Control, Primed
Sphaeralcea grossulariifolia	Gooseberryleaf globemallow	Control, Scarified, Primed

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

Project Agreement No. 15.IA.11221632.066

Principal Investigators and Contact Information:

Jeff Ott, Post-doctoral Research Geneticist
United States Forest Service
Rocky Mountain Research Station
322 E. Front Street, Suite 401
Boise, ID 83702
208.373.4353, Fax 208.373.4391
jeott@fs.fed.us

Francis Kilkenny, Research Biologist
United States Forest Service
Rocky Mountain Research Station
322 E. Front Street, Suite 401
Boise, ID 83702
208.373.4376, Fax 208.373.4391
ffkilkenny@fs.fed.us

Additional collaborators:

Tyler Thompson
Utah Department of Natural Resources
Division of Wildlife Resources
1594 W. North Temple
Suite 2110, Box 146301
Salt Lake City, UT 84114
801.538.4876
tylerthompson@utah.gov

Danny Summers
Utah Department of Natural Resources
Division of Wildlife Resources
Great Basin Research Center
494 West 100 South
Ephraim, UT 84697
435.283.4441
dannysummers@utah.gov

Steve Petersen
Department of Plant and Wildlife Sciences
Brigham Young University
Provo, UT 84602
801.422.4885
steven_petersen@byu.edu

Partial funding provided by the Joint Fire Sciences Program.

Highlights

- To better understand long-term effects of post-fire seed mixes, we revisited study sites in Tintic Valley, Utah, where seeding experiments had been initiated following a 1999 wildfire. Four different mixes had been applied using rangeland drills at a shrubland site and aerial seeding followed by chaining at a woodland site. Two seed mixes were comprised entirely of native species; the other two were conventional mixes containing introduced species.

- New vegetation data collected 16-18 years post-fire (2015-2017) revealed changes relative to data collected during the first 3 years (2000-2002). Total vegetation cover was higher during the later period, but also fluctuated between years within both periods.

- The higher-elevation aerial-seeded site had more residual perennials and fewer exotic annuals than the lower-elevation drill-seeded site. Seeding was successful at the aerial-seeded site, but in the absence of seeding there was still substantial recovery of perennial shrubs, grasses, and forbs. Some residual perennials also recruited into unseeded areas at the drill-seeded site, but these areas became largely dominated by exotic annuals.

- Native and exotic annual forbs were abundant during years 1-3, but cheatgrass (*Bromus tectorum*) became the dominant annual by year 16. Suppression of exotic annuals was greatest in conventional mixes, but native-only mixes also suppressed exotic annuals more than unseeded control treatments.

- Seeded treatments became dominated by seeded species, especially perennial grasses. Most seeded species increased in cover between years 1-3 and 16-18, but some decreased, presumably because of competitive interactions and/or maladaptation to site conditions.

- Shrub cover was minimal in conventional seed mix treatments, likely because these seed mixes had contained little shrub seed and/or because species in these seed mixes competitively suppressed shrub recruitment.

Project Description

Introduction

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

Objectives

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

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

			Mud Springs Aerial Seeding				**Jericho Drill Seeding**			
Species	**Variety/Cultivar**	**PLS[1]**	**ARS[2]**	**BLM**	**NH**	**NL**	**ARS**	**BLM**	**NH**	**NL**
Non-native Perennial Grasses										
Crested wheatgrass	Hycrest	0.85	—	4.5[3]	—	—	—	2.2	—	—
Crested wheatgrass hybrid	CD II	0.93	3.6	—	—	—	1.8	—	—	—
Intermediate wheatgrass	Luna	0.92	—	3	—	—	—	2.2	—	—
Tall wheatgrass	Alkar	0.83	—	3	—	—	—	2.2	—	—
Russian wildrye	Bozoisky	0.86	3	3	—	—	1.5	2.2	—	—
Siberian wheatgrass	Vavilov	0.89	3.8	—	—	—	1.9	—	—	—
Smooth brome	Lincoln	0.81	—	3	—	—	—	—	—	—
Native Perennial Grasses										
Basin wildrye	Magnar	0.86	—	—	3	—	—	—	2.2	—
Bluebunch wheatgrass	Whitmar	0.85 E	—	—	4.5	4.5	—	—	2.2	2.2
Bluebunch wheatgrass	Goldar	0.86	—	3	4.5	4.5	—	—	2.2	2.2
Bluebunch wheatgrass	Secar	0.89	2.5	—	—	—	1.3	—	—	—
Indian ricegrass	Rimrock	0.92	1.2	—	—	—	0.6	—	—	—
Indian ricegrass	Nezpar	0.85 E	—	—	3	3	—	—	2.2	2.2
Needle and thread	VNS	0.88	—	—	3	—	—	—	2.2	—
Sandberg bluegrass	—	0.85	—	—	3	1.5	—	—	2.2	—
Squirreltail	VNS	0.77	—	—	3	—	—	—	2.2	—
Thickspike wheatgrass	Critana	0.93	1.2	—	—	—	0.6	—	—	—
Western wheatgrass	Rosanna	0.85 E	2.4	—	3	3	1.2	—	2.2	1.1
Western wheatgrass	Aribba	0.88	—	—	—	—	—	1.1	—	—
Non-native Shrubs										
Forage kochia	Immigrant	0.71	0.8	—	—	—	0.4	—	—	—
Native Shrubs										
Antelope bitterbrush	—	0.8 E	+	+	+	+	—	—	1.1	1.1
Fourwing saltbush	—	0.32	+	+	+	+	—	0.6	1.1	1.1
Wyoming big sagebrush	—	0.14	—	—	3	1.5	—	—	2.2	1.1
Non-native Forbs										
Alfalfa	Rangelander	0.56	3	—	—	—	1.5	—	—	—
Alfalfa (inoculated)	Ladak	0.92	—	—	—	—	—	0.6	—	—

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

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

[3] Seeding rates shown are in kg ha^{-1}; + indicates seeds dribbled onto tractor treads at total rate of 2.2 kg ha^{-1}.

Methods

Seeding treatments were carried out during the fall and winter following the 1999 fire. Seeding techniques involved rangeland drills at a lower-elevation shrubland site (Jericho) and aerial seeding followed by chaining at a higher-elevation shrubland/woodland site (Mud Springs). Four different seed mixes, plus an unseeded control, were applied in randomly-arranged rectangular plots within five blocks. Two 'conventional' seed mixes formulated by the U.S. Bureau of Land Management (BLM) and Agricultural Research Service (ARS) contained non-native species introduced from Eurasia (Table 1). The other two mixes were unconventional in that they contained only native species. The Native Low (NL) mix fewer species and lower seeding rates than Native High (NH) (Table 1).

Vegetation data were collected from experimental plots each summer in 2000-2002, as reported by Thompson et al. (2006), then again in 2015-2017. Each treatment-block combination was sampled using 100 quadrats of 0.25 m^2 positioned on permanently-marked transects. Cover was measured for each plant species occurring in each quadrat using modified Daubenmire cover classes (Daubenmire 1959).

Analyses were carried out to assess responses to seeding treatments and changes over time for plant species and functional groups. Species were grouped based on origin (native/exotic), longevity (annual/perennial), and whether they had been included in seed mixes. Cover values were converted to percentages using midpoints of cover classes.

Results

The two sites differed in resilience to fire disturbance and response to seeding treatments, as shown by summaries of functional group cover (Fig. 1-2). The aerial-seeded site had more residual non-seeded perennials that resprouted or recruited following the fire (Fig 1). The drill-seeded site was more degraded and more susceptible to invasion by non-native annuals (Fig. 2). Seeded plants established more successfully at the aerial-seeded site (Fig. 1) than the drill-seeded site (Fig. 2)

Annual forbs were abundant during the first three years, especially at the drill-seeded site where they dominated all treatments (Fig. 1-2). By the 2nd year (2001), native annual forbs were largely replaced by invasive non-native annual forbs, e.g. desert alyssum (*Alyssum desertorum*), tumblemustard (*Sisymbrium altissimum*), and Russian thistle (*Salsola tragus*) (Fig. 1-2). By years 16-18 (2015-2017), invasive non-native annual grasses (primarily cheatgrass) had become more abundant than annual forbs (Fig. 1-2). Non-native annuals were least abundant in conventional seed-mix treatments (ARS, BLM) characterized by high cover of non-native perennial grasses (Fig. 1-2), suggesting that these grasses were most effective for reducing annual invasion.

Seeded perennial species had relatively low cover during the first 3 post-fire years (2000-2002), but rose to dominance by years 16-18 (2015-2017) (Fig. 1-2). Cover of perennial grasses and forbs (as well as annuals) fluctuated from year to year during 2000-2002 and 2015-2017 (Fig. 1-2) because of inter-annual variation in precipitation and grazing pressure.

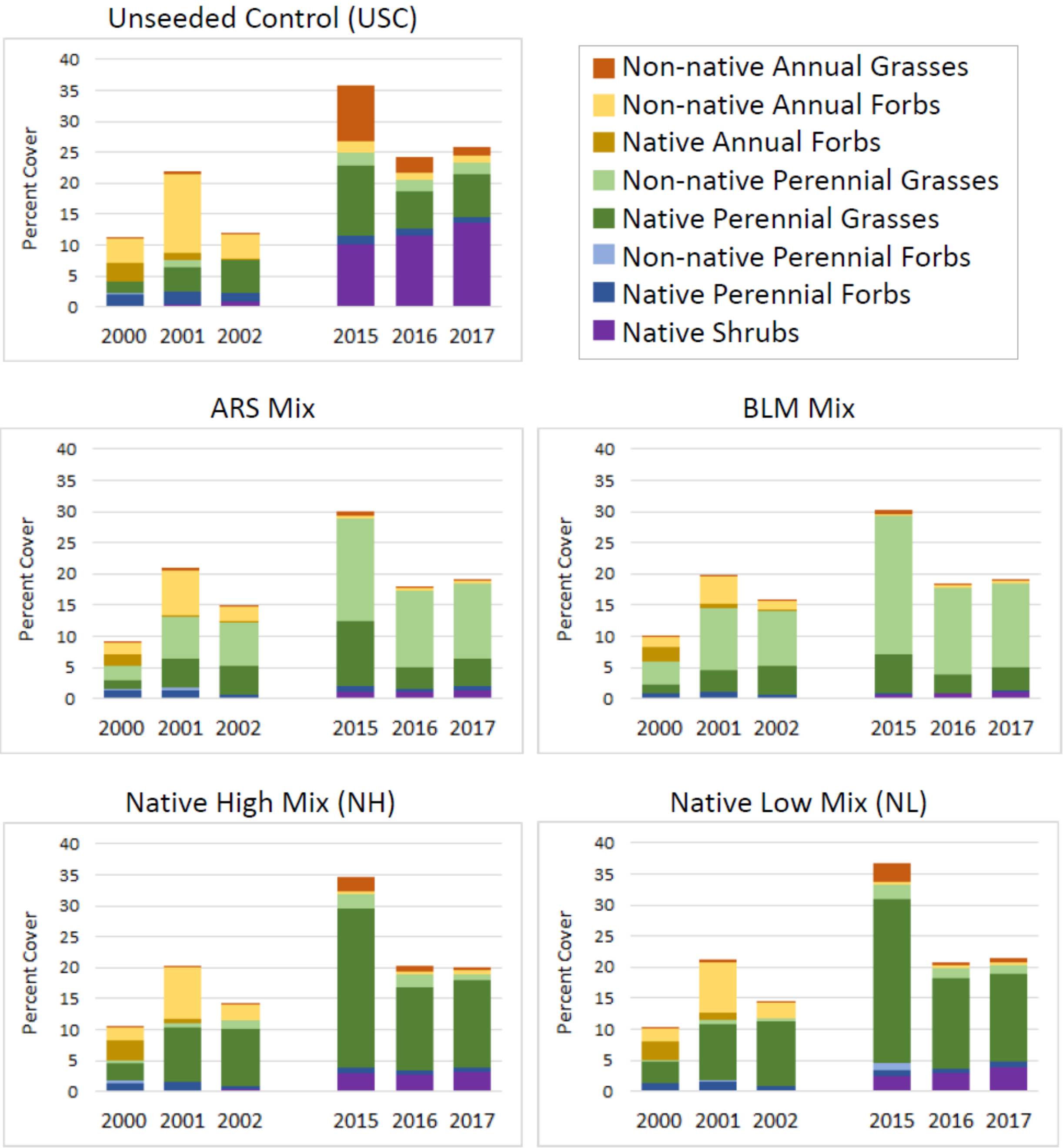


Figure 1. Cover by plant functional group across years in different treatments at the Mud Springs aerial-seeded site, Tintic Valley, Utah. Aerial seeding and chaining were applied in seeded treatments (ARS, BLM, NH and NL) following the 1999 Railroad fire.

Figure 2. Cover by plant functional group across years in different treatments at the Jericho drill-seeded site, Tintic Valley, Utah. Rangeland drill seeding was applied in seeded treatments (ARS, BLM, NH and NL) following the 1999 Railroad fire.

Non-native perennial grasses (e.g. crested wheatgrass, intermediate wheatgrass [*Thinopyrum intermedium*], and smooth brome [*Bromus inermus*]), became dominant in treatments where they had been part of the seed mix (ARS, BLM), while native perennial grasses (e.g. western wheatgrass [*Pascopyron smithii*], needle-and-thread [*Hesperostipa comata*]) and shrubs (e.g. big sagebrush [*Artemisia tridentata*], antelope bitterbrush [*Purshia tridentata*], and fourwing saltbush [*Atriplex canescens*]) became dominant in native-only seeding treatments (NH, NL) (Fig. 1-2). Although most seeded species increased between the 3rd and 16th year, some did not (e.g. alfalfa [*Medicago sativa*], bluebunch wheatgrass [*Pseudoroegneria spicata*], and Indian ricegrass [*Achnatherum hymenoides*]), presumably because of competitive interactions and/or maladaptation to site conditions. Significant native shrub cover was present 16-18 years after the fire (2015-2017), primarily in the unseeded control (USC) and the native-only seed mix treatments (NL, NH) (Fig. Fig. 1-2). Shrub cover was minimal in the ARS and BLM treatments (Fig.1-2), likely because their seed mixes had contained less shrub seed and/or because other species in their seed mixes competitively suppressed shrub recruitment.

Management Applications

This study shows that post-fire seeding can have lasting effects on vegetation patterns in Great Basin plant communities. While the abundance and dominance of particular species are likely to change over time, the initial seed mix can have a strong influence on later plant community composition. Consequently, seed mixes should be carefully formulated to promote long-term management objectives. Some sites may be able to recover with little or no seeding if residual plant populations are present. At sites where exotic annual invasion is likely, conventional seed mixes containing large amounts of competitive introduced grasses may be especially effective for exotic annual suppression, but native-only mixes can also serve this purpose to a lesser degree while avoiding drawbacks of non-native species introductions.

Presentations

Ott, J. E. 2017. Strategies and equipment for large-scale, multi-species native seedings in North American drylands. VII World Conference on Ecological Restoration, Aug. 27-Sep. 1, Iguassu, Brazil.

References

Daubenmire, R. 1959. A canopy coverage method of vegetational analysis. Northwest Science 33:4366.

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

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

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

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

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

SCIENCE DELIVERY

Project Title SeedZone Mapper Mobile App Development

Project Agreement No. 13-IA-11221632-161

Principal Investigators and Contact Information

Andrew Bower
Olympic National Forest,
1835 Black Lake Blvd SW
Olympia, WA 98502.
360.956.2405
abower@fs.fed.us

Charlie Schrader-Patton
Geospatial Technology and Applications Center
1657 NW John Fremont
Bend, OR 97701.
541.312.4291
cschrader@fs.fed.us

Project Description

Introduction

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

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

Objectives

Develop a mobile device (iOS or Android smartphone or tablet) app that would allow anyone with a smartphone or tablet device to utilize their devices on-board GPS to determine the provisional seed zone at their location even if a cell signal is not available. The app would show the user the seed zone that they are currently located in, along with a scrollable and zoomable map that would allow the user to determine the proximity of adjacent seed zones, and view other base map layers such as roads, contours, and land ownership, and collected pertinent data on materials being collected

Methods

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

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

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

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

Results and Discussion

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

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

Android only. Statewide PSZ maps are available for: Washington, Oregon, California, Idaho, Montana, Wyoming, Colorado, Utah, Nevada, New Mexico, and Arizona

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

References:

Bower, A.D., St. Clair, J.B., and Erickson, V.E. 2014. Generalized provisional seed zones for native plants. Ecological Applications. 25:913-919

Project Title Science Delivery for the Great Basin Native Plant Project

Project Agreement No. 14-JV-11221632-018

Principal Investigators and Contact Information

Corey Gucker, Outreach Coordinator
Corey Gucker Company
416 N. Garden St.
Boise, Idaho 83706
208.373.4342 or 208.703.7378
coreylgucker@fs.fed.us

Project Description

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

Objectives

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

Results and Discussion

In the final year of this project, there was considerable investment in the beginning development of a species-based manual, *Western Forbs: Biology, Ecology, and Use in Restoration*. The document synthesizes native forb research, particularly the many studies conducted over the last two decades, and knowledge gained from practical experience, largely a result of the GBNPP and work by its cooperators. This document will aid seed collectors, seed growers, nurserymen, landowners, restoration contractors, and public land managers as they increase the supply and use of native forbs in the Intermountain West. Each chapter will focus on an individual forb species and reviews current knowledge of its biology, ecology, seed technology, and use in restoration. This document is a major piece of the Project Description put forth through this agreement. Although not completed, considerable progress was made in 2018 developing a list of priority species to include in the document, the desired content, flow, and layout of species/chapter information, and working back and forth with a partner in development of a template for future species/chapters, which will be useful to both on-line and hard copy users.

Next steps are to secure additional funding to continue this endeavor and ensure the document contains all priority species and can be periodically updated.

As a result of this agreement and cooperative endeavors with the GBNPP, the following projects, events, features, and documents were completed:

- Great Basin Native Plant Project Meeting 2014. Boise, ID: March 17-18, 2014. Entirely hosted, organized, developed, advertised, and run by Boise-based GBNPP.
- Kilkenny, Francis; Shaw, Nancy; Gucker, Corey. 2014. Great Basin Native Plant Project: 2013 Progress Report. Boise, ID: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 222 p.
- Gucker, Corey; Shaw, Nancy; Halford, Anne; MontBlanc, Génie; Malcomb, Alexis. 2018. Native wildfires and post-fire restoration. Poster Presentation. Missoula, MT: Fire Continuum Conference; 2018 May 21-24.
- GBNPP briefings (1-2/year) at regional and local cooperator meetings.

The following were collected, maintained, continued, or started:

- Great Basin Native Plant Project website http://www.greatbasinnpp.org/ Regular additions, updates, edits, and payments for maintenance.
- Gathered and organized forb seed collecting and cleaning information from BLM Seeds of Success Program, USFS Region 6, Bend Seed Extractory.
- Developed template for organization of online and hard copy species/chapters for *Western Forbs: Biology, Ecology, and Use in Restoration*
- Drafted content of 11 species/chapters for *Western Forbs: Biology, Ecology, and Use in Restoration*

Project Title Climate-Smart Restoration Tool

Project Agreement No. 15-JV-11261953-071

Principal Investigators and Contact Information

Brad St. Clair, Research Geneticist
US Forest Service – Pacific Northwest Research Station
3200 SW Jefferson Way, Corvallis, OR
541.750.7294, Fax 541.750.7329
bstclair@fs.fed.us

Nikolas Stevenson-Molnar, Software Engineer
Conservation Biology Institute
136 SW Washington Ave, Suite 202, Corvallis, OR
541.368.5814, Fax 541.752.0518
nik.molnar@consbio.org

Brendan C. Ward, Chief Software Engineer
Conservation Biology Institute
136 SW Washington Ave, Ste 202
Corvallis, OR 97333
541.757.0687, Fax 541.752.0518
bcward@consbio.org

Francis Kilkenny, Research Biologist
US Forest Service – Rocky Mountain Research Station
322 E. Front St., Suite 401, Boise, ID
208.373.4376. Fax 208.373.4391
ffkilkenny@fs.fed.us

Bryce Richardson, Research Geneticist
US Forest Service – Rocky Mountain Research Station
735 N. 500 E., Provo, UT
801.356.5112, Fax 801.319.0114
brichardson02@fs.fed.us

Project Description

The Climate-Smart Restoration Tool (CSRT) is envisioned as a web-based application with interactive maps matching current seed sources with future climate conditions.

Introduction

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

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

Objectives

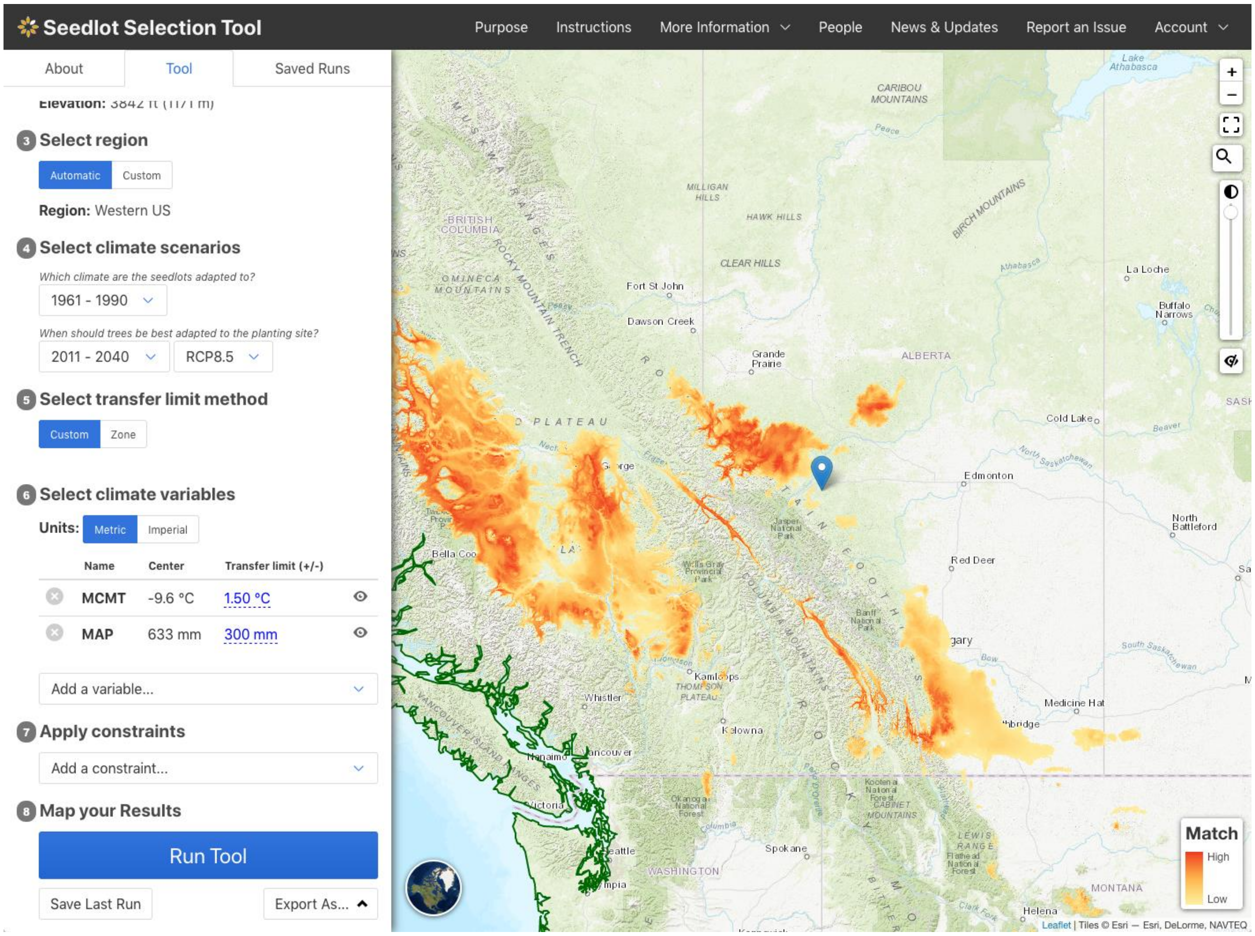
The CSRT will deliver information on current and future climate and seed zones. Information on species distributions (i.e., potential future habitats) can be incorporated in this tool in the future. Climate associated with existing ecoregions and seed zones will be displayed so that natural resource managers can choose the appropriate seed source for their restoration site, or decide where seed from a particular source can be planted in the future.

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

Methods

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

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



Elevation: 3842 ft (1171 m)

3 Select region

Region: Western US

4 Select climate scenarios

Which climate are the seedlots adapted to? 1961 - 1990

When should trees be best adapted to the planting site? 2011 - 2040 RCP8.5

5 Select transfer limit method

6 Select climate variables

Units: Metric

Name	Center	Transfer limit (+/-)
MCMT	-9.6 °C	1.50 °C
MAP	633 mm	300 mm

7 Apply constraints

8 Map your Results

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

Expected Results and Discussion

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

Management Applications and/or Seed Production Guidelines

Populations of trees, shrubs, grasses and forbs are genetically different from one another, and are adapted to different climatic conditions. Natural resource managers must match the climatic adaptability of their seed sources to the climatic conditions of their restoration sites.

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

Presentations

Stevenson-Molnar, Nikolas. 2017. Climate-Smart Restoration Tool. Great Basin Native Plant Project Workgroup Meeting; 2017 November 8-9; Reno, NV.

Stevenson-Molnar, Nikolas; Howe, Glenn; St. Clair, Brad; Bachelet, Dominique; Ward, Brendan C. 2017. Climate-Smart Seedlot Selection Tool: Reforestation and Restoration for the 21st Century; 2017 December 13; New Orleans, LA.
Abstract:
Local populations of trees are generally adapted to their local climates. Historically, this has meant that local seed zones based on geography and elevation have been used to guide restoration and reforestation. In the face of climate change, seeds from local sources will likely be subjected to climates significantly different from those to which they are currently adapted. The Seedlot Selection Tool (SST) offers a new approach for matching seed sources with planting sites based on future climate scenarios. The SST is a mapping program designed for forest managers and researchers. Users can use the tool to to find seedlots for a given planting site, or to find potential planting sites for a given seedlot. Users select a location (seedlot or planting site), climate scenarios (a climate to which seeds are adapted, and a current or future climate scenario), climate variables, and transfer limits (the maximum climatic distance that is considered a suitable match). Transfer limits are provided by the user, or derived from the range of values within a geographically defined seed zone. The tool calculates scores across the landscape based on an area's similarity, in a multivariate climate space, to the input. Users can explore results on an interactive map, and export PDF and PowerPoint reports, including a map of the results along with the inputs used. Planned future improvements include support for non-forest use cases and ability to download results as GeoTIFF data. The Seedlot Selection Tool and its source code are available online at https://seedlotselectiontool.org. It is co-developed by the United States Forest Service, Oregon State University, and the Conservation Biology Institute.

Publications

N/A

Additional Products

Source code and developer documentation for the CSRT will be made freely available on GitHub prior to the end of the project. Common code for both the SST and CSRT is currently available at https://github.com/consbio/seedsource-core.

References

N/A

SPECIES INTERACTIONS

Project Title Assessing Host Preferences for Arbuscular Mycorrhizal Fungi in Wyoming Big Sagebrush Seedlings and Sudan Grass

Project Agreement No. 14-JV-11221632-014

Principal Investigators and Contact Information

Marcelo D. Serpe, Professor
Department of Biological Sciences, Boise State University
1910 University Drive, Boise, ID, 83725-1515
208.426.3687
mserpe@boisestate.edu

Project Description

Introduction

Arbuscular mycorrhizal fungi (AMF) are obligate biotrophs that obtain organic carbon from the host plant and, in return, facilitate plant nutrient uptake (Smith et al. 2010). In a previous study, we investigated the AMF taxa colonizing Wyoming big sagebrush seedlings growing in seven sites through southwestern Idaho (Carter et al. 2014). Based on molecular analyses, this study revealed 6 AMF phylotypes and 34 operational taxonomic units (OTUs). Notwithstanding this diversity, certain OTUs were much more common than others. In this study, we analyzed whether differences in OTU abundance within the seedlings reflected differences in OTU abundance in the soil or preferences for certain OTUs by the host plant. For this purpose, soil from a field site was used to grow Wyoming big sagebrush and Sudan grass under greenhouse conditions. Subsequently, we compared the AMF communities colonizing these two species.

An additional motivation for comparing the AMF community composition of sagebrush and Sudan grass roots was that the latter species is often used to multiply AMF in pot cultures (Morton et al. 2004). Pot cultures could be a feasible alternative for the multiplication of native AMF, but questions remain about the changes in the AMF community that occur during pot culture cultivation (Sykorova et al. 2007). Such changes can be attributed to preferences by the plant host species for particular AMF or differences in growing conditions. To determine the extent to which plant host and growing conditions may affect AMF composition over that initially present in the field, we not only compared the AMF communities of sagebrush and Sudan grass but also the AMF community of sagebrush seedlings grown in the greenhouse with that of seedlings directly collected from the field.

Objectives

1) Determine whether the AMF taxa colonizing Sudan grass differ from those colonizing sagebrush seedlings.
2) Analyze whether AMF taxa colonizing sagebrush plants in the field varies from that colonizing sagebrush under greenhouse conditions.

3) Identify AMF taxa that colonize sagebrush seedlings at high frequency in both the field and greenhouse environments.

Methods

The AMF taxa present in sagebrush roots was first analyzed in 6 to 12 month old seedlings that were collected near Big Foot Butte, Idaho (43°18'48.43"N, 116°21'48.57"W), within the Morley Nelson Snake River Birds of Prey, National Conservation Area. The AMF taxa colonizing individual seedlings were identified based on phylogenetic analysis of sequences from the large subunit-D2 rDNA region as previously described (Carter et al. 2014). Sequences were also grouped into operational taxonomic units (OTUs) with sequence similarities ≥ 94% using the Mothur program (Schloss et al. 2009).

To compare the AMF community of sagebrush and Sudan grass roots, these plants were grown in a greenhouse in soil collected at the Big Foot Butte site. Subsequently, plants from each species were selected and the AMF present in the roots of each seedling identified as described above. Possible differences in AMF composition between sagebrush and Sudan grass seedlings or between field- and greenhouse-grown sagebrush seedlings were analyzed using non-metric multidimensional scaling (NMDS)(Minchin 1987).

Results and Discussion

Similar to other sites in southwestern Idaho (Carter et al. 2014), sagebrush seedlings at the Big Foot Butte site were colonized by several AMF taxa but a few of them were dominant (Fig. 1). In particular the OTUs *Funneliformis* 1, *Glomus II*-1, and *Glomus II*-2 were present at much higher frequency than other AMF taxa.

After growing sagebrush and Sudan grass in soil collected from the Big Foot Butte site, both species were colonized by similar AMF taxa. The NMDS analysis indicated no significance difference between the two AMF communities ($p = 0.3756$, Fig. 2). These results suggest that under the greenhouse conditions tested Wyoming big sagebrush seedlings did not have preferences for particular AMF taxa or if they did the preferences were similar to those of Sudan grass.

Comparison of the AMF community of sagebrush seedlings collected from the field site versus those growing in the same soil but in the greenhouse revealed clear differences in the AMF community ($p < 0.001$, Fig. 3). These results indicate that the AMF community colonizing sagebrush seedlings was influenced by the growing conditions. However, this varied among AMF taxa. Two OTUs (F1, and GII-2) were common in both field and greenhouse plants. In contrast, the percent of seedlings with GII-1 was much higher in field- than greenhouse plants, while OTUs within the *Rhizophagus* phylotype were more common in greenhouse- than field-grown seedlings (Fig. 4).

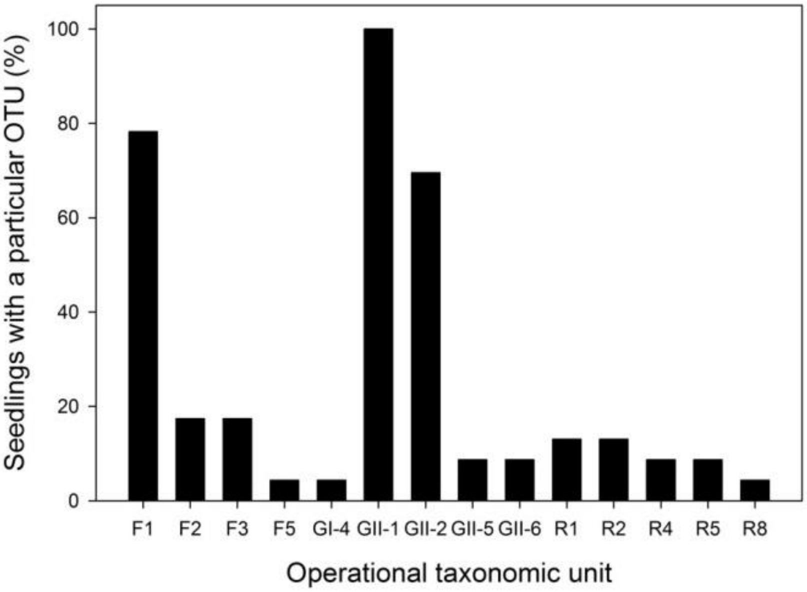


Figure 1. Percent of Wyoming big sagebrush seedlings collected at the Big Foot Butte site colonized by particular AMF OTUs. The AMF taxa were classified based on their phylotype (F, *Funneliformis*; GI, *Glomus I*; GII, *Glomus II*; R, *Rhizophagus*) and OTU within a phylotype. On average, each seedling was colonized by AMF belonging to 3.6 (± 1.2) OTUs.

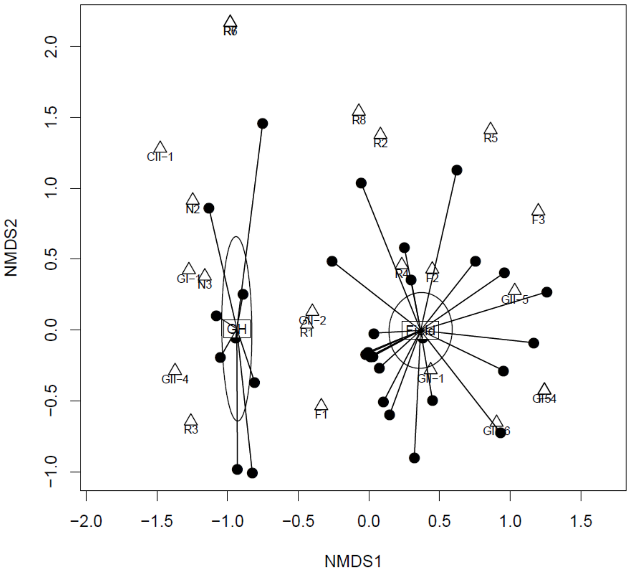


Figure 2. Comparison of arbuscular mycorrhizal communities in Wyoming big sagebrush and Sudan grass seedlings by non-metric multidimensional scaling. Both species were grown in soil collected at the Big Foot Butte site. OTUs are represented by open triangles and seedlings with filled circles. The centroids for each species are labeled (SG, Sudan grass; AT, *Artemisia tridentata*) and linked to the samples that relate to them. Ellipses represent 95% confidence limits around the centroids of each species. OTUs are labeled based on their phylotype and OTU number within its phylotype as described above.

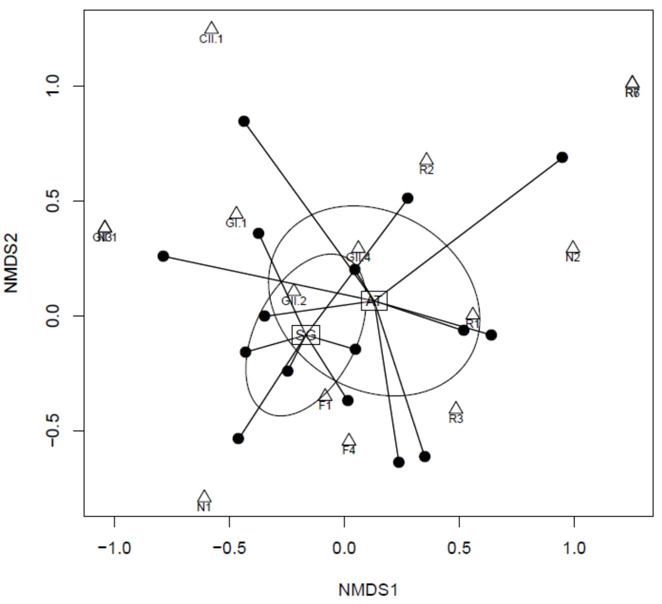


Figure 3. Comparison of arbuscular mycorrhizal communities in field- and greenhouse-grown Wyoming big sagebrush seedlings by non-metric multidimensional scaling. OTUs are represented by open triangles and seedlings with filled circles. The centroids for each growing environment are labeled (GH, greenhouse and Field) and linked to the samples that relate to them. Ellipses represent 95% confidence limits around the centroids of each growing environment. The analysis indicates a significance difference between the two AMF communities ($p < 0.001$).

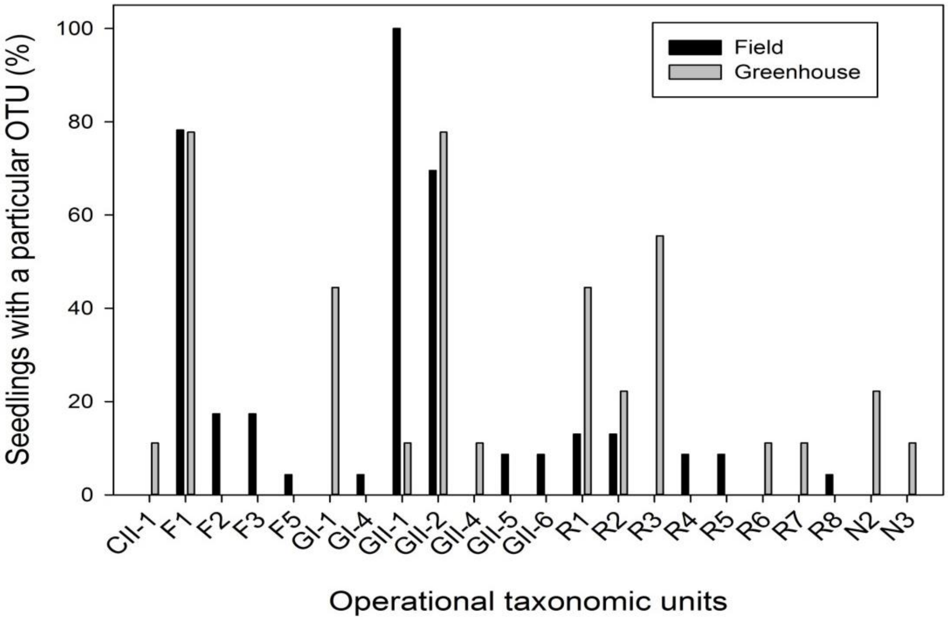


Figure 4. Percent of field- and greenhouse grown Wyoming big sagebrush seedlings colonized by particular AMF OTUs. Both field- and greenhouse-grown seedlings were on average colonized by 3.6 (± 1.3) OTUs per seedling.

Management Applications

In the sagebrush steppe, AMF spore density in the soil can be low, particularly after invasion by exotic annuals or wildfires (Wicklow-Howard 1989; Busby et al. 2013). Under this scenario, practices that increase the AMF propagule density such as inoculation of sagebrush seedlings before or at the time of transplanting can increase seedling survival (Davidson et al. 2016). For inoculation of seedlings, native AMF are valuable because they are adapted to local climatic and edaphic conditions and thus are more likely to survive and propagate after transplanting than non-native AMF (Weinbaum et al. 1996; Requena et al. 2001). A limitation with native AMF is that they may be difficult to multiply in pot cultures (Sykorova et al. 2007).

The results of this study indicates that at least two native AMF that frequently colonized sagebrush seedlings in the field, *Funneliformis* 1 and *Glomus II*-2, also grow well under greenhouse conditions. For inoculation of sagebrush seedlings with AMF, use of *Funneliformis* 1 and *Glomus II*-2 may have advantages over other inoculum because it may be easier to maintain a high density of these taxa in pot cultures. Moreover, their common occurrence in sagebrush seedlings in the field suggests that they are likely to maintain infectivity after transplanting. Current experiments are aimed at further testing these notions.

Presentations

Carpenter, C.L.; Serpe, M.D. 2017. Analysis of the symbiosis between a dark septate fungi and *Artemisia tridentata* seedlings. Morley Nelson Snake River Birds of Prey National Conservation Area science working group annual symposium.

References

Busby, R.R.; Stromberger, M.E.; Rodriguez, G.; Gebhart, D.L.; Paschke, M.W. 2013. Arbuscular mycorrhizal fungal community differs between a coexisting native shrub and introduced annual grass. Mycorrhiza 23:129–141. doi: 10.1007/s00572-012-0455-x

Carter, K.A.; Smith, J.F.; White, M.M.; Serpe, M.D. 2014. Assessing the diversity of arbuscular mycorrhizal fungi in semiarid shrublands dominated by *Artemisia tridentata* ssp. *wyomingensis*. Mycorrhiza 301–314.

Davidson, B.E.; Novak, S.J.; Serpe, M.D. 2016. Consequences of inoculation with native arbuscular mycorrhizal fungi for root colonization and survival of *Artemisia tridentata* ssp. *wyomingensis* seedlings after transplanting. Mycorrhiza. doi: 10.1007/s00572-016-0696-1

Morton, J.B.; Koske, R.E.; Stürmer, S.L.; Bentivenga, S.P. 2004. Mutualistic arbuscular endomycorrhizal fungi. In: Mueller G, Bills G, Foster M (eds) Biodiversity of fungi: inventory and monitoring methods. Academic Press, pp 317–336

Requena, N.; Perez-Solis, E.; Azcon-Aguilar, C.; Jeffries, P.; Barea, J.M. 2001. Management of indigenous plant-microbe symbioses aids restoration of desertified ecosystems. Appl Environ Microbiol 67:495–498 . doi: 10.1128/aem.67.2.495-498.2001

Schloss, P.D.; Westcott, S.L.; Ryabin, T.; Hall, J.R.; Hartmann, M.; Hollister, E.B.; Lesniewski, R.A.; Oakley, B.B.; Parks, D.H.; Robinson, C.J.; Sahl, J.W. 2009. Introducing mothur: open-source, platform-independent, community-cupported coftware for describing and comparing microbial communities. Appl Environ Microbiol 75:7537–7541 . doi: 10.1128/aem.01541-09

Smith, S.E.; Facelli, E.; Pope, S.; Smith, F.A. 2010. Plant performance in stressful environments: interpreting new and established knowledge of the roles of arbuscular mycorrhizas. Plant Soil 326:3–20

Sykorova, Z.; Ineichen, K.; Wiemken, A.; Redecker D. 2007. The cultivation bias: different communities of arbuscular mycorrhizal fungi detected in roots from the field, from bait plants transplanted to the field, and from a greenhouse trap experiment. Mycorrhiza 18:1–14 . doi: 10.1007/s00572-007-0147-0

Weinbaum, B.S.; Allen, M.F.; Allen, E.B. 1996. Survival of arbuscular mycorrhizal fungi following reciprocal transplanting across the Great Basin, USA. Ecol Appl 1365–1372

Wicklow-Howard, M. 1989. The occurrence of vesicular-arbuscular mycorrhizae in burned areas of the Snake River Birds of Prey Area, Idaho. Mycotaxon 34:253–257

Project Title Comprehensive Assessment of Restoration Seedings to Improve Restoration Success

Project Agreement No. 15-JV-11221632-197

Principal Investigators and Contact Information

Kari E. Veblen, Assistant Professor
Utah State University
5230 Old Main Hill
Logan, UT 84322-5230
435.797.3970, Fax 435.797.3796

Thomas Monaco, Ecologist
USDA-ARS Forage and Range Res. Lab.
Utah State University
Logan, Utah 84322-6300
435.797.7231, Fax 435.797.3075

Other collaborators

Jason Vernon, Danny Summers, Kevin Gunnell (Great Basin Research Station), Eric Thacker (USU), Joe Robins (USDA-ARS), Lacey Wilder (USU), Corinna Riginos (TNC)

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 63 sagebrush 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 are assessing the relative success of seeded grass, forb, and shrub species as part of an ongoing effort to determine environmental and ecological factors controlling sagebrush ecosystem restoration.

Objectives

Specific project objectives are to 1) determine the separate and combined effects of soils, environmental parameters, restoration treatments, and seeding techniques on plant species establishment and persistence, 2) decipher the association between plant species traits and seedling establishment and persistence in the field, and 3) quantify the cost effectiveness and efficiency of these seeding efforts.

Methods

Detailed vegetation monitoring has been conducted at WRI sites before and at various intervals after applying restoration/seeding treatments. In the first year of this project we compiled cover and density data and assessed species establishment and persistence with respect to environmental parameters, restoration treatments, and seeding techniques. We used effect-size analysis (e.g., log response ratio of pre/post species cover and density) to analyze field data collected between 2003 and 2013. Effect sizes can either be positive or negative, depending on whether a species established or failed, respectively. This technique is ideal for analysis of disparate sites and treatment years.

We used this approach to assess responses of 15 perennial species including seven grasses, five forbs, and three shrubs to aerator, pipe harrow and fire treatments across 63 project sites (Table 1). We separately examined establishment (1-4 years after treatment) and persistence (5-10 years after treatment) of the focal plant species. Moderator analyses also were used to explore the effects of environmental factors such as soil type, sagebrush community type, ecoregion, native vs. introduced, and species*treatment effects.

Table 1. Scientific name, common name, species code used, and growth form (S, shrub; F, forb, and G, grass) of seeded species. Arrange by growth form and then in alphabetical order.

Species	**Common Name**	**Species Code**	**Growth Form**	**Native/ Introduced**
Atriplex canescens (Pursh) Nutt.	fourwing saltbrush	ATCA	S	Native
Bassia prostrata (L.) A.J. Scott	forage kochia	BAPR	S	Introduced
Artemisia tridentata Nutt.	Sagebrush	ARTR	S	Native
Linum perenne	Blue Flax	LIPE	F	Introduced
Melilotus officinalis (L.) Lam.	yellow sweetclover	MEOF	F	Introduced
Medicago sativa L.	Alfalfa	MESA	F	Introduced
Onobrychis viciifolia Scop.	Sainfoin	ONVI	F	Introduced
Sanguisorba minor Scop.	small burnet	SAMI	F	Introduced
Achnatherum hymenoides (Roem. & Schult.) Barkworth	Indian Ricegrass	ACHY	G	Native
Agropyron cristatum (L.) Gaertn.	crested wheatgrass	AGCR	G	Introduced
Elymus lanceolatus (Scribn. & J.G. Sm.) Gould	thickspike wheatgrass	ELLA	G	Native
Leymus cinereus (Scribn. & Merr.) Á. Löve	Great Basin Wildrye	LECI	G	Native
Pascopyrum smithii (Rydb.) Á. Löve	western wheatgrass	PASM	G	Native
Psathyrostachys juncea (Fisch.) Nevski	Russian Wildrye	PSJU	G	Introduced
Pseudoroegneria spicata (Pursh) Á. Löve	bluebunch wheatgrass	PSSP	G	Native

Results and Discussion

Forage kochia frequency increased much more than the native shrubs and its abundance was more than two fold greater in the fire treatment compared to mechanical shrub removal treatments (Fig. 1). Seeded forb cover was also generally higher in the fire treatment. All forbs except yellow sweet clover also increased in the pipe harrow treatment in the short term, but this effect disappeared in the long term for alfalfa and small burnet. In contrast, cover for three forb species (i.e., blue flax, sainfoin, and small burnet) increased in the aerator treatment, but only in the short term. For grasses, treatments influenced grass species differently. For example, Great Basin wildrye was not affected by any of the treatments, yet cover of western wheatgrass increased in the mechanical treatments but not in the fire treatment. The most dramatic variation in grass species responses among treatments emerged in the long term when increases in crested wheatgrass, thickspike wheatgrass, Great Basin wildrye and bluebunch wheatgrass within the fire treatment exceeded both mechanical treatments. Cover values for crested wheatgrass and Russian wildrye were also higher in the pipe harrow treatment compared to the aerator treatment. Although grass abundance was generally lower in the aerator treatment compared to the other treatments in the long term, it improved the overall abundance of four grasses, especially the native Indian ricegrass.

The abundance of introduced species exceeded that of native species in both timeframes, especially for shrubs, whose native counterpart showed no net change in either timeframe (Fig. 2). Differences between introduced and native species were most pronounced during in the long term (i.e., 5-10 yrs post treatment).

Overall, this project assesses the success of restoration plant materials over a broad range of ecological sites throughout Utah. Our assessment will provide critical information to identify the most successful species-treatment combinations. Our results 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.

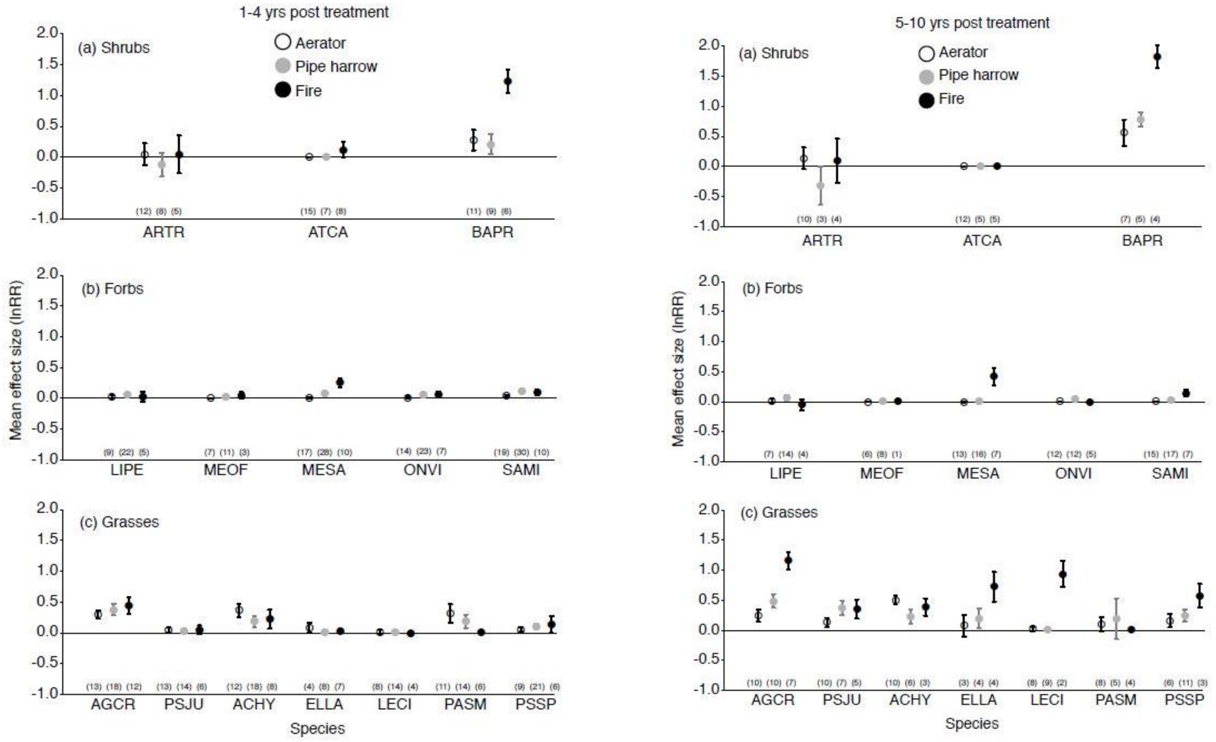


Figure 1. Effect sizes of species performance 1-4 years (left panel, “establishment”) and 5-10 years (right panel, “persistence”) after aerator, pipe harrow, and fire treatments for seeded shrubs, forbs and grasses. See Table 1 for species abbreviations. Error bars represent 95% confidence intervals.

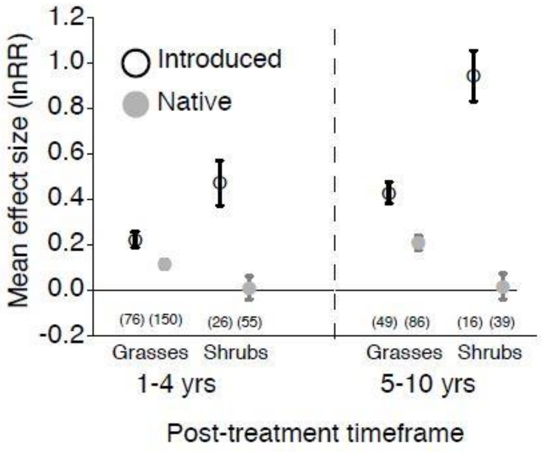


Figure 2. Effect sizes for species establishment (1-4 years post-treatment) and persistence (5-10 years post-treatment) for introduced vs. native grasses and shrubs. Forbs were excluded from analysis because they were all introduced. Error bars represent 95% confidence intervals.

Management Applications and/or Seed Production Guidelines

A cautionary result of our assessment is the possibility that the notably greater increases of introduced species may have interfered with either the establishment or growth of native species (i.e., Knutson et al. 2014). This speculation is based on the observation of more rapid increases in cover for the most successful species in each functional group (i.e., forage kochia, alfalfa, and crested wheatgrass), while native counterparts were slower to increase, possibly due to competition. Rapid development of these three species has been linked to their capacity to diminish species richness and suppress later developing species (Monaco et al. 2003). However, disentangling potential interference among seeded species is challenging in this context because seed mixes varied across sites and we did not simultaneously analyze species abundances in the same response years. The relative abundance of forage kochia may be a concern on these restoration sites, especially given its ability to spread within sagebrush ecosystems following disturbances (Gray et al. 2013). Subsequent monitoring is needed to determine if vigorous species that rapidly establish diminish over time as native sagebrush plants recover or whether they spread outside of the seeded area into native shrublands (Sullivan et al. 2013).

We conclude that all three functional groups experienced notable increases in abundance, but just a few species were actually responsible for these increases. In addition, the greatest increases were observed in introduced species that tended to do better within certain shrub-reduction treatments. The interaction between species and treatment was most dramatic over the long term due to fire having a greater influence than mechanical treatments on species abundance. Based on these results, the influence of potential shrub reduction treatments on restoration seedings should be considered on a species by species basis. Because the sites we evaluated had high potential for success, our study offers an unbiased comparison of species-treatment interactions. In addition, greater increases for introduced species signal the need to better understand the long-term implications and potential pitfalls of shifting understory composition from native to introduced species. Future research is also needed to determine how post-treatment wildlife management influences forb persistence. In addition, the greater seeded species increases within the fire treatment beckons the need to develop management strategies to utilize the period following wildfires to opportunistically seed sites (Pyke et al. 2013). Lastly, further research is needed to clarify how mechanical treatments influence seedbed conditions, especially for native species that have not been specifically developed for the prevailing anthropogenic disturbances that currently exist within sagebrush ecosystems.

Presentations

None to report

Publications

Wilder, L.E.; Veblen, K.E.; Gunnell, K.L.; Monaco, T.A. [In preparation, to be submitted to Restoration Ecology]. Influence of burning and mechanical sagebrush reduction treatments on restoration seedings in Utah.

Additional Products

- Fact sheet on effects of shrub reduction treatments (in preparation)

References

Chambers, J.C.; Bradley, B.A.; Brown, C.S.; D'Antonio, C.; Germino, M.J.; Grace, J.B. 2014. Resilience to stress and disturbance, and resistance to *Bromus tectorum* L. invasion in cold desert shrublands of western North America. Ecosystems 17:360-75.

Gray, E.C.; Muir, P.S. 2013. Does *Kochia prostrata* spread from seeded sites? An evaluation from southwestern Idaho, USA. Rangeland Ecology & Management 66: 191-203.

Hardegree, S.P.; Jones, T.A.; Roundy, B.A.; Shaw, N.L.; Monaco, T.A. 2011. Assessment of range planting as a conservation practice. In Briske, D.D. ed. Conservation Benefits of Rangeland Practices: Assessment, Recommendations, and Knowledge Gaps. Allen Press, Lawrence, KS, USA. pp. 171-212.

James, J.J.; Svejcar, T. 2010. Limitations to postfire seedling establishment: the role of seeding technology, water availability, and invasive plant abundance. Rangeland Ecology and Management 63:491-5.

Knutson, K.C.; Pyke, D.A.; Wirth, T.A.; Arkle, R.S.; Pilliod, D.S.; Brooks, M.L.; Chambers, J.C.; Grace, J.B. 2014. Long-term effects of seeding after wildfire on vegetation in Great Basin shrubland ecosystems. Journal of Applied Ecology 51:1414-1424.

Monaco T.A; Waldron, B.L.; Newhall, R.L.; Horton, W.H. 2003. Re-establishing perennial vegetation in cheatgrass monocultures. Rangelands 25:26-29.

Pyke D.A.; Wirth T.A.; Beyers J.L. 2013. Does seeding after wildfires in rangelands reduce erosion or invasive species? Restoration Ecology 21:415-421.

Sullivan A.T.; Anderson V.; Fugal R.A. 2013. *Kochia prostrata* establishment with pre-seeding disturbance in three plant communities. International Research Journal of Agriculture and Soil Science 3:353-361.

APPENDIX I – PLANT INDEX