



Great Basin Native Plant Project

2013 Progress Report

Improving the availability of native plant
materials and providing the knowledge and
technology required for their use in restoring diverse
native plant communities across the Great Basin.



GREAT BASIN NATIVE PLANT PROJECT

2013 PROGRESS REPORT

USDA FOREST SERVICE, ROCKY MOUNTAIN RESEARCH STATION

AND USDI BUREAU OF LAND MANAGEMENT, BOISE, ID

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Great Basin Native Plant Project

2013 Progress Report

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

Research priorities are to:

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

We thank our many collaborators for their dedication and their institutions for their in-kind contributions. The wide array of expertise represented by this group has made it possible to address the many challenges involved with this endeavor. We thank Corey Gucker for the careful editing and compiling of this report and other outreach materials and Jan Gurr for managing our financial reporting. Special thanks also to our resident students: Erin Denney for her artistic ability and development of outreach materials and Matt Fisk and Alexis Malcomb for expertly managing the often arduous, challenging, and always multifaceted field and laboratory research.

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Great Basin Native Plant Project

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

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HIGHLIGHTS FOR 2013

GENETICS AND SEED ZONES

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

Francis Kilkenny and Brad St. Clair

- Seed was collected in summer 2013 from 138 populations in eight seed zones in the Snake River Plain and the Northern Basin and Range ecoregions (southern transect) and in eight seed zones in the Columbia Plateau and Blue Mountains ecoregions (northern transect).
- Populations were mapped relative to the seed zones and five populations from each of eight seed zones in the northern and southern transects were selected for inclusion in the study.
- Candidate test sites and potential collaborators have been identified in each seed zone.

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

Francis Kilkenny and Brad St. Clair

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

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

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

- Study objectives are to collect key Great Basin species and establish common garden studies to quantify genetic variation in plant traits associated with phenology, production, and morphology and its relationship to source location climates.
- Data analysis from Sandberg bluegrass (*Poa secunda*) common gardens has been completed, and seed zone models were developed for mapping across the Great Basin.

- Basin wildrye (*Leymus cinereus*) data collection was completed on 112 source locations over two garden sites and three years. Initial analysis indicates climate-linked genetic variation and interactions with ploidy are important in adaptation.
- Data collection in common gardens continued for squirreltail and Thurber's needlegrass (*Achnatherum thurberianum*) from Central Ferry, Washington; Powell Butte, Oregon; and Reno, Nevada.

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

Bryce Richardson, Nancy Shaw, and Matthew J. Germino

- Project objectives are to use common garden experiments to determine climatic factors important to adaptation and develop climate-based seed zone maps for big sagebrush races.
- Flower phenology and mortality show an association with climate of origin.
- The electronic nose shows promise in diagnosing big sagebrush subspecies based upon volatile compound profiles.

Selecting Big Sagebrush Seed Sources for Restoration in a Variable Environment: Assessment of Young Seedling Responses to Climate and Management Treatments of Herbs

Matthew J. Germino and Martha Brabec

- Landscape-scale experiments have been established in the USDI Bureau of Land Management Morley Nelson Birds of Prey National Conservation Area to test the importance of seed source, manager options for treating herbs, and climate variability on growth and survival of big sagebrush seedlings.
- Seedling response to experimental warming in burned areas varies considerably among the subspecies, according to preliminary findings.
- Land treatments that target herb community abundance and composition, such as herbicide application, mowing, seeding, or their combinations, can impact survival of outplanted big sagebrush seedlings.

Field-testing Competitive Native Plant Genotypes for Restoration in Cheatgrass-invaded Rangelands

Elizabeth A. Leger and Daniel Z. Atwater

- Study objectives are to identify heritable root traits in squirreltail and determine how these traits affect emergence, survival, and height of seedlings after one growing season in the field.
- We conducted field plantings with native seeds, which were wild-collected and screened for early root growth characteristics by growing seedlings for 10 days in a greenhouse. Siblings of these seeds were planted back into their home site.
- Root architecture strongly affected performance of squirreltail in northern Nevada rangelands. Squirreltail families that produced the longest, thickest roots with the most tips had up to a six-fold increase in seedling survival and a 1.5-fold increase in size in 2012.

- Root length, specific root length (length/volume), root mass ratio (root dry mass/total dry mass), and days-to-emergence were inherited in greenhouse conditions.
- Effects of specific root traits were complex, with some traits having linear effects on performance and other traits with intermediate values being favored.
- Seed mass had weak but complex effects on squirreltail height and survival probability, with important direct effects but also complex indirect effects on performance mediated by effects of seed mass on root architecture.

Dynamics of Germination and Cold Hardiness for Great Basin Native Plants

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

- Master's thesis titled: Advancing Nursery Production of Big Sagebrush Seedlings: Cold Storage and Variation in Subspecies Growth was completed by Emily Overton.
- Germination characteristics of sulphur-flower buckwheat (*Eriogonum umbellatum*) were examined and analyzed.
- Research was initiated on cold tolerance acclimation and loss in sulphur-flower buckwheat.
- Initial research results indicate there are cold hardiness differences across the range of sulphur-flower buckwheat. This information is critical in defining seed transfer guidelines.
- Sulphur-flower buckwheat plants have been propagated by USFS Rocky Mountain Research Station, Moscow Forestry Sciences Laboratory personnel to be used in subsequent work testing seedling cold tolerance levels across ecoregions, collection years, elevation and longitudinal gradients, and provisional seed zones.

Modeling Seedling Root Growth of Great Basin Species

Bruce A. Roundy, Kert Young, and Nathan Cline

- We developed thermal accumulation models for seedling root penetration for forbs, grasses, and cheatgrass.
- The general trend across species in soil was that annual grasses required the least amount of thermal time, forbs required the most thermal time, and perennial grasses were intermediate; although Secar Snake River wheatgrass (*Elymus wawawaiensis*) was quite slow for a grass.
- Cheatgrass (*Bromus tectorum*) roots grew the fastest at cool temperatures. However, crested wheatgrasses (*Agropyron cristatum* and *A. desertorum*) and Anatone bluebunch wheatgrass (*Pseudoroegneria spicata* subsp. *spicata*) definitely grew well enough to compete with cheatgrass.
- We addressed a concern that germination timing response at extremely warm (> 86 °F [30 °C]) and cool (< 41 °F [5 °C]) temperature ranges would have high variability and may require further investigation if a large sum of thermal time occurs at those temperatures. Our results indicate that a minority of time is spent at the temperature ranges of concern. As a result, germination prediction models based on the summation of thermal time should be valid.

Pre-inoculation of Wyoming Big Sagebrush Seedlings with Native Arbuscular Mycorrhizae: Effects on Mycorrhizal Colonization and Seedling Survival after Transplanting

Marcelo D. Serpe and Bill E. Davidson

- Objectives of this study were to determine whether pre-inoculation of Wyoming big sagebrush (*Artemisia tridentata* subsp. *wyomingensis*) with arbuscular mycorrhizal fungi (AMF) increases colonization in roots that develop after transplanting, causes changes in the AMF community composition of the roots, and affects seedling survival.
- Pre-inoculation of Wyoming big sagebrush seedlings with native AMF increased colonization of the roots that developed after transplanting but only for seedlings transplanted in the fall.
- Higher levels of colonization after transplanting were associated with an increase in seedling survival.

Smoke-induced Germination of Great Basin Native Forbs

Robert Cox

- Study objectives were to test the effects of smoke on the germination of select Great Basin species.
- Tests for smoke response have been completed for 11 species: Indian ricegrass (*Achnatherum hymenoides*), Thurber's needlegrass (*A. thurberianum*), common yarrow (*Achillea millefolium*), bigflower agoseris (*Agoseris grandiflora*), big sagebrush, fourwing saltbrush (*Atriplex canescens*), rubber rabbitbrush (*Ericameria nauseosa*), silverleaf phacelia (*Phacelia hastata*), king desertparsley (*Lomatium graveolens*), royal penstemon (*Penstemon speciosus*), and Sandberg bluegrass.
- Big sagebrush showed a strong negative response to a 1:10 concentration of smoke.
- Fourwing saltbrush demonstrated a significant positive response to smoke at a 1:1000 concentration.
- The results from bigflower agoseris, Indian ricegrass, common yarrow, Thurber's needlegrass, rubber rabbitbrush, king desertparsley, silverleaf phacelia, Sandberg bluegrass, and royal penstemon were not statistically significant.

PLANT MATERIALS AND CULTURAL PRACTICES

Developing Protocols for Maximizing Establishment of Great Basin Legume Species

Douglas A. Johnson and B. Shaun Bushman

- Study objectives were to evaluate how scarification treatments, soil crusting, and soil type affected germination and emergence of select legume species and how these findings can improve establishment of legumes in the field.
- Greenhouse studies showed that seed scarification markedly improves germination and seedling emergence in western prairie clover (*Dalea ornata*), Searls' prairie clover (*D. searlsiae*), and to a lesser extent that of basalt milkvetch (*Astragalus filipes*).

- Seeded plots were established in fall 2012 and spring 2013 at Clarno, Powell Butte, and Ontario, OR. Because of extremely low spring and summer precipitation at these sites, seedlings did not establish. Plots will be seeded again in fall 2014 and spring 2015.
- Three ecotypes of Searls' prairie clover successfully established at Pleasant View, CO. Plants flowered and produced seed in the first year.

Native Forb Cultural Practices, Seed Increase, and Forb Island Plantings

Jason Stettler, Kevin Gunnell, and Alison Whittaker

- This project involved studies to produce native lupine seed (*Lupinus* spp.), treat iron deficiency in four cultivated native lupine species, collect germplasm for native penstemon species (*Penstemon* spp.), and utilize ecological niche models to identify germplasm sources.
- Native lupine seed production was tracked for a 5-year period in two common garden locations.
- Second-year data was collected for the native lupine iron deficiency chlorosis study, and seed was harvested for silky lupine (*L. sericeus*).
- Ecological niche models were developed for Palmer's penstemon (*P. palmeri*) and firecracker penstemon (*P. eatonii*) to prioritize locations for germplasm collections.
- There were 89 seed collections made of 22 native forb species.

Plant Material Evaluations at the Shrub Sciences Laboratory

Scott Jensen

- Study objectives were to provide additional seed of Great Basin forbs adapted to specific seed zones.
- Collected seed from 32 wildland sources for 5 species.
- Increased seed for 14 species representing 53 source populations.
- Evaluated emergence rates of 20 native forb species.
- Compared emergence rates of basin wildrye sources.

Aberdeen Plant Materials Center Report of Activities

Loren St. John and Derek Tilley

- The Aberdeen Plant Materials Center (PMC) is involved with plant collection, selection, and development, and seed and plant production for improving degraded or disturbed lands as well as the transfer of their garnered plant species production, establishment, and management knowledge to others.
- Natural Resource Conservation Service Plant Guides were completed or revised for: Palmer's penstemon, thistleleaf penstemon (*P. pachyphyllus*), Rydberg's penstemon (*P. rydbergii*), Columbia needlegrass (*Achnatherum nelsonii*), bigflower agoseris, showy goldeneye (*Heliomeris multiflora*), and limestone hawksbeard (*Crepis intermedia*).
- The Aberdeen PMC is progressing toward releasing seed of: Douglas' dustymaiden (*Chaenactis douglasii*), hoary tansyaster (*Machaeranthera canescens*), and Wyeth and sulphur-flower buckwheat (*Eriogonum heracleoides* and *E. umbellatum*).

Bee Pollination and Breeding Biology Studies

James H. Cane

- Established plantings of six prevalent Great Basin forb species were subjected to controlled burning of stepwise intensities and durations designed to mimic wildfires in big sagebrush communities.
- Several species largely survived burning (<30% mortality) and flowered the following year: basalt milkvetch, prairie clover, and fernleaf biscuitroot (*Lomatium dissectum*). Two others were sensitive to prolonged heating where surface temperatures were 572 °F (300 °C) or greater: blue penstemon (*Penstemon cyaneus*) and sulphur-flower buckwheat.

Etiology, Epidemiology, and Management of Diseases of Native Wildflower Seed Production

S. Krishna Mohan and Clinton C. Shock

- In 2013, the major objective of this project was to identify potentially important diseases especially powdery mildews that can result in serious native plant material losses.
- We identified many powdery mildew species, some new to the United States and some using hosts reported here for the first time.

Seed Production of Great Basin Native Forbs

Clinton C. Shock, Erik B. Feibert, Lamont D. Saunders, Nancy Shaw, and Ram K. Sampangi

- New forb establishment trials for seed production demonstrated reliable ways to establish 12 species.
- Long-term irrigation trials on perennial forbs demonstrated the water needs for more than 12 species and their longevity.
- Shorter-term irrigation trials on new forb species determined their water requirements.
- New irrigation trials on annual forb species were initiated in 2013, and preliminary results are reported.
- New preemergence and postemergence herbicide trials indicate promising products for seed production of a number of species.

SEED INCREASE

Stock Seed Production and Inventory for Native Plants in the Great Basin

Stanford Young and Michael Bouck

- The Utah Crop Improvement Association Buy-Back project facilitates development of a seed market for specific germplasm accessions, pooled accessions, and/or formal germplasm releases developed through the Great Basin Native Plant Project and rewards initial seed growers financially for the risks they assumed to participate in the program.
- Progress was made in defining seed accession groupings, knowledge of agronomic seed production techniques, and understanding the reality of the commercial seed marketplace.

Coordination of Great Basin Native Plant Project Seed Increase and Eastern Oregon/Northern Nevada Seed Collections

Berta Youtie

- Through the use of known collection sites and provisional seed zone maps, we can strategically identify future seed collection efforts for genecology (common garden) studies, germplasm conservation, and wildland seed collection or agricultural seed field increase for restoration.
- Maps were developed for three important Great Basin restoration species: sulphur-flower buckwheat, fernleaf biscuitroot, and nineleaf biscuitroot (*Lomatium triternatum*) to prioritize seed collection within the range of each species.

HORTICULTURAL USES OF NATIVE PLANTS

Demonstration, Propagation, and Outreach Education Related to Great Basin Native Plant Project Plant Materials

Heidi A. Kratsch

- Project objectives were to increase awareness and use of native Great Basin plants by the public in northwestern Nevada through use of trainings and publications.
- Created a penstemon demonstration garden with interpretive signage on the grounds of the Washoe County Cooperative Extension building.
- Developed three University of Nevada Cooperative Extension (UNCE) Fact Sheets/Special Publications on horticultural use of native Great Basin plants.
- Developed an educational module, *Native Plants in the Landscape*, for UNCE's face-to-face and online Master Gardener training programs and for Nevada's Grow Your Own consumer education program.

SPECIES INTERACTIONS

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

Keirith A. Snyder and Shauna M. Uselman

- Project objectives were to determine the relative success of early-seral and late-seral native species against aggressive nonnative species that are typically problematic in Great Basin restoration.
- Seedling emergence and early survival of early-seral native species was generally greater than that of late-seral native species when seeded with cheatgrass or medusahead (*Taeniatherum caput-medusae*).
- Native grasses were more successful than native forbs and shrubs in terms of emergence and early seedling survival, especially in a coarse-textured soil.
- Emergence and survival of medusahead was consistently very high on divergent soil types, supporting the need for preventive measures against its spread in the Intermountain West.
- Early-seral natives show promise for improving success of rangeland restoration/rehabilitation efforts in the Great Basin.

- When the early-seral native forb, bristly fiddleneck (*Amsinckia tessellata*), established successfully, its substantial biomass and reproductive output suppressed the biomass and reproductive output of medusahead.

SCIENCE DELIVERY

Science Delivery for the Great Basin Native Plant Project

Corey Gucker

- Project objectives were to facilitate delivery of Great Basin Native Plant Project (GBNPP) science.
- Became acquainted with Great Basin Native Plant Project (GBNPP) cooperators, maintained contact and correspondence throughout the year about upcoming events and project due dates.
- Developed posters and brochures for Great Basin events and meetings.
- Updated the GBNPP website with meeting announcements, new publications, and updated cooperator information.
- Worked through all aspects of planning, logistics, scheduling, and running the GBNPP annual meeting with about 100 participants.
- Compiled and edited the GBNPP annual progress report of more than 200 pages.

CRESTED WHEATGRASS DIVERSIFICATION

Evaluating Strategies for Increasing Plant Diversity in Crested Wheatgrass Seedings

Kent McAdoo and John Swanson

- Project objectives were to determine the effect of crested wheatgrass (*Agropyron cristatum*) control methods on revegetation and establishment of native seeded species.
- Preliminary results showed that density of seeded native grasses was greatest in plots that received the disking + spring glyphosate treatment for reduction of crested wheatgrass.
- Forb densities were greatest in plots receiving the disk + glyphosate treatments.
- Data analysis is currently in progress and preliminary indications suggest that glyphosate was more effective in reducing crested wheatgrass than imazapic or chlorsulfuron + sulfometuron.

The Ecology of Great Basin Native Forb Establishment

Jeremy James

- The broad objective of this research is to examine the degree to which wheatgrass competition, soil texture, and annual precipitation influence recruitment of three key Great Basin native forb species.
- Simultaneously seeding wheatgrass and forbs does not decrease forb establishment.
- Field germination of native forbs can vary 20-fold across sites within a year, but even in the best germination scenarios, more than 98% of germinated seeds die before they emerge.
- Our ability to increase forb abundance and diversity in restoration will depend on identifying traits and populations that have greater emergence probabilities.

Recruitment of Native Vegetation into Crested Wheatgrass Seedings and the Influence of Crested Wheatgrass on Native Vegetation

Kirk Davies and Aleta Nafus

- Study objectives are to determine what factors are associated with native plant recruitment in crested wheatgrass plant communities and the successional trajectories and persistence of native perennial bunchgrasses that are planted with crested wheatgrass.
- Twenty crested wheatgrass-dominated sites with a range of native vegetation establishment were sampled between June and September 2013.
- Management (Actual Use/Seeding) records were obtained for most of our 121 sites.

RESTORATION STRATEGIES AND EQUIPMENT

Revegetation Equipment Catalog Website Maintenance

Robert Cox

- The Revegetation Equipment Catalog has been fully redesigned and redeployed on the Texas Tech University server system.

Evaluation of Imazapic Rates and Forb Planting Times on Native Forb Establishment

Corey Ransom

- This project attempts to determine the tolerance of basalt milkvetch and Blue Mountain prairie clover to herbicides that are often used to control cheatgrass in conjunction with revegetation efforts.
- Scarification trials revealed that basalt milkvetch germination generally increased with longer durations of scarification up to 90 minutes, but durations above 45 minutes appeared to injure cotyledons.
- Basalt milkvetch seed germination increased dramatically when seeds were scarified for 30 minutes and then subjected to cold stratification.
- Testing forb tolerance to herbicides using an agar-based system was not a viable testing technique using the methods employed in this study.
- Impact of herbicides on germination was highly variable, and while some treatments were significantly different from each other, there were no logical trends; basalt milkvetch appeared tolerant of Prowl H₂O, but seedling development was reduced by high rates of Plateau and Matrix.

Development of Seeding Equipment for Establishing Diverse Native Communities

James Truax

- For the last 15 years, a number of modifications have been made and tested to improve the performance, durability, and success of the Truax Roughrider Minimum-till Drill in rangeland restoration.
- Modifications to improve the drill have included: changing materials to reduce drill weight, adding materials for improved seed placement, modifications to limit clogging of

seed delivery mechanisms, and altered mechanics to improve durability of drill components.

Seeding Native Species following Wildfire in Wyoming Big Sagebrush (*Artemisia tridentata* ssp. *wyomingensis*)

Jeff Ott and Nancy Shaw

- Density and cover of selected plant species were monitored for two years following fire and seeding treatments at four Wyoming big sagebrush sites in the northern Great Basin.
- Responses of large-seeded drilled species and cheatgrass were compared for two types of rangeland drills, conventional and minimum-till. For small-seeded species, comparisons were made between drill-broadcasting and hand-broadcasting (simulating aerial seeding) in combination with both drill types.
- Seeding treatment resulted in similar density and cover of large-seeded species regardless of drill type. Density decreased while cover increased between the first and second years.
- Compared to the non-drilled, non-seeded control, first-year cheatgrass density was lower in the conventional drill treatments, but second-year cover was lower in the minimum-till seeded treatment.
- Higher Wyoming big sagebrush density resulted when it was drill-broadcast through the minimum-till drill compared to the conventional drill. For both drills, density increased with seeding rate over the range tested (ca. 50-500 pure live seed m⁻²). Hand-broadcasting resulted in lower sagebrush density than drill-broadcasting at a comparable rate, with the exception of fall hand-broadcasting following conventional drilling, which yielded density equal to drill-broadcasting.
- Density of residual Sandberg bluegrass was reduced following conventional drilling compared to minimum-till drilling. Density of new Sandberg bluegrass seedlings was similar when drill-broadcast using either drill type, and hand-broadcasting resulted in density equal to or lower than drill-broadcasting.
- Density of western yarrow did not differ between seeded treatments, but cover was highest in the minimum-till drill-broadcast treatment.

Reducing Cheatgrass: Research on *Bromus tectorum*-*Sordaria fimicola* Symbiosis and the *Fusarium-Ventenata* System

George Newcombe

- Study objectives are to determine whether *sordaria* (*Sordaria fimicola*) and *fusarium* (*Fusarium*) negatively impacts cheatgrass growth and if these fungal species affect growth of native grasses.
- Explored the relationship between endophytic fungi and population ecology of invasive grasses *ventenata* (*Ventenata dubia*) and cheatgrass.
- Developed an understanding of why some native bunchgrasses such as bluebunch wheatgrass do not compete well with some exotic winter annual grasses, such as cheatgrass and *ventenata*.
- Assessed the effects of *Sordaria fimicola* isolate CID 323 on growth and fecundity of cheatgrass in the greenhouse and field experiments. Evidence of a reduction in biomass and fecundity is mixed, and may depend on genetics of cheatgrass population tested.

- Assessed the effects of twenty *Fusarium* strains isolated from ventenata and cheatgrass on emergence and aboveground biomass of ventenata, cheatgrass, and bluebunch wheatgrass.
- Determined that bluebunch wheatgrass and cheatgrass were negatively affected by most *Fusarium* strains from both exotic grasses, while ventenata had either resistance to negative effects, less negative effects, or even positive effects from *Fusarium* from both hosts.
- Accumulated evidence that *Fusarium* strains associated with ventenata act as pathogens against bluebunch wheatgrass and cheatgrass, giving ventenata a competitive advantage as a primary or secondary invader.

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CRESTED WHEATGRASS DIVERSIFICATION

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

Project Agreement No. 13-IA-11221632-161

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Project Description

Objectives

- Evaluate adaptation (establishment, survival, growth, and reproduction) over time of bluebunch wheatgrass (*Pseudoroegneria spicata*) populations from local seed zones relative to distant seed zones.
- Model adaptation as a function of the climates of source locations and test sites.
- Characterize traits and climates important for adaptation.
- Model effects of climate change on native populations and the consequences of assisted migration for responding to climate change.

Methods

Previous genecological research funded by the Great Basin Native Plant Project found that bluebunch wheatgrass populations differed in traits important for adaptation to drought and cold. Based on results of that study, seed zones were delineated for the interior Northwest including the Great Basin, Snake River Plain, Columbia Plateau, and Blue Mountains. This study tests the efficacy of seed zones delineated in the previous study for differences in re-establishment and adaptation of bluebunch wheatgrass populations from local seed zones compared to climatically distant seed zones with the hypothesis that local sources will show better establishment as well as better survival, growth, and reproduction in the long-term. To test this hypothesis, seed was collected from five populations in each of eight seed zones in each of two broad regions. Plants from each seed zone will be planted back into a single test site representative of the climate of each of the eight seed zones in a region. The two broad regions include— 1) a transect from the hot, dry climates of the lower Snake River Plain to the cool, somewhat wet climates of the

transverse ranges of the Great Basin to the cold, dry climates of the upper Snake River Plain and 2) a transect from the hot, dry climates of the Columbia Plateau to the cool, wet climates of the Blue Mountains to the cold, dry climates east of the Blue Mountains. In addition to populations from each seed zone, two widely used varieties will be included at each test site. The experimental design at each of the eight test sites per transect will be a split-plot design with a plot represented by 25 plants from each seed zone and the subplots being five populations per seed zone. Each site will include five replications. Planting spacing will be 0.5 m between plants.

Results and Discussion

This study was initiated in 2013 beginning with seed collections from 138 populations from throughout the two broad regions. From these, 78 populations were chosen for inclusion in the study based on their distribution within each of the seed zones and the amount of available seed (only four populations, not five, were available from the hottest, driest seed zone within each transect). The seed has been cleaned and is ready for sowing. The University of Idaho has been contracted to produce the containerized planting stock for the study. Potential collaborators were contacted during the past winter to help with providing test sites on their lands.

Future Plans

Test sites will be finalized this spring, and any necessary site preparation will be done over the summer. Planting stock will be grown over the summer. Test sites will be established in the fall beginning with the higher elevation sites in early September and ending with the lower elevation sites in October or November. Plans are to measure the sites every year for an indefinite length of time, but with early results presented after two growing seasons. The primary variables of interest are cover and biomass of bluebunch wheatgrass on each seed zone plot over time, but survival, plant height, crown diameter, and biomass of individual plants of each population is also of great interest. Cover and biomass of competing vegetation in each plot will also be measured. Other variables of interest include phenological, morphological, and physiological variables (including root characteristics) of bluebunch wheatgrass plants, but the extent of measurements for these other adaptive traits will depend on future funding and potential collaborators. In addition, seed from populations will be set aside for potential research looking at germination, emergence, and early establishment from seed in the climates of each seed zone, an adaptive component that we were unable to consider in this study for practical reasons.

Management Applications and/or Seed Production Guidelines

This study will test the efficacy of recently delineated seed zones for bluebunch wheatgrass for ensuring successful re-establishment and long-term adaptation, and maintaining genetic diversity of this ecologically important restoration species. The study will also explore the consequences of changing climates for adaptation by substituting space for time to evaluate different populations in different climates. Long-term productivity and adaptation will be modeled to allow evaluation of trade-offs between different management options for current and future climates. Population movement guidelines and associated seed zones can be adjusted based on results from this study and management objectives.

Presentations

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

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

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

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

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Publications

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

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

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

Additional Products

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

Testing seed zones for a key restoration species: bluebunch wheatgrass. 2013. In: Finch, D., ed. Grassland, Shrubland, and Desert Ecosystems Science Update May 2013.

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

Project Agreement No. 13-IA-11221632-161

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Project Description

Prairie junegrass

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

Objectives

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

Methods

Seed was collected from endemic stands of prairie junegrass during the summers of 2003 to 2006. Populations came from Oregon, Washington, and adjacent areas of Idaho, primarily east of the Cascade Mountains. Two families (maternal parents) were sampled from each of 114

populations, while only a single family was sampled from 12 populations, for a total of 240 families from 126 populations. Common garden studies were established in 2008 at two contrasting sites in Oregon: the USDA Natural Resources Conservation Service, Plant Materials Center in Corvallis, Oregon, and Oregon State University's Agricultural Experiment Station at Powell Butte, Oregon. A variety of traits were measured in 2009 and 2010 to assess plant growth, morphology, phenology, and fecundity. Analyses have been done to evaluate differences among test sites, years, populations, families within populations, and interactions between these factors. Analyses have also investigated the relationship between population variation and climatic variation at source locations. Maps of genetic variation across the landscape have been produced, and preliminary seed zones have been delineated based on the results.

Results

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

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

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

temperatures (i.e., selection for quicker responses to springtime warming). The general patterns that emerged from this preliminary analysis were largely congruent with large-scale ecoregions, suggesting that Omernick's Level III ecoregions may be useful for seed zones. Preliminary seed zones are presented in Figure 1.

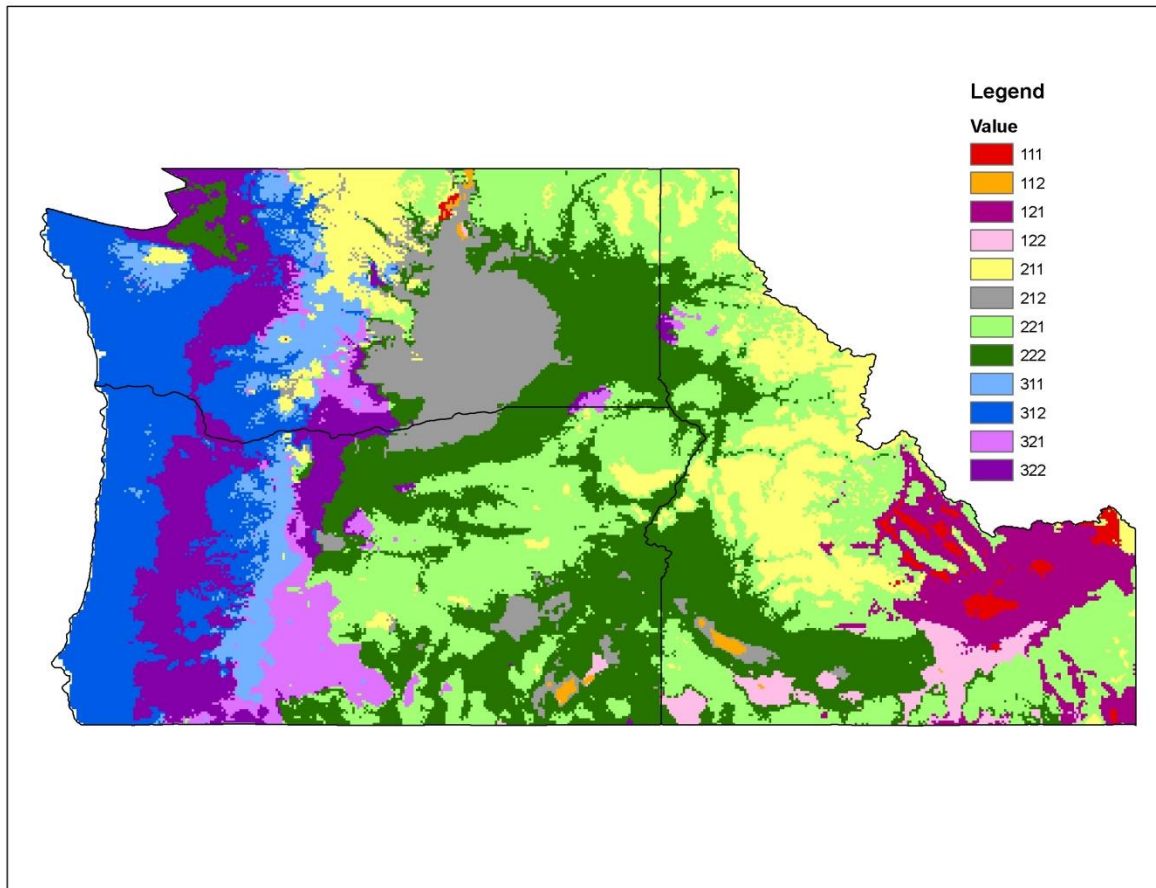


Figure 1. Preliminary seed zones for prairie junegrass. Seed zones are based on dividing the area in three principle components that represent small, intermediate, or large plant size, early or late phenology, and narrow or wide leaves.

Squirreltail

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

climatic factors across the Great Basin, the greater range of the species in a large set of diverse populations, or the mean and variation of cultivars with that of the species as a whole. Determining the extent to which adaptive genetic variation is related to climatic variation is needed to ensure that the proper germplasm is chosen for revegetation and restoration. Furthermore, comparisons of cultivars with the natural range of variation will address questions of the suitability of cultivars over larger areas.

Objectives

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

Methods

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

Results

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

Management Applications and Seed Production Guidelines

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

Publications

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

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

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

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

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

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

Additional Products

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

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

Project Agreement No. 10-IA-11221632-023

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Project Description

Native plant species are critical for wildlife habitat, livestock grazing, soil stabilization, and ecosystem function in the Western US. Yet current germplasm releases of our study species do not specifically match natural genetic diversity with local climatic variation. Using a genecology approach, seed zones matching climate with genetic variation are developed and used to facilitate management decisions, ensure restoration with adapted plant material, and promote biodiversity needed for future natural selection with climate change. Seed zones have been completed and published for tapertip onion (*Allium acuminatum*), Indian ricegrass (*Achnatherum hymenoides*), and bluebunch wheatgrass (*Pseudoroegneria spicata*) (Johnson et al. 2012; Johnson et al. 2013; St. Clair et al. 2013). Ongoing work with additional Great Basin species includes Sandberg bluegrass (*Poa secunda*), basin wildrye (*Leymus cinereus*), Thurber's needlegrass (*Achnatherum thurberianum*), squirreltail (*Elymus elymoides*), and sulphur-flower buckwheat (*Eriogonum umbellatum*).

Objectives

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

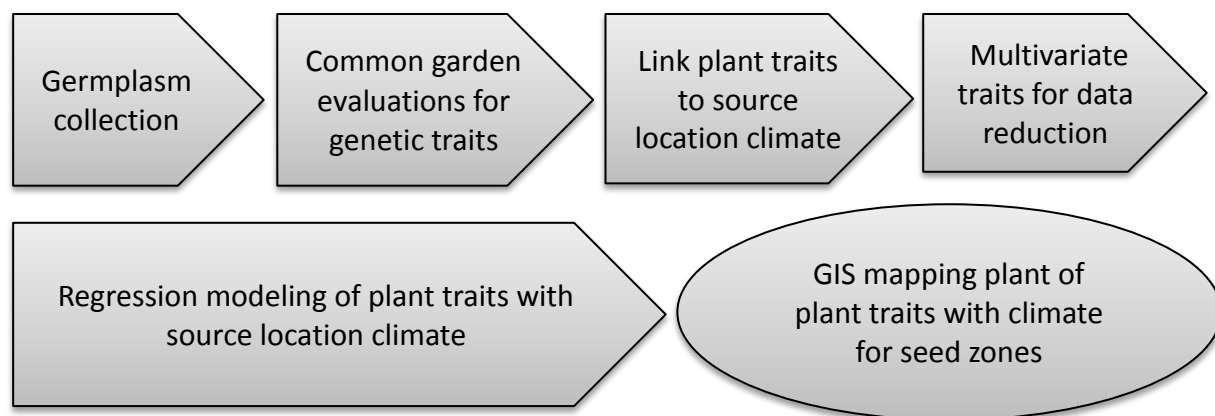


Figure 1. Schematic showing the steps for genecology studies to establish seed zones.

Sandberg bluegrass

Sandberg bluegrass common gardens were established at Powell Butte, Oregon; Central Ferry, Washington; and Sidney, Montana in 2008 using seed from 130 collection locations mostly from the Great Basin. Data was collected in each garden in 2009 and 2010 for phenology, production, and morphological traits. Analyses of variance indicated strong genetic variation among Sandberg bluegrass source locations with plant traits often correlating with climatic factors (Table 1). Canonical correlation (CanCorr) was used to develop composite plant traits for regression modeling with climate. Canonical variables 1, 2, and 3 explained 41%, 14%, and 12% of the variation, respectively, for a total of 67%. All three CanCorr variables had significant correlations with climatic factors, but CanCorr 1 correlations were strongest and most frequent (Table 1). For CanCorr variables 1, 2, and 3, regression models were developed linking genetic variation and climate. CanCorr 1 scores resulted in especially strong regression models, explaining 70% of the variation. These models will be used to develop seed zones for Sandberg bluegrass.

Table 1. Pearson correlation coefficients between garden traits and representative climatic factors for Sandberg bluegrass grown at Central Ferry, WA and Powell Butte, OR

Trait	MAT†	MWMT	MCMT	TD	MAP	MSP	AH:M	PAS	EXT
Phenology									
Heading	-0.15	-0.27**	0.08	-0.41**	0.42**	0.26**	-0.43**	0.21*	-0.30**
Blooming	0.08	0.00	0.21*	-0.25**	0.26**	0.08	-0.27**	-0.02	-0.03
Maturity	0.11	-0.27**	0.09	-0.42**	0.48**	0.32**	-0.49**	0.24**	-0.31**
Head to bloom	0.40**	0.50**	0.21*	0.31**	-0.36**	-0.39**	0.33**	-0.45**	0.49**
Head to bloom	0.14	0.19*	-0.03	0.25**	-0.24**	-0.15	0.24**	-0.14	0.20*
Bloom to maturation	-0.19*	-0.21*	-0.20*	0.01	0.00	0.12	-0.01	0.20*	-0.19*
Production									
Survival	0.09	0.26**	-0.06	0.37**	-0.43**	-0.34**	0.42**	-0.30**	0.34**
Panicles	0.11	0.09	0.15	-0.07	-0.08	-0.14	0.01	-0.21**	0.08
Dry weight	0.01	-0.06	0.08	-0.16	0.12	0.10	-0.25**	-0.02	-0.05
Crown area	-0.08	-0.15	0.02	-0.20*	0.23**	0.23**	-0.31**	0.15	-0.18*
Morphology									
Leaf l × w	0.39**	0.43**	0.20*	0.25**	-0.16	-0.31**	0.31**	-0.34**	0.40**
Leaf l × w	-0.11	-0.20*	0.00	-0.23**	0.38**	0.26**	-0.43**	0.25**	-0.17
Habit	0.07	0.03	0.19*	-0.20*	0.00	-0.17	-0.07	-0.19*	-0.03
Culm length	0.00	-0.06	0.09	-0.18*	0.10	0.07	-0.23**	-0.07	-0.02
Panicle length	0.09	0.06	0.12	-0.09	0.08	-0.01	-0.12	-0.09	0.06
CanCorr1	-0.35**	-0.53**	-0.02	-0.58**	0.60**	0.47**	-0.65**	0.47**	-0.56**
CanCorr2	-0.14	-0.18	-0.15	-0.02	0.19*	0.37**	-0.17	0.32**	-0.17
CanCorr3	0.31**	0.20*	0.27**	-0.09	0.23**	-0.03	-0.15	-0.06	0.14

†Annual climatic variables as given by Wang et al. (2012); those not shown correlate at $r > 0.80$ with a variable presented; MAT (mean annual temperature); MWMT (mean warmest month temperature); MCMT (mean coldest month temperature); TD (continentality MWMT- MCMT); MAP (mean annual ppt.), MSP (mean summer ppt. May-Sept.); AH:M (annual heat moisture index $[(MAT + 10^{\circ}C)/[MSP \text{ mm}/1000]]$); PAS (ppt. as snow), EXT (extreme max. temperature over 30 years).*, ** Significant at $p < 0.05$ ($r > 0.18$) and $p < 0.01$ ($r > 0.23$), respectively.

Basin wildrye

Common gardens of basin wildrye were established at Pullman and Central Ferry sites in Washington in 2010. The cultivars 'Trailhead', a tetraploid ($2n=4x=28$) type, and 'Magnar', an octoploid ($2n=8x=56$) type, were also included. Plants from 114 collection locations were randomized in complete blocks with six replications. Data collection for phenology, production, and morphological traits was completed 2011, 2012, and 2013. Analysis of common garden data is now underway.

Ploidy differences are likely critical to basin wildrye distribution and adaptation (Culumber et al. 2013). Collections of basin wildrye were made in the Columbia Plateau in Washington where the octoploid form is common and in the Great Basin where tetraploid and octoploid forms can be found (Culumber et al. 2013). Ploidy for all collection locations was determined using a cytometer with a Partec CyFlow® Ploidy Analyzer as described by Jakubowski et al. (2011). The analysis of field collected sources revealed 58 octoploids and 56 tetraploids. Preliminary analyses indicate production differences associated with ploidy that will be considered in climate adaptation models.

Thurber's needlegrass

Thurber's needlegrass common gardens were established in fall 2011 in Central Ferry, Washington, and Reno, Nevada. The study consists of 67 source locations predominantly from the Northern and Central Basin and Range Ecoregions. Plants from each location were randomized in eight complete blocks at both garden sites. Data was collected on numerous phenology, production, and morphological traits in 2012 and 2013.

Squirreltail

Common gardens of squirreltail were established in 2012 at Central Ferry, Washington; Powell Butte, Oregon; and Reno, Nevada, and plant collections were completed in 2013. Taxonomic considerations in squirreltail can be complex (Parson et al. 2011). The majority of common garden accessions were found to consist of *Elymus elymoides* subsp. *elymoides*, but subsp. "C" (Parson et al. 2011), subsp. *californicus*, and subsp. *hordeoides* were also represented.

Sulphur-flower buckwheat

Collections of sulphur-flower buckwheat were completed in 2012 resulting in 21 accessions. There has also been ongoing collection through the BLM Seeds of Success (SOS) program resulting in 48 accessions. Seeds from the 2012 collection and the SOS collections will be used to establish plants and common gardens.

Seeds of Success activities

Seeds of Success (SOS) and the National Plant Germplasm System (NPGS) are partnering to collect, distribute, and evaluate key native plant materials needed for conservation and restoration. In 2013, more than 1,500 new native plant accessions were added to the SOS-NPGS collections, which now total more than 8,600 accessions. Since 2006, nearly 3,300 seed distributions have been made for research projects including federal, state, US commerce, and private cooperators (Figure 2). Distribution continued to increase in 2013 with substantially more orders from international sources and US commerce compared to 2012 (Table 2).

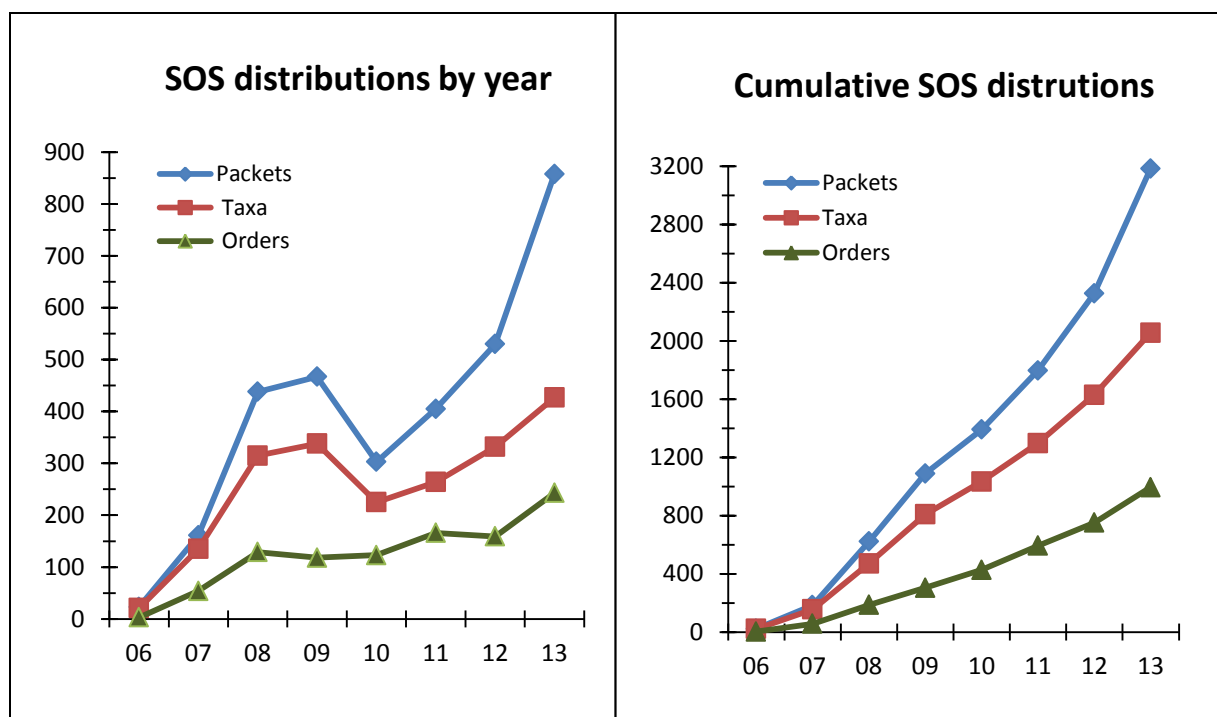


Figure 2. Distribution data for SOS accessions within the NPGS from 2006 through 2013.

Table 2. Institutional sources of SOS seed orders distributed from the NPGS over the last eight years

Year	International	State	ARS	US Commerce	Other Federal	US Individual	US Nonprofit	Other
2006	0	0	1	0	2	0	0	0
2007	7	17	2	8	3	13	1	3
2008	25	38	5	18	3	12	3	25
2009	22	35	5	15	4	10	4	23
2010	29	40	7	11	7	10	5	14
2011	40	46	14	16	4	14	7	25
2012	26	74	11	14	9	25	9	25
2013	53	68	13	25	3	33	16	32
Totals	202	318	58	107	35	117	45	147

Management Applications and/or Seed Production Guidelines

- Maps visualizing the interaction of genetic variability and climate for restoration species allow informed decisions regarding the suitability of genetic resources for restoration in varying Great Basin and southwestern environments.
- The recommended seed zone boundaries may be modified based on management resources and land manager experience without changing their basic form or links between genetic variation and climate.

- We recommend utilization of multiple populations of a given species within each seed zone to promote the biodiversity needed for sustainable restoration and genetic conservation.
- Collections representing each seed zone should be released, grown, and used for ongoing restoration projects.

Presentations

Johnson, R. C. 2013. Ecological genetics and seed zones: home on the range. Intermountain Native Plant Summit; 2013 March 26; Boise, ID.

Johnson, R. C. 2013. Genecology for seed zones: problems and solutions. National Native Seed Conference; 2013 April 8-11; Santa Fe, NM.

Publications

Johnson, R. C. 2013. Genecology for Indian ricegrass in the Southwest US. In: Plant and Animal Genome XXI Conference; 2013 January 12-16; San Diego, CA. Abstract W532.

Johnson, R. C. 2013. Genecology for seed zones: problems and solutions. In: National Native Seed Conference Abstracts; 2013 April 8-11; Santa Fe, NM.

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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.

Additional Products

- Seed zone maps for key Great Basin restoration species ensure plant materials used for restoration are adapted, suitable, and diverse.
- Collection and conservation of native plant germplasm through cooperation between NPGS, the Western Regional Plant Introduction Station in Pullman, Washington, the USDA Forest Service, and the USDI Bureau of Land Management SOS program. This ensures availability of native plant genetic resources that otherwise could be lost to disturbances such as fire, invasive weeds, and climate change.

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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.

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

Project Agreement No. 13-IA-11221632-161

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Project Description

Big sagebrush (*Artemisia tridentata*) is one of the most ecologically important and dominant landscape plant species in western North America. This species is a major focus for ecosystem restoration after disturbances because of its importance as wildlife forage, in invasive weed exclusion (e.g., cheat grass [*Bromus tectorum*]), and for snow catchment and nutrient cycling. Big sagebrush is divided into three major subspecies: *tridentata*, *vaseyana*, and *wyomingensis* that typically occupy distinct ecological niches. However, subspecies are known to form hybrid zones in some areas (Freeman et al. 1991). Maladaptation is a serious problem in restoration and becomes more complex with climate change. Planting big sagebrush seed sources outside their adaptive breadth will lead to continued ecosystem degradation and encroachment of invasive species. Successful restoration of big sagebrush requires an understanding of the climatic factors involved in defining subspecies and populations.

Objectives

- Establish common gardens from collected seed sources across the range of big sagebrush.
- Determine climatic factors important to adaptation within and among big sagebrush ecological races.
- Develop climate-based seed zone maps across the range of big sagebrush.
- Develop an approach to determine subspecies from plant material in the seed warehouse.

Methods

Common Garden Establishment and Measurements

Collection of seed and plant tissue began in fall 2009. A total of 93 seed sources were collected, largely by collaborators, in 11 western states. In January 2010, seeds were planted in greenhouse containers. Up to 10 families from each of 56 seed sources were outplanted at each of the common gardens (Table 1). Outplanting of seedlings occurred in May and June of 2010. First-year measurements were conducted in October and November of 2010. Measurements included mortality, height, crown area (from overhead photos), and seed yield estimates. Plants were supplemented with water until August 2010, and mortality was minimal for the first year (< 2%). No supplemental water was added in subsequent years.

Table 1. Location information and average minimum temperature (mmin) of three big sagebrush common garden sites

Site name	Latitude	Longitude	Elevation (m)	mmin (°C)*
Orchard, Idaho	43.328	-116.003	976	-6.3
Ephraim, Utah	39.369	-111.580	1686	-11.5
Majors Flat, Utah	39.337	-111.521	2088	-12.0

* mmin estimated from weather station data recorded from 1961 to 1990.

Common Garden Analyses

In this report, we focus on mortality at the Ephraim common garden and flower phenology at all gardens as it relates to climate from the site of origin for each population. The site-specific climate variables were estimated from a spline model based upon weather station data recorded between 1961 and 1990 (<http://forest.moscowfsl.wsu.edu/climate/>). We used a June 2013 tally of mortality. Mortality of each population was calculated as a frequency. These data were regressed with 18 climate variables and 16 interacting variables to evaluate correlation and autocorrelation among climate variables. Ephraim garden mortality was analyzed together, as separate subspecies, and as ploidy groups (i.e., diploids and tetraploids). For flower phenology, linear models were developed independently for each garden. Variable selection followed the same strategy as mortality with the addition of photoperiod. In this case, latitude of each population was used as a surrogate for photoperiod.

Electronic Nose

Volatile organic compound (VOC) analyses of subspecies were conducted using a Cyranose 320 electronic nose (Sensigent, Inc). Leaf tissue was placed into a headspace chamber and allowed to equilibrate for approximately five minutes. Air within the chamber was then drawn into the electronic nose where it was analyzed with 32 sensors. Canonical correspondence analysis was then used to discern the sensor responses within and among subspecies.

Results and Discussion

Mortality Responses to Climate

Plant mortality varied considerably among the common gardens by spring of 2013. Orchard and Majors Flat gardens had 4% (accounting for early insect mortality) and 3.6% mortality, respectively. However, at the Ephraim garden, mortality was 48%. There were strong patterns to subspecies and population survival at Ephraim. Regardless of subspecies, there was significant correlation ($p < 0.001$, $r = -0.46$) between mortality and summer-winter temperature differentials. Seed sources from more continental climates (i.e., greater temperature differentials) were more likely to survive at Ephraim. However, when populations were analyzed based upon ploidy groups (diploids and tetraploids), a different set of temperature and moisture interactions provided better correlation. For diploids, including subspecies *tridentata* and *vaseyana*, preliminary analyses suggested growing-season precipitation (April-September) and temperature differential best explained mortality patterns ($p < 0.0001$, $r = -0.69$). This suggests that diploid subspecies *tridentata* and *vaseyana* were more likely to survive at Ephraim if they originated from areas that experienced greater temperature extremes and greater growing season precipitation levels (Figure 1). Since these climate variables are driven by continentality, it would be expected that mortality is associated with longitude. The correlation between longitude and mortality was significant ($p < 0.0001$, $r = -0.68$).

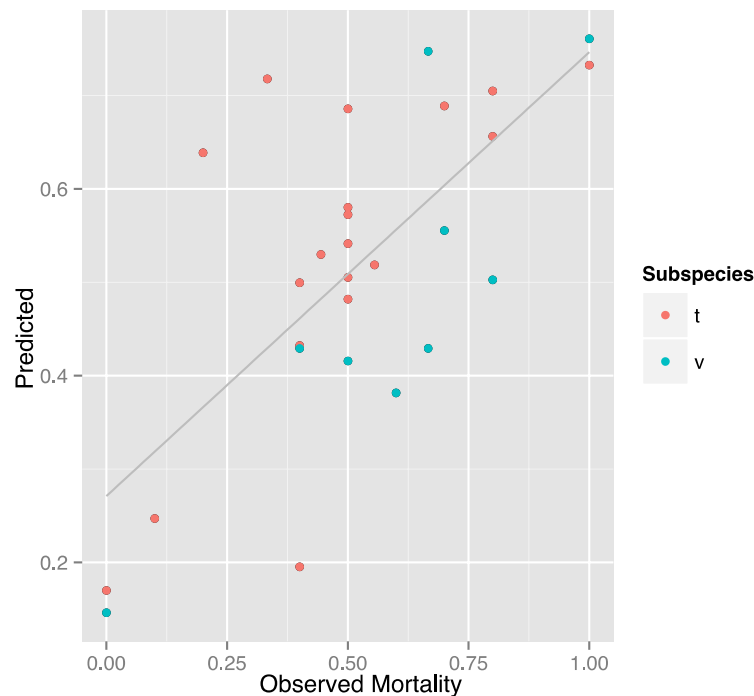


Figure 1. Average frequency of mortality (June 2013) of each diploid big sagebrush population regressed with a linear model of growing season precipitation and temperature differential, t = *tridentata* and v = *vaseyana*.

As for tetraploids, a linear model with temperature differential and the addition of growing season precipitation did not improve model fit, nor were tetraploid populations associated with longitude. However, preliminary analyses of mortality and an interaction between aridity (summer warmth/mean annual precipitation) and the accumulation of winter temperatures below 32 °F (0 °C) best explained mortality patterns ($p = 0.0003$, $r = -0.72$). Plants originating from areas with cold winters and greater aridity were more likely to survive at Ephraim (Figure 2). This relationship is analogous to the responses observed in blackbrush (*Coleogyne ramosissima*) using the same climate predictors (Richardson et al. 2014). Tetraploid big sagebrush is shallow-rooted like blackbrush. It could be that shallow-rooted desert shrubs are principally adapted to aridity and winter temperatures, whereas deep-rooted shrubs can access to deep moisture longer throughout the year.

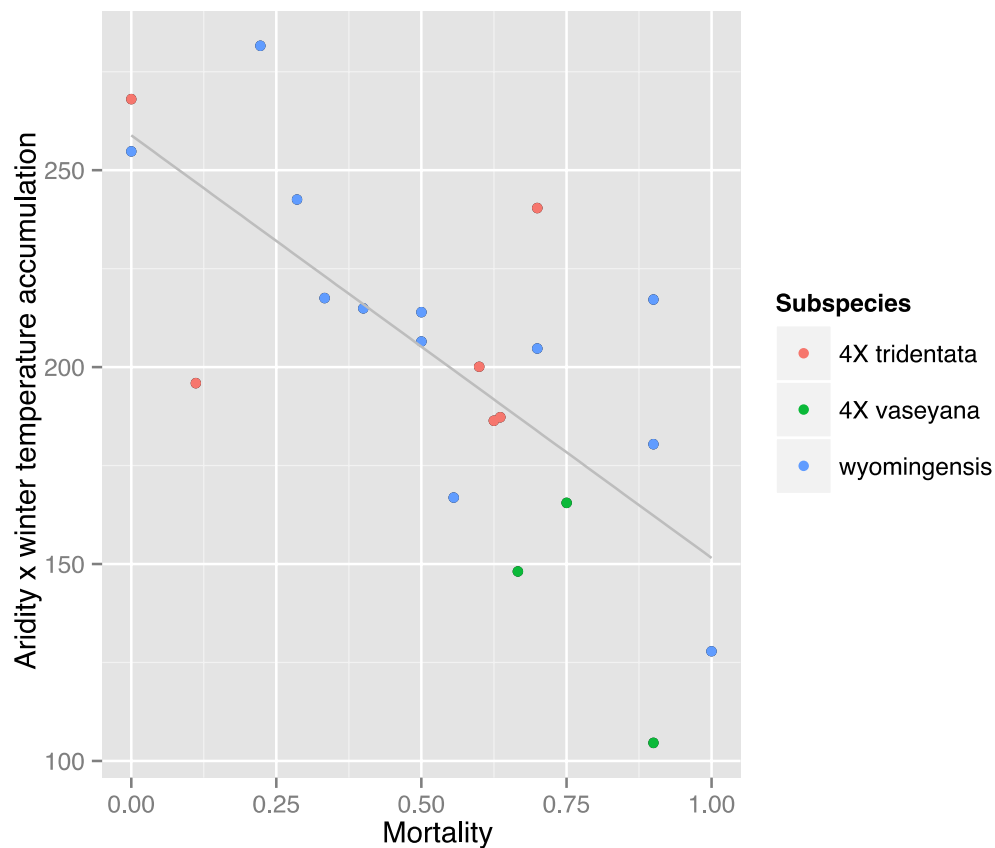


Figure 2. Average frequency of mortality (June 2013) of each tetraploid big sagebrush population regressed with an interaction of aridity and the accumulation of winter cold temperature.

Flower Phenology

Plant phenology is principally driven by temperature and photoperiod (Laube et al. 2013). For most plants, increases in spring temperatures promote early flowering; however for big sagebrush, a fall-flowering species, early spring temperatures appear to delay flowering. Photoperiod also affects flower phenology in big sagebrush. Populations collected from higher latitudes had earlier fall flowering. Preliminary analyses suggested a linear model of latitude

(photoperiod) and accumulating thermal degree-days ($> 41^{\circ}\text{F}$ [5°C]) best explained flower phenology variation ($p < 0.0001$, $r = 0.92$). Populations with longer summer photoperiod (i.e., higher latitude) and/or later spring temperatures had earlier flowering (Figure 3). Furthermore, plants in colder gardens (e.g., Ephraim) flowered, on average, 16 days earlier than plants from the same populations in warmer gardens (e.g., Orchard). When phenology was modeled within gardens, flowering responses to latitude and spring warmth were parallel (Figure 3).

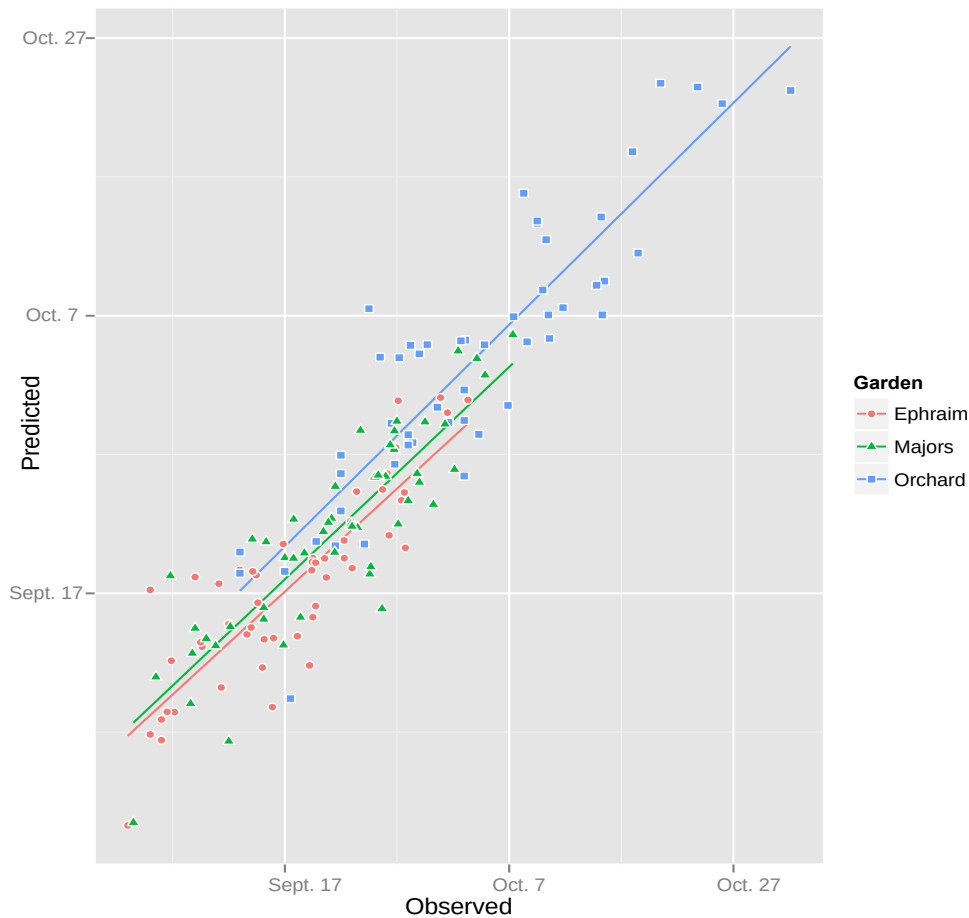


Figure 3. Average date of flowering predicted using the interaction between latitude (a surrogate for photoperiod) and spring warmth.

Subspecies Diagnostics

Developing a robust approach to discern big sagebrush subspecies from volatile compounds is ongoing, but preliminary analyses suggest it is possible. A canonical correspondence plot of all sensors indicates that there are differences in volatile composition among subspecies (Figure 4). Currently, our efforts are focused on sample preparation and determining which sensors are more discriminating in specific volatiles, such as methacrolein, which is abundant in subspecies *tridentata*.

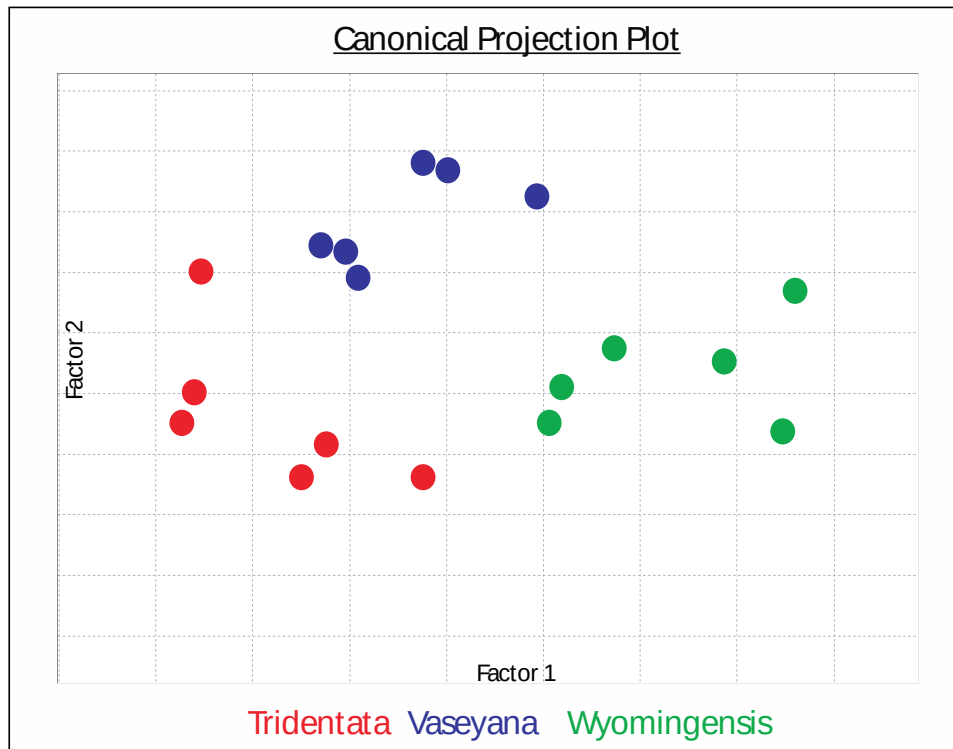


Figure 4. A canonical correspondence plot of volatile composition from 32 sensor responses recorded from an electronic nose. Eighteen samples from three subspecies were included. Colored points represent subspecies: *tridentata* (red), *vaseyana* (blue), and *wyomingensis* (green).

Future Plans

Seed collected in 2012 and 2013 and additional flower phenology data from 2013 will augment ongoing analyses. Quantitative genetic data will also be analyzed and compared with an assembly of ecophysiological datasets (Germino et al.), which should provide additional insights. Bioclimatic modeling is currently underway to provide an estimate of the big sagebrush climatic niche, and a map displaying this niche could be developed to overlay ecological genetic models, such as the data presented above. Initial planning and preparation of journal manuscripts are underway.

The goal of electronic nose diagnostics is to develop a protocol that would provide reliable results in subspecies determination and seed certification for seed warehouses. We also plan to look at other attributes including seed weight and size that appear to vary among subspecies or ploidy group.

Management Applications and/or Seed Production Guidelines

The goal of this research is to provide a comprehensive set of tools and knowledge to manage and restore big sagebrush for contemporary and future conditions. This includes development of seed zones based on some of the data presented above and reliable diagnostic techniques for determining subspecies from volatile profiles and seed characteristics. These tools and

knowledge will help ensure that big sagebrush seed is correctly identified and then directed to appropriate sites so that restoration is successful and established communities are resilient.

Presentations

Richardson, B. A.; Shaw, N. L. 2013. New insights into the genetic relationships and adaptive variation of big sagebrush subspecies. Intermountain Native Plant Summit; 2013 March 26-27; Boise, ID.

Richardson, B. A.; Huynh, M.; Shaw, N. L.; Udall, J. A. 2013. Correspondence between phylogenetic relationships and taxonomic characters in big sagebrush: implications for seed certification. 2nd National Native Seed Conference; 2013 April 8-11; Santa Fe, NM. Abstract.

Richardson, B. A.; Shaw, N. L. 2013. Ecological genetics of big sagebrush. 2nd National Native Seed Conference; 2013 April 8-11; Santa Fe, NM. Abstract.

Additional Products

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

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Project Title Selecting Big Sagebrush Seed Sources for Restoration in a Variable Environment: Assessment of Young Seedling Responses to Climate and Management Treatments of Herbs

Project Agreement No. 14-IA-11221632-012

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Project Description

Increased frequency and areal extent of wildfires pose a major challenge for big sagebrush (*Artemisia tridentata*) and its dependent species. Big sagebrush is not fire adapted and re-establishes by seed following fire. Its seeds are relatively short-lived and have limited natural dispersal distances from unburned or reproductive re-established plants. Given the threats to big sagebrush-dependent species such as greater sage-grouse (*Centrocercus urophasianus*), planting and seeding of big sagebrush are becoming increasingly common. Success in restoring big sagebrush has been mixed, often producing few or no shrubs. 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. The large areas designated for post-fire rehabilitation seedings are also creating a high demand for seed, which is increasing the need for information on seed transfer guidelines to appropriately match seed supply to restoration sites.

Big sagebrush has high intraspecific diversity, and selection of appropriate seed source is increasingly a concern in designing and implementing big sagebrush restoration treatments.

Recent data suggests that ploidy level is as important as subspecies in explaining the functional diversity in big sagebrush. Studies also suggest that functional variability among provenances within a subspecies or cytotype can be even greater (Richardson et al. 2012; Germino 2013). The diversity of big sagebrush increases the potential for populations to have local climate adaptation, which, in turn, suggests that development of seed-transfer zones may improve seeding success. Whether seed sources from warmer and drier sites are (or will be) better suited than local seed sources on a given site is an important question for climate adaptation in restoring native species in rangelands.

Preliminary seed zones for big sagebrush will largely be based on common gardens of big sagebrush established from seedlings grown for 4 to 5 months in the greenhouse then outplanted into weeded gardens with supplemental initial watering (Richardson et al. 2012). While the information culminating from these gardens is highly valuable for understanding persistence of different provenances and genotypes, it is also useful to evaluate smaller and younger plants in their critical seedling survival stage under a range of neighborhood vegetation conditions that represent different post-fire conditions. Climate responses of seedlings are often very different than those expressed by adults. Additionally, ploidy level variations, which appear important to the phylogeny and diversification of big sagebrush (Richardson et al. 2012), might influence seedling stress responses and establishment.

Big sagebrush seeding or planting treatments are often accompanied by treatments that reduce wildfire fuels and abundance of invasive species or increase abundance of native herbs through mowing, herbicide applications, or rangeland drill seeding. Neighboring herbs can have strong effects on big sagebrush seedling establishment and survival, which can relate to competition for water and other soil resources (DiCristina and Germino 2006). Physiological water balance, soil water uptake, and soil water use all vary considerably among big sagebrush subspecies and provenances and are likely important to climate adaptation (Kolb and Sperry 1999; Germino 2013). Different amounts and types of neighboring herbs likely affect microenvironmental factors such as soil water availability differently; so, it is reasonable to expect that provenances might differ in their ability to establish in different herb communities as they vary naturally or with land use and treatments.

Our previous research with the Great Basin Native Plant Project focused on climate adaptation of established, reproductive-aged big sagebrush plants in common gardens. Our current research focuses on seedlings undergoing the process of establishment, within the first months to a year following germination or outplanting as small individuals. The data collected will allow tests for local adaptation and will help identify the climate and ecophysiological variables that appear to exert strong limitations and should be emphasized in selection analyses.

Objectives

- Assess climate responsiveness of seedlings from different big sagebrush seed sources to experimental warming on burned sites.
- Assess the influence of management treatments on seedlings from different big sagebrush seed sources.

- Compare ecophysiological-climate adaptation in established plants to that of seedlings, and relate differences in ecophysiology to establishment success under different management treatments.

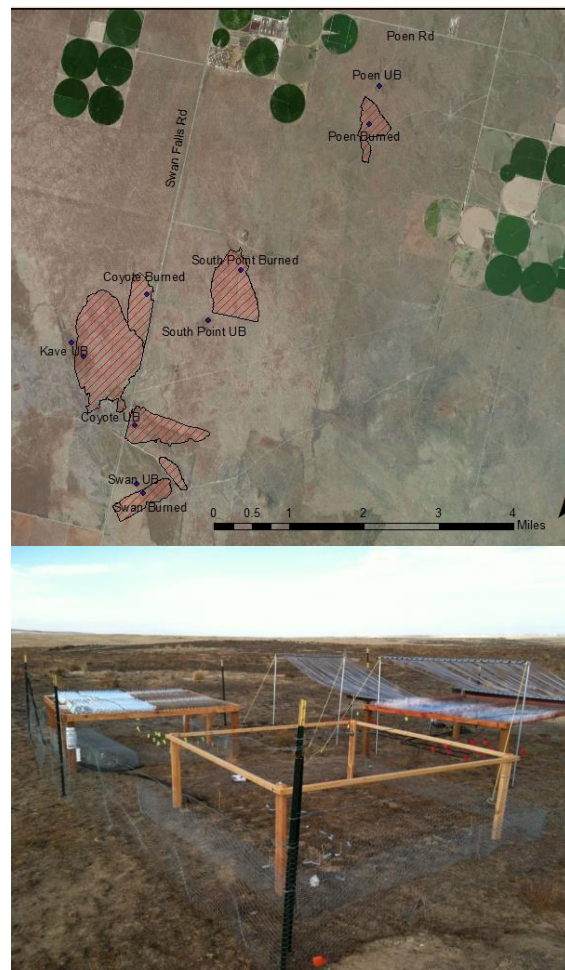
Methods

Climate experiment on burned areas

Warming chambers paired with unwarmed control plots were established at five separate sites burned by wildfires in summer 2012 in the USDI Bureau of Land Management Morley Nelson Birds of Prey National Conservation Area (BOP NCA, Figure 1). Each burned block has a corresponding unburned block of intact big sagebrush communities, and only the burned blocks received planting and seeding treatments. The unburned blocks will be utilized to record natural vegetation response to the treatments. The five sites: Poen, South Point, Swan Falls, Coyote, and Kave burned in 2012 and represent a variety of prefire conditions in the sagebrush steppe. Where sagebrush was present before the fires, it was a blend of Wyoming and basin big sagebrush (*A. t. wyomingensis* or *A. t. tridentata*). The Kave site was considered intact sagebrush steppe prior to the 2012 fire, whereas the Poen site was drill seeded with forage kochia (*Kochia prostrata*) after a fire in 1993. The South Point site was also drill seeded after a fire in 1998 but it was seeded with Russian wildrye (*Psathyrostachys juncea*). The Swan and Coyote sites were big sagebrush communities with an understory of cheatgrass before burning.

Experimental passive warming frames were installed in fall 2012 prior to the planting and seeding to create the desired warming treatment effect. Warming frames are open-sided with louvered strips of clear plastic in the roof that increase long-wave solar radiation for plants and soil surfaces. Warming frames increase minimum nighttime temperatures by 4 to 7 °F (2-4 °C) (devised by Germino and Smith 1999; modified by Germino and Demshar 2008). Frames dimensions are 7.9 × 7.9 ft² (2.4 × 2.4 m²) in area and 24 inches (60 cm) in height. Roofless frames (with clear nylon string to mimic structure of the warming frames) were placed on control plots. Air temperatures, soil

Figure 1. Map (top) and photo (bottom) showing location (south of Boise in the BOP NCA) and style of warming and control chambers. Red hatched areas in the map are burned, and “UB” refers to unburned sites that also received the treatments as part of an associated study. Photo (bottom) shows the warming frame (leftmost) and two frames with rainout shelters (back) for a related project.



temperatures, and water content at the soil surface (≤ 0.8 inch [2 cm] deep) and at 2 inches (5 cm) deep were measured and logged at one- and six-hour intervals, respectively, on all plots.

Table 1. Genotypes (provenances or populations) outplanted and seeded into five sites in the BOP NCA that were burned by wildfire in 2012. At each site, planting and seeding was done on control or experimentally warmed plots. Ten seedlings or 50 seeds were planted into each treatment and replication occurred across five sites. Seed source selection represented local sources or distant sources with climates different from the BOP NCA. “Rationale” refers to the reason for inclusion, which is either to provide local or distant genotypes or climate differences in seed transfer. “Local site” refers to seed transfer distances of 5 to 10 miles (8-16 km) without change in elevation or soils; “local region” refers to transfer distances of about 20 miles (32 km), and climate described is relative to BOP NCA

Provenance code name	State of origin	Subspecies of big sagebrush	Rationale (climate of origin)	Treatments planted into	Ploidy
IDT-2	ID	<i>tridentata</i>	Local region	Warmed+Control	2N
BOP-W	ID	<i>wyomingensis</i>	Local site	Warmed+Control	4N
IDV-2	ID	<i>vaseyana</i>	Local region	Warmed+Control	2N
NMT-2	NM	<i>tridentata</i>	Warm/Dry	Control	4N
UTT-1	UT	<i>tridentata</i>	Cool/Wet	Control	2N
IDW-2	ID	<i>wyomingensis</i>	Local region	Control	4N
ORT-2	OR	<i>tridentata</i>	Warm/Dry	Control	2N
MTW-3	MT	<i>wyomingensis</i>	Cool/Wet	Control	4N
ORV-1	OR	<i>vaseyana</i>	Cool/Wet	Control	4N
IDW-3	ID	<i>wyomingensis</i>	Warm/Dry	Control	4N
IDV-3	ID	<i>vaseyana</i>	Cool/Wet	Control	2N
CAT-2	CA	<i>vaseyana</i>	Warm/Dry	Control	2N

As a split-plot factor, different subspecies and provenances of big sagebrush (Table 1) were planted or seeded into each plot, excluding the outer 16 inches (40 cm) of the plot area to avoid edge effects. Fifty seeds were sown into one 8 × 8-inch (20 × 20 cm) frame per seed source per plot. Four-month old outplants from three seed sources that were grown outdoors in native soil and cone-tainers were planted under each warming frame (10 plants per seed source per frame), and all seed sources were planted into control plots. Seedlings were bare-root planted at 4-inch (10 cm) spacings in November 2012, and seeds were sown in December 2012. Seed sources represented geographically local sources of all three subspecies of big sagebrush, to provide a strong contrast in climate adaptation. The other seven seed sources were selected to cover a range of ploidy and provenance conditions, including diploid, tetraploid, *tridentata* and *vaseyana* subspecies, and provenances from relatively warm or cool and wet or dry areas. One warm seed source came from near the Mojave Desert in California where winter is nearly lacking. Additionally, provenances known to have relatively vigorous growth (ORT-2) or slow growth (CAT-2) rates were selected.

We are measuring a suite of dependent variables including survival, growth, chlorophyll fluorescence, measurements of water status (pressure chamber), isotopic assessment of water-use efficiency, photosynthesis, and stomatal conductance. Measurements of community cover are

made periodically, and variation in soil properties will also be assessed. Repeated-measure, split-plot ANOVAs are being used to determine significant differences.

Responses to Management Treatments of Herbs

Seedling responses to management treatments of herbs are being assessed for the sources shown in Table 1. Outplanting occurred in pre-existing, landscape-scale herbicide, mowing, or seeding treatments in spring 2013 when plants were 4 months old. Treatments were arrayed in a full factorial pattern on grazed and fenced areas in three replicate blocks in the BOP NCA as part of a Joint Fire Sciences Project led by Doug Shinneman at the US Geological Survey (unburned area of Figure 2). A unique feature of this experiment is that plots are large (2.5 acres [1 ha]) and dispersed over a large landscape, mimicking the scale of an actual management treatment. A second planting using only local seeds of Wyoming big sagebrush was implemented with 12-inch (30 cm) tall, year-old seedlings on all burned plots in fall 2013 (see Figure 2). Results of the second planting on burned plots will be described in a future report.

Each unburned plot had nine seedlings of each of four seed sources planted, with four basin big sagebrush sources planted equally into all fenced plots and a more complex mixing of the other seed sources in unfenced plots (due to numbers of seedlings available). Seedling spacing was greater than 16 feet (>5 m) in the unburned plots. In burned plots, 25 seedlings were planted at 3-feet (1 m) spacing. Seedlings received approximately one liter of water after planting. Mortality was very high following the spring 2013 planting on unburned plots because of drought conditions, but initial establishment of the fall 2013 planting on burned plots appears to be very high.

Key to accomplishing these large-scale plantings (>3,000 seedlings) was the volunteer program available through agency partners, specifically crews from Boise State University, the Master Naturalist Programs led by Anne Halford of the USDI Bureau of Land Management, and volunteer efforts led by Michael Young and Mary Dudley of the Idaho Fish and Game. Growth and survival are being monitored periodically on both plantings, and additional physiological measurements are planned for the Bigfoot fire.

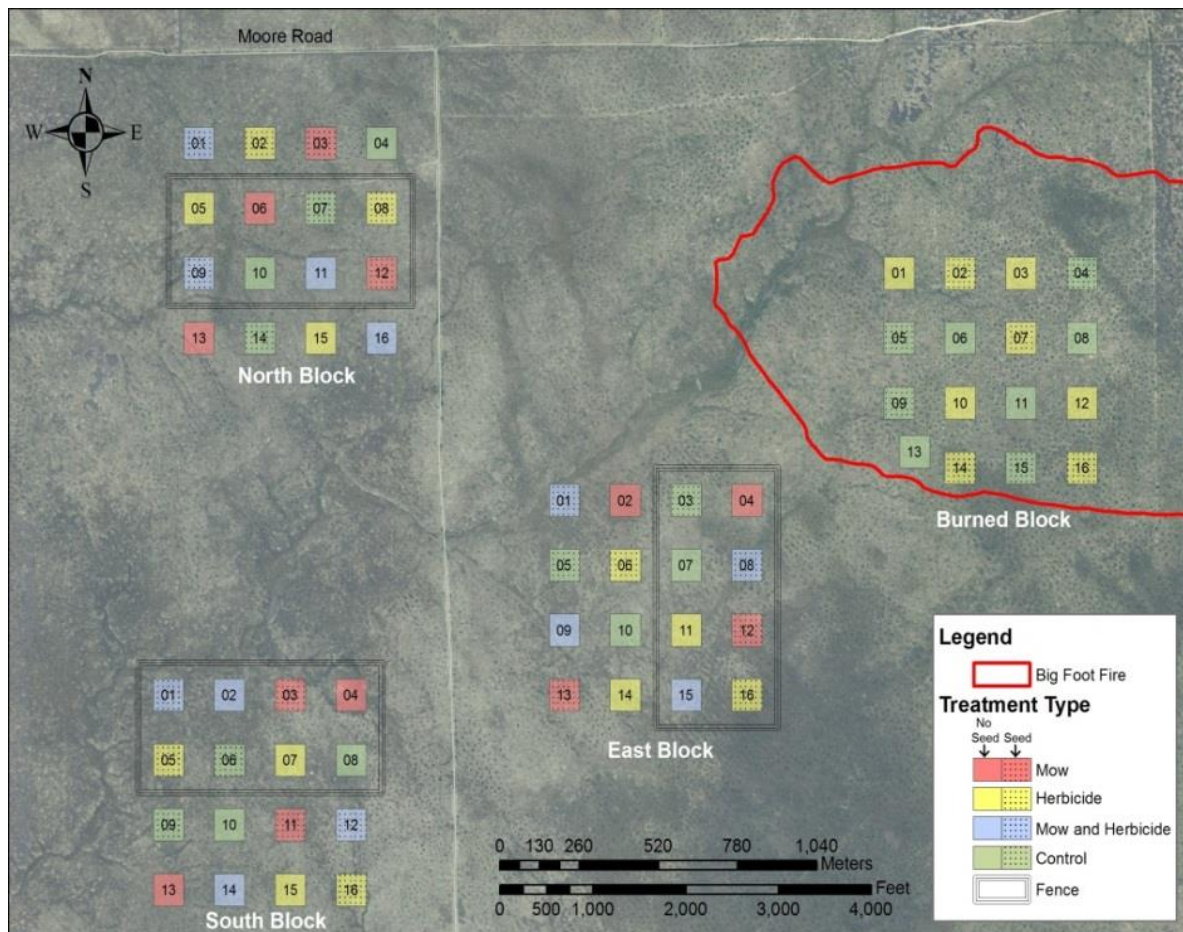


Figure 2. Experimental layout of management treatments of herbs in the BOP NCA. Map courtesy of D. Shinneman.

Results and Discussion

Precipitation was notably scarce in spring 2013, such that little greening was observed throughout the BOP NCA, and this likely contributed to seed and seedling establishment.

Response to Climate Treatments on Burned Areas

Emergence was low from the seed sown, and emergence appeared to occur earlier in the year under the warming compared to control frames (not shown and statistical tests pending) and was followed by high mortality. As of fall 2013, there were only six seedlings that emerged from seed in warmed frames and all but one were Wyoming big sagebrush from Idaho seed sources. In comparison, only two seedlings remained in the control frames.

In unwarmed plots where the rest of seed sources from Table 1 can be compared, a small and as-of-yet insignificant pattern appears to be emerging in which seedlings of diploid seed sources have somewhat lower survivorship (Figure 4). In contrast, the greatest height growth may be in diploid basin big sagebrush (non-local, Figure 5 compared to less height in local seed provenances, Figure 3), as was observed in the Orchard common garden (Germino 2013). An important tradeoff in height growth and survivorship may be emerging in these seedlings, which contrasts with patterns observed in the older plants in the Orchard common garden.

Response to Treatments of Herbs on Unburned Areas

Very high mortality occurred when precipitation fell far below average from April to June 2013. Of provenances planted into fenced areas (all basin big sagebrush), the local IDT2 source had a larger number of survivors than the distant provenances that included tetraploids and sources from warmer or drier sites (Figure 6, Table 1). Seedling survivorship was greater by May on plots that had an array of treatments which lead to reduced herb cover (specifically those that had been mowed and treated with herbicide and not drill seeded with herbs) compared to plots that had been seeded (Figure 7, $p < 0.05$), although substantive emergence of seeded herbs was not readily detected in the treatments (not shown).

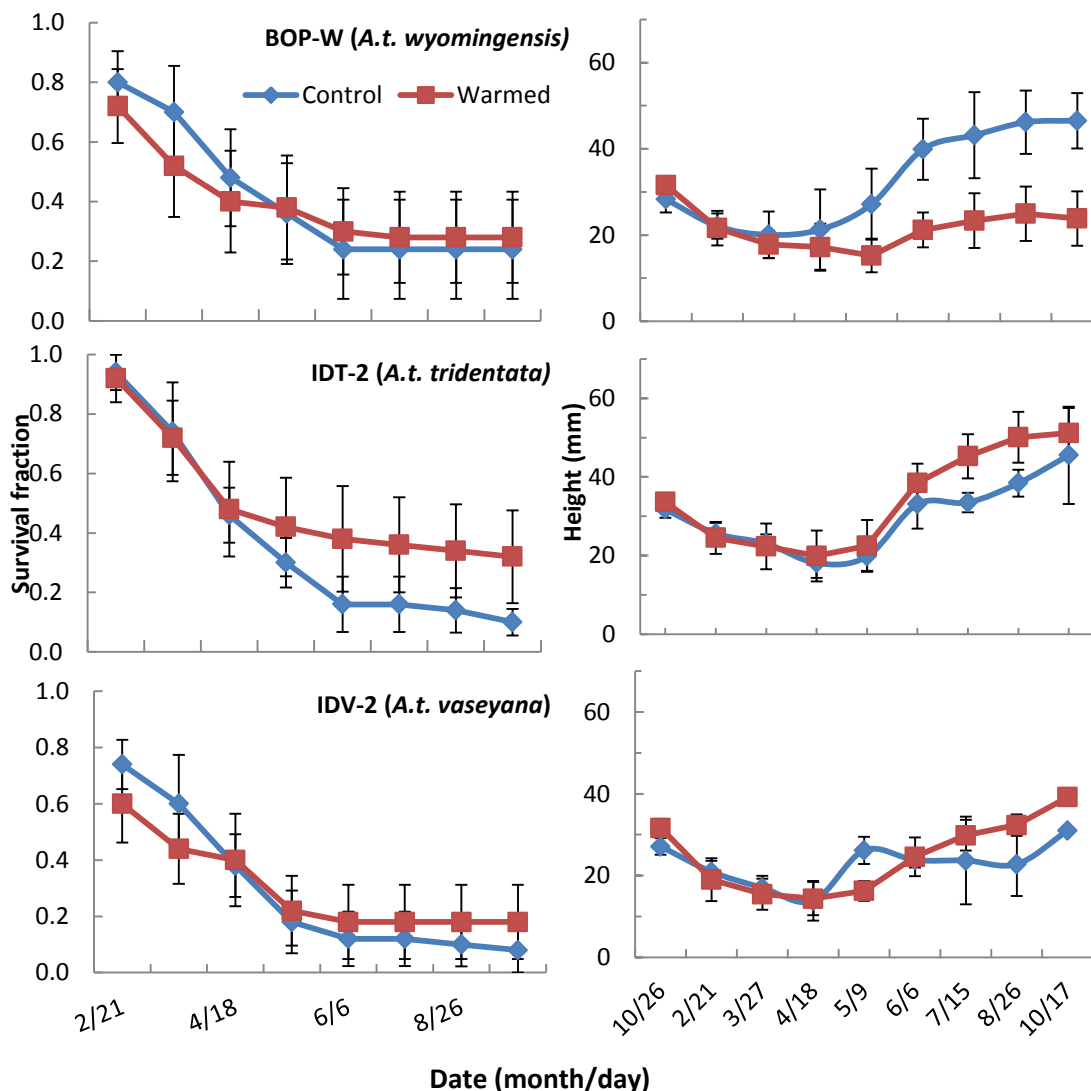


Figure 3. Survival and growth as indicated by height of seed sources of each big sagebrush subspecies under experimentally warmed or control conditions at the BOP NCA from late 2012 through 2013. N = 5 plots.

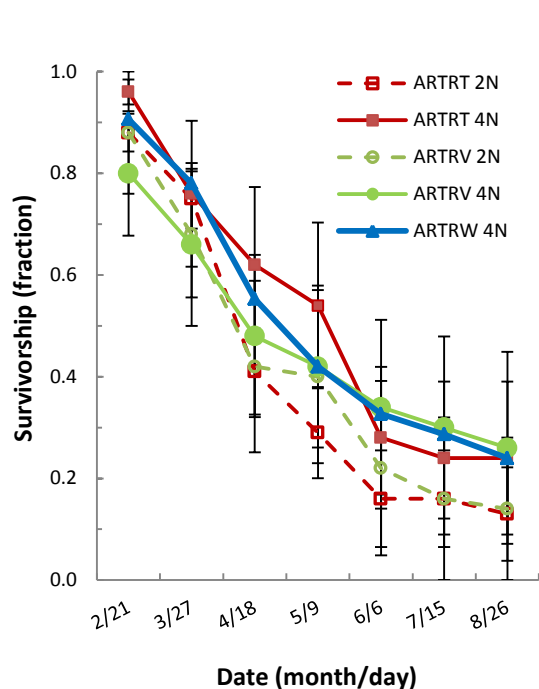


Figure 4. Survival of seedlings based on subspecies and ploidy (Table 1), from unwarmed control plots. N = 5.

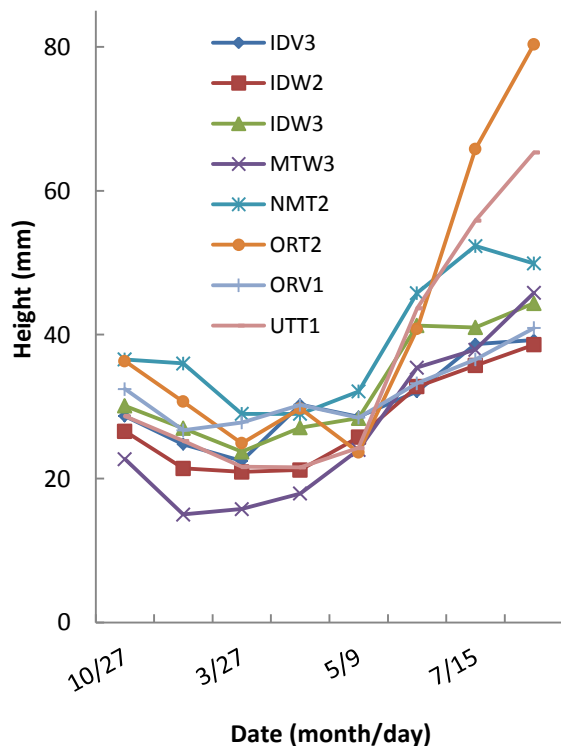


Figure 5. Height growth of seedlings of the different provenances (Table 1) in unwarmed control plots. N = 5.

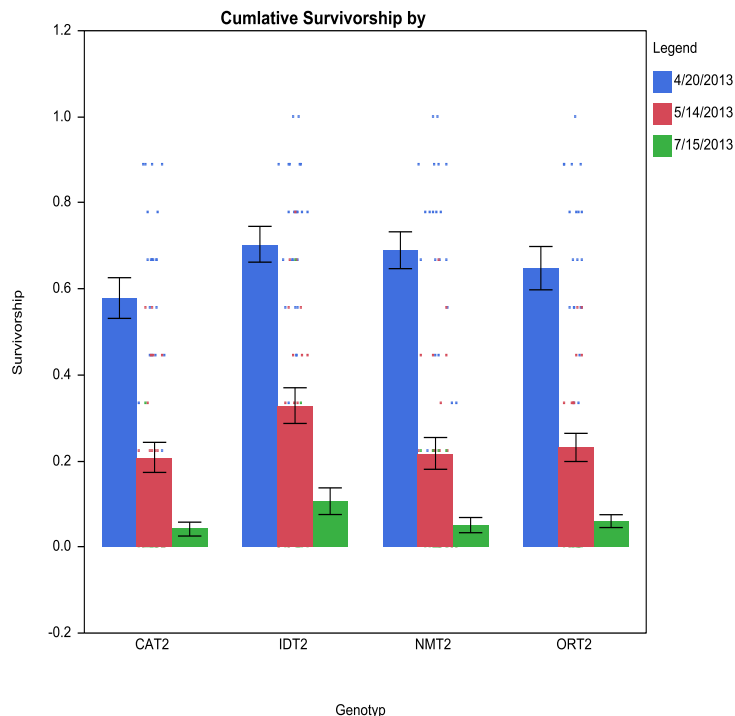


Figure 6. Differences in survivorship for four seed sources of basin big sagebrush; IDT2 is the local seed source, and in fall 2013 comprised 35% of survivors; CAT2 is from a warm site in California; ORT2 is from Oregon and fast-growing; NMT2 is tetraploid from New Mexico, and in fall 2013, comprised 12% of survivors. N = 216.

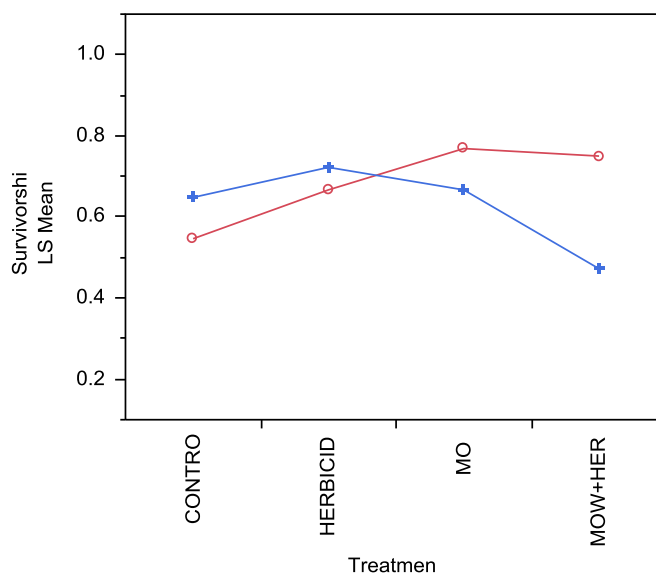


Figure 7. Differences in survivorship among eight treatments as of May 2013. Red open circles represent non-seeded plots; blue crosses represent seeded plots. For the comparison of unseeded and seeded plots on mowed + herbicide plots, $p < 0.05$.

Our preliminary findings from a dry year and a small number of surviving seedlings offer some indication that 1) tetraploids could have greater survival but diploids (of basin big sagebrush) may have greater growth, 2) Wyoming big sagebrush might have greater survival in the BOP NCA under current conditions but basin big sagebrush would be favored by warming, and 3) local seed sources may perform better in basin big sagebrush (aside from greater performance of tetraploids, which are not local to BOP NCA). We hypothesize that potentially greater performance of basin big sagebrush and reduced performance of Wyoming big sagebrush under warming may relate to greater water stress for Wyoming big sagebrush that is overcome by extraction of deeper soil water sources by basin big sagebrush. There is some indication of greater success of tetraploid seed sources, and that management treatments reducing herb presence may enhance big sagebrush seedling establishment.

We will continue to monitor patterns of growth, survival, and ecophysiological variation that may provide a more sensitive indicator of climate relationships. Overall, low survivorship and low numbers of surviving seedlings are the result of a dry spring and summer in 2013. We will seek means of reproducing and expanding our assessment of seedling establishment of the different seed sources. In 2014, ecophysiological assessments will include measurement of carbon isotopes as an indicator of water use and low-temperature resistances so that we may improve our resolution of genecological and climate adaptation effects, which are key for developing seed transfer zone guidelines. Also, through the use of leveraged funding, an associated experiment evaluating wind and microclimate amelioration was begun with the second planting in the Joint Fire Sciences treatment plots burned by the Bigfoot fire. We will continue to monitor that experiment and report on how use of sheltering devices, topographic variation, or sagebrush planting arrangements that modify wind regimes impact seedling outplant success.

Management Applications and/or Seed Production Guidelines

We anticipated that ploidy, subspecies, and provenance of big sagebrush would matter to planting success under the range of plot conditions we are evaluating, perhaps even more than for larger plants. The implication of these predictions is that resolute selection of seeds is important for sagebrush planting success. As an example of how the developing information may apply: a management objective for the sites we evaluated to quickly increase big sagebrush presence and structure on the landscape under a warming climate (e.g. to provide shrub canopy amelioration of microclimate, creation of safe sites for native herb establishment) might benefit from planting seedlings of local diploid basin big sagebrush following treatments such as mowing and herbicide. Growth/survival tradeoffs may also have implications for seeding efforts in which assurance of germination and initial establishment are the primary concerns, in which case, tetraploid seed sources for seeding (and possibly local Wyoming big sagebrush) may improve outcomes. Additional data will substantiate or modify these types of findings and management applications.

Presentations

Germino, M. J. 2013. Sagebrush responses to climate, seminar given at the College of Idaho; 2013 October 28; Caldwell, ID.

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

Germino, M. J. 2013. Climate adaptation and sagebrush: biological and management perspectives. Brown-bag seminar given to Bureau of Land Management; Idaho State Office; 2013 May 22; Boise, ID.

Germino, M. J.; Brabec, M.; Davidson, B.; Shinneman, D.; Halford, A.; Richardson, B. 2013. Post-fire sagebrush establishment across the landscapes: experimental tests to inform restoration success. Poster presented at the Great Basin Consortium Conference; 2013 December 9-10; Reno NV.

Germino, M. J.; Lazarus, B.; Richardson, B.; Shaw, N. 2013. Ecophysiological variation of big sagebrush in common gardens: Local climate adaptation, ploidy effects, and implications for restoration practice. Poster presented at the 98th Annual Meeting of the Ecological Society of America; 2013 August 4-9; Minneapolis, MN.

Germino, M. J.; Richardson, B.; Lazarus, B.; Shaw, N. 2013. Local ecophysiological adaptation evident in tetraploid but not diploid big sagebrush. 2nd National Native Seed Conference; 2013 April 8-11; Santa Fe, NM.

Richardson, B. A.; Germino, M. J.; Kitchen, S. G.; Pendleton, R. L.; Pendleton, B. K.; Meyer, S. E. 2013. Climate-adapted populations of blackbrush (*Coleogyne ramosissima*). 2nd National Native Seed Conference; 2013 April 8-11; Santa Fe, NM.

Richardson, B. A.; Kitchen, S. G.; Pendleton, R. L.; Pendleton, B. K.; Germino, M. J.; Rehfeldt, G. E.; Meyer, S. E. 2013. Climate-adapted populations of blackbrush (*Coleogyne ramosissima*): implications for current and future management. 5th World Conference on Ecological Restoration; 2013 October 6-11; Madison, WI.

Richardson, B.; Shaw, N.; Germino, M. J.; Ortiz, H.; Carlson, S.; Sanderson, S.; Still, S. 2013. Development of tools and technology to improve the success and planning of restoration of big sagebrush ecosystems. Poster presented at the Great Basin Consortium Conference; 2013 December 9-10; Reno, NV.

Publications

The ongoing data collections will be useable for potential publications after summer 2014. Several manuscripts are in preparation from work on established sagebrush in common gardens, described in two prior Great Basin Native Plant Project reports.

Additional Products

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

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Germino, M. J.; Demshar, D. 2008. A new approach for passive warming in field experiments. In: 93rd annual meeting of the Ecological Society of America; 2008 August 7; Milwaukee, WI. Abstract.

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Kolb, K. J.; Sperry, J. S. 1999. Differences in drought adaptation between subspecies of sagebrush (*Artemisia tridentata*). *Ecology*. 80(7): 2373-2384.

Richardson, B. A.; Page, J. T.; Bajgain, P.; Sanderson, S. C.; Udall, J. 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.

Project Title Field-testing Competitive Native Plant Genotypes for Restoration in Cheatgrass-invaded Rangelands

Project Agreement No. 13-JV-11221632-080

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Project Description

Background

In arid systems, seedling survival can pose a substantial barrier to restoration. From both an ecological and management perspective, there is an urgent need to better understand how plant traits affect performance of native plant seedlings in field conditions. For example, it is widely held that locally accessed seeds represent the ideal restoration material but such seeds are not always available. Identifying traits that improve native plant establishment may allow managers to identify possible restoration materials based on plant traits rather than provenance.

Research from previous studies has shown the potential for root traits to have strong effects on plant competitive performance and resistance to drought, yet relatively little is known about how these traits affect seedling survival and growth in the field. In this study, we sampled natural squirreltail populations, recorded root traits of over 100 squirreltail families, and monitored the performance of those families in field conditions.

Objectives

The objectives of this study were to— 1) identify heritable root traits in squirreltail and 2) determine how these traits affect emergence, survival, and height of seedlings after one growing season in the field.

Methods

Seeds of squirreltail (*Elymus elymoides*) were collected from 53 families at each of two sites in northern Nevada: Paradise Valley and Orovida. Seeds from each family were grown in the greenhouse and seedling root traits were measured 10 days after emergence. We also planted 20

seeds from each family into field plots near the sites where seeds were collected. Seeds were planted in late October and monitored every three to four weeks for emergence until June, when they were measured for height and leaf count. We used a generalized linear mixed model and model averaging to investigate the importance of root length, specific root length (SRL: root length/volume), number of tips, root mass ratio (RMR: root mass/plant mass), days-to-emergence (DTE), and seed mass.

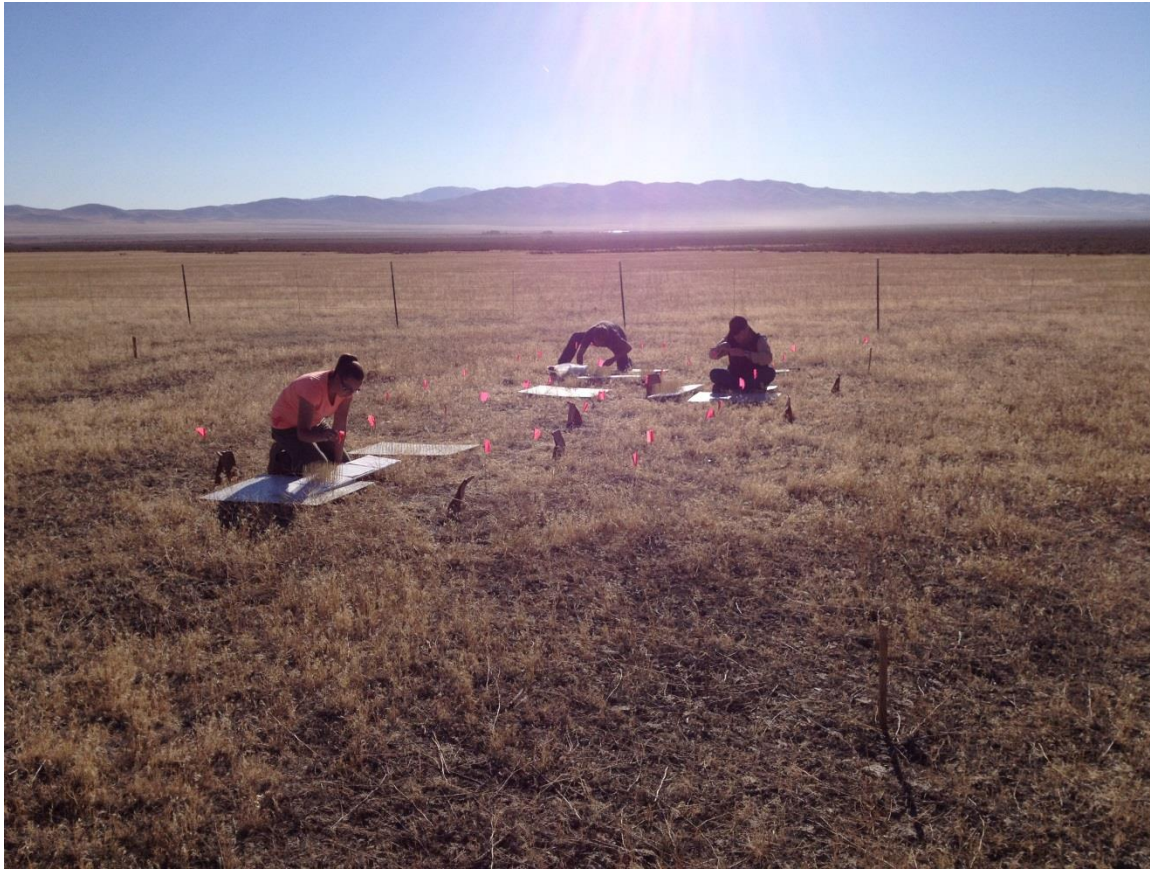


Figure 1. Installing squirreltail experiment at the Paradise Valley field site.

Results

Root traits had strong effects on squirreltail field performance at both sites. Emergence success was primarily determined by seed mass, but survival probability was strongly affected by root traits with plants with thick, prolific roots having a 6-fold increase in survival probability at one site and a 1.5-fold increase in survival probability at the other site. Seedling size at six months showed an up to 2-fold increase due to root traits. Performance increased linearly in response to root traits, although many traits also showed pronounced non-linear responses to seed traits, with intermediate values being favored. Seed mass had weak effects on root traits. Path analysis indicated that about 80 to 90% of effects of root traits on performance were independent of seed mass, while the remaining effects mediated indirect effects of seed mass.

Conclusions

Our results suggest there is potential for root traits to have strong and predictable effects on the germination, survival, and size of squirreltail seedlings in the field. While seed size was the

primary determinant of emergence probability, survival at both sites was primarily influenced by root traits. Prevalent non-linear effects of root traits indicate the importance of restoring rangelands using genotypes that have traits correctly matched for their environment. We are further investigating this phenomenon by relating root traits to performance of squirreltail genotypes collected from 35 populations throughout the Great Basin.

Management Applications and/or Seed Production Guidelines

This research examines a pressing management concern: the identification of native plant materials for restoration. Although it has been the subject of considerable debate, it is commonly held that locally-sourced seeds are the ideal restoration material, because they have already adapted to the unique conditions of their home site. However, local seeds are not always available in the numbers needed for restoration, and there is question about whether using local seeds by default is an optimal restoration strategy. The root traits we observed were measured after only 10 days of greenhouse growth and were easily and quickly obtained using commercially available root imaging software. While our results provide evidence that locally accessed seeds possess traits that are well-matched for their home environment, they also suggest it may be possible to identify substitute restoration material based on seedling root traits. We are undertaking further research to determine whether this is feasible and applicable to multiple sites.

Project Title Dynamics of Germination and Cold Hardiness for Great Basin Native Plants

Project Agreement No. 13-JV-11221632-066

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Project Description

Germination Characteristics of Northern Great Basin Sulphur-flower Buckwheat

Objectives

Sulphur-flower buckwheat (*Eriogonum umbellatum*) is a perennial forb native to western North America for which little scientific information exists. Widely distributed across the Great Basin, sulphur-flower buckwheat exhibits a variety of traits that are valuable for wildlife (including sage-grouse), pollinators, livestock, restoration, landscaping, and ethnobotanical uses. The Great Basin ecosystem is rapidly becoming degraded; consequently, native plant materials for

restoration are lacking. Because sulphur-flower buckwheat has a broad distribution, occupies wide elevational gradients, and has broad ecoregional representation, understanding the spatial and temporal differences among populations will help maximize restoration efforts within the Great Basin. There are three main objectives to this research:

- Measure and compare seed morphology characteristics across multiple years and populations.
- Measure and test non-stratified germination parameters across geographical and temporal gradients.
- Investigate seed morphology and germination among populations collected along an elevational gradient.

Materials and Methods

Wildland seed collections were made starting in 2003. Seeds were cleaned and then placed in cold storage at -12 °F (-24 °C). The USFS Rocky Mountain Research Station Moscow Forestry Sciences Laboratory germinated 21 seed collections representing nine populations collected in 2009 and two sources collected across seven years, which encompassed a 2,750- to 5,740-foot (840-1750 m) elevational gradient. Seeds were sown 29 June 2013 with two seeds per cell and five replications of 28 cells each. Seedlings were grown under controlled greenhouse conditions. Daily germination counts started the day after sowing and continued for four weeks (Figure 1).

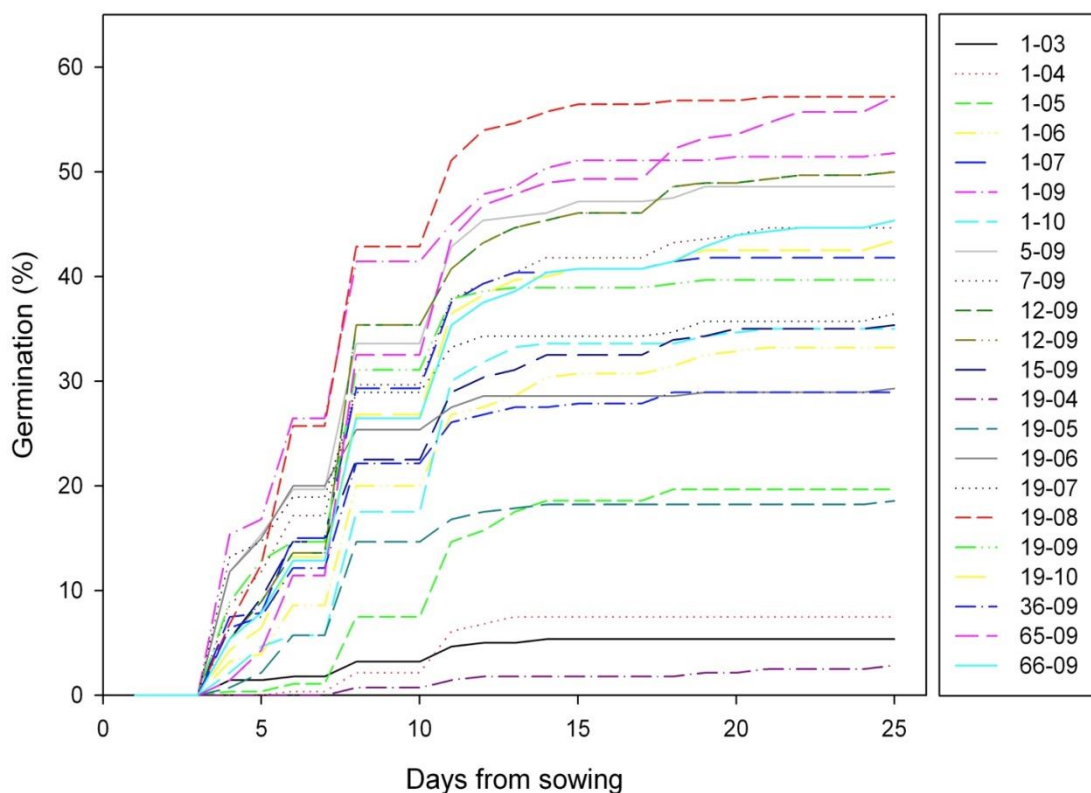


Figure 1. Sulphur-flower buckwheat germination percentage of nine seed sources over a 25-day period after sowing on 29 June 2013. Source 1 and 19 are also represented across seven different years. Figure legend gives source number-collection year.

Results and Discussion

Germination for seed sources was significantly different across all sources for 2009 ($p < 0.0001$; Figure 2A). Seed sources 1 and 19 displayed significant differences in total germination ($p < 0.0001$; Figure 2B&C) and seed weights ($p < 0.0001$; Figure 3A&B) across multiple years. Elevation was not significantly correlated among seed sources for either seed weight ($p = 0.1446$) or germination ($p = 0.3981$). The results indicate different germination among years and seed sources when stratification is withheld during the propagation process, which leads us to believe the age of non-stratified seed had an impact on germination success when seedlings were grown in the same environment. We noticed an increase in germination following after-ripening periods of four to five years in dry cold storage.

Future Direction

When propagating on a large scale for restoration, seed germination characteristics can be an important factor for success. Little to no stratification is desirable in some instances. Germination is only one important feature to consider when selecting a seed source for restoration plantings, and it is important to keep the original seed source component as the main driving factor. There are ways around germination obstacles of desirable sources such as fall planting in the field or artificial stratification.

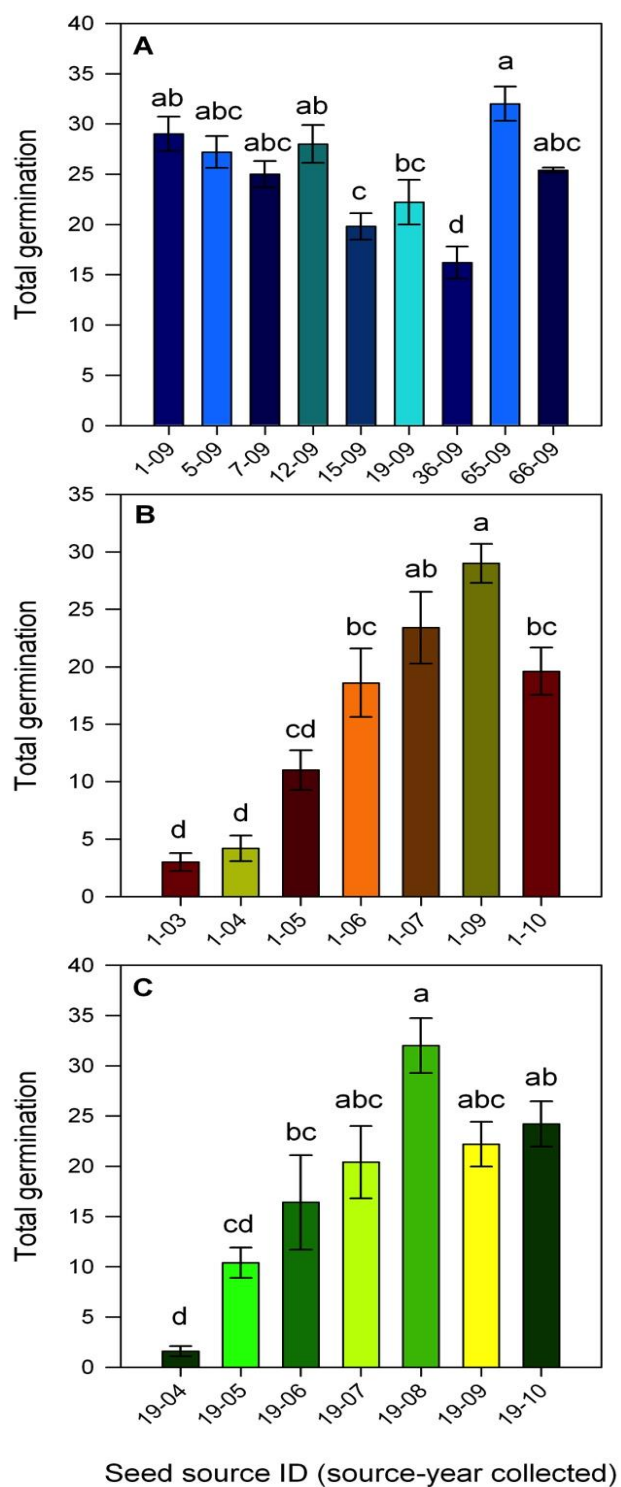


Figure 2. Mean ($\pm$ SE) total germination (of 280 sown seeds) of sulphur-flower buckwheat among seed sources collected in 2009 (A) and for source 1 (B) and 19 (C) collected across seven different years. Different letters indicate a separation of means (Tukey, $\alpha=0.05$).

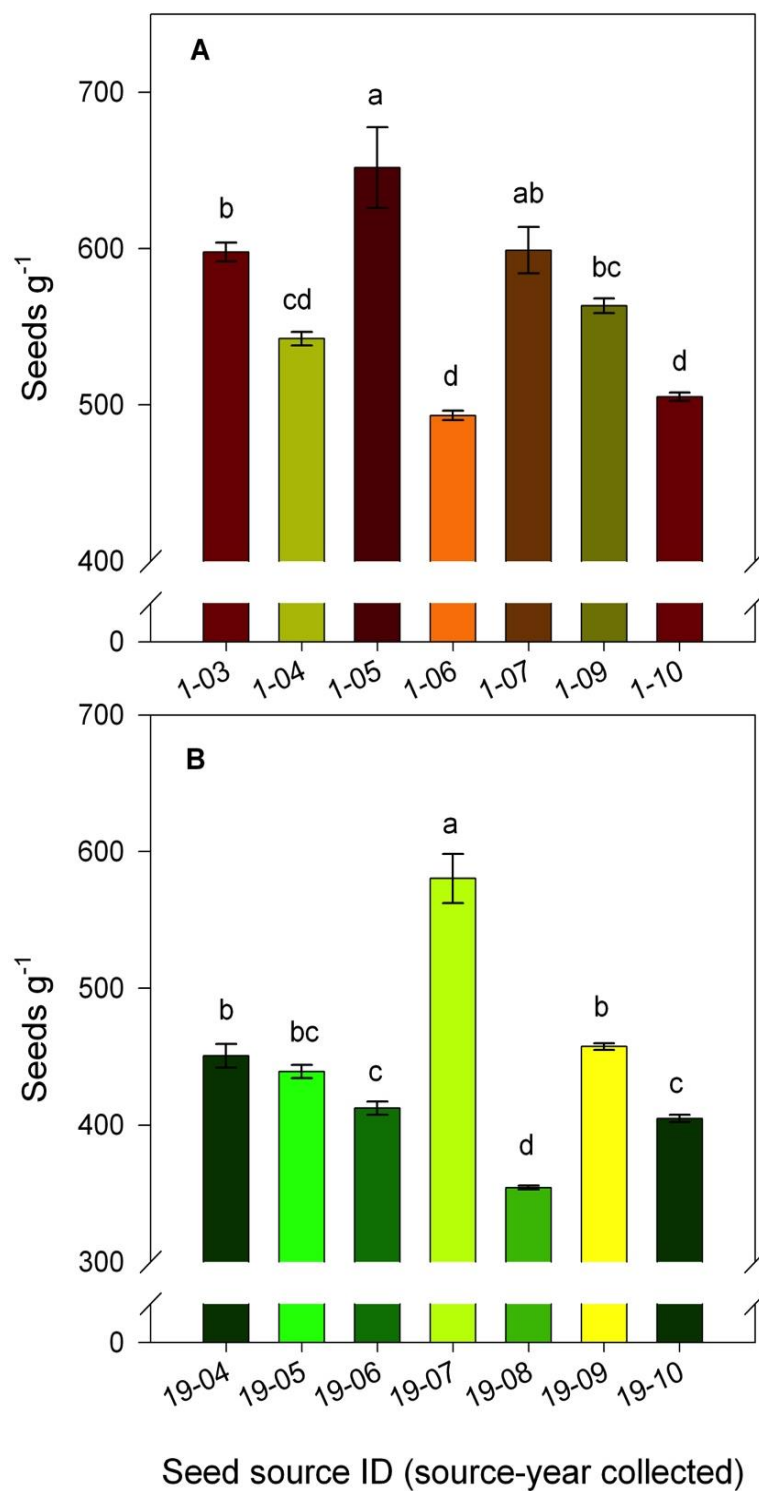


Figure 3. Mean ($\pm$ SE) sulphur-flower buckwheat seeds per gram for seed source 1 (A) and 19 (B) collected across seven different years. Different letters indicate a separation of means (Tukey, $\alpha=0.05$).

Cold Hardiness Accumulation and Loss in Sulphur-flower Buckwheat across the Great Basin

Objectives

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

The current research goals are to provide a streamlined strategy for plant producers and restoration specialists in the Great Basin to follow when testing the cold hardiness of forb species and specific genetic sources. This could provide better guidelines for developing and testing seed zones and improve the understanding of the influence of changing climatic conditions on plant populations. Using important candidate forb species, we are working with public and private collaborators to develop guidelines that evaluate a species' cold tolerance. This will greatly enhance our ability to both understand the role cold temperatures play in native plant establishment following planting as well as potential implications of changing climatic conditions for restoration in the Great Basin.

Materials and Methods

Seeds were procured for an important native Great Basin forb, sulphur-flower buckwheat to provide the basis for understanding seasonal cold tolerance accumulation and loss in seedlings through laboratory work and field plantings. Plants are being propagated by USFS RMRS Moscow Forestry Sciences Laboratory personnel for use in subsequent work to test seedling cold tolerance levels among populations collected across ecoregions, collection years, elevational and longitudinal gradients, and seed zones.

Mature sulphur-flower buckwheat plants are also being examined. Six accessions growing in a common garden planted in fall 2006 in Boise, Idaho were selected as representative of the species' geographical range occurring within provisional seed zones, ecoregions, and elevational and longitudinal gradients. One wildland source was selected for research and it is also represented in the common garden. Seedlings from this source are being grown at the RMRS greenhouse. Leaf tissue samples were collected from the field in August and December of 2013 and transported to University of Idaho laboratory for processing. The Freeze-Induced Electrolyte Leakage (FIEL) method has been used to test cold tolerance of all collected samples and LT50 calculations were made.

Results and Discussion

As this research is currently in the beginning stages, all results have not yet been analyzed. However, initial investigations of the data show some geographic and seasonal differences among accessions.

Future Plans

Ongoing work will continue to examine and employ the FIEL method for, where appropriate, foliage, stem, and root tissue. Whole plant freeze tests, coupled with qualitative assessments and

chlorophyll fluorescence of foliage or bark chlorenchyma will be conducted as applicable. We may also analyze carbohydrates in plant tissues with cold hardiness accumulation and loss.

Management Applications and/or Seed Production Guidelines

Upon further investigation of plant materials across geographic distributions, we will be able to determine the degree to which cold hardiness results can be extrapolated and applied to other species and across species and populations. The project will provide a streamlined strategy for plant producers and restoration specialists in the Great Basin to test cold hardiness of forb species, particular genetic sources, and other plant materials in an effort to provide better guidelines for developing and testing seed zones and improve our understanding of the influence of changing climatic conditions on plant distributions. In order to fill major knowledge gaps, there is a definite need for a manual for analyzing and evaluating cold hardiness.

Presentations

Kildisheva, Olga A. 2013. A short synopsis of seed dormancy research. 6th Annual Pacific Northwest Native Plant Meeting; 2013 December 9-11; Vancouver, WA.

Kildisheva, Olga A.; Davis, A. S. 2013. Temperature and moisture as drivers of survival and seedling physiology of a Great Basin perennial. 2nd National Native Seed Conference; 2013 April 9-12; Santa Fe, NM.

Kildisheva, Olga A.; Davis, A. S. 2013. New directions in operational seed handling. Poster presented at the 2nd National Native Seed Conference; 2013 April 9-11; Santa Fe, NM.

Pete, Kenneth W.; Santos, Vannesa; Fisk, Matthew R.; Pinto, Jeremy R.; Davis, Anthony S. 2013. Germination characteristics of northern Great Basin *Eriogonum umbellatum*. Poster presented at Idaho EPSCoR Annual Meeting; 2013 October 7-8; McCall, ID.

Pinto, Jeremy R.; Overton, Emily C.; Davis, Anthony S. 2013. Subspecies variation in Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) growth and morphology. 2nd National Native Seed Conference; 2013 April 9-12; Santa Fe, NM.

Publications

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Overton, Emily C. 2012. Advancing nursery production of big sagebrush seedlings: cold storage and variation in subspecies growth. Moscow, ID: University of Idaho. 33 p. Thesis. Available: http://www.fs.fed.us/rm/pubs_other/rmrs_2012_overton_e001.pdf [1 April 2014].

Overton, Emily C.; Davis, Anthony S.; Pinto, Jeremiah R. 2013. Insights into big sagebrush seedling storage practices. *Native Plants Journal*. 14: 225-230.

Additional Products

- Fisk, Matthew R. 2013. 34th Intermountain Container Seedling Growers' Association Meeting; 2013 September 17-19, Moscow, ID. (Meeting moderator).

Project Title Modeling Seedling Root Growth of Great Basin Species

Project Agreement No. 09-JV-11221632-056

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Project Description

This work is designed to model seedling root growth of revegetation species using thermal accumulation. Plant scientists have sought to select plant materials for revegetation of rangelands based on physiological and morphological characteristics that allow establishment under conditions of limiting temperatures and available water for plant growth. Thermal and hydrothermal models have been used to predict germination under the environmental conditions of rangelands (Meyer and Allen 2009; Rawlins 2009; Hardegree et al. 2010). However, low seedling survival limits revegetation success on rangelands, even if seeds germinate. Using a thermal accumulation model to predict seedling root growth would allow us to assess the potential for seedlings to survive under a range of field conditions and possibly suggest opportunities for plant improvement.

Objectives

- Develop thermal accumulation models for seedling root penetration for forbs, grasses, and cheatgrass.
- Test the ability of thermal models to predict root depth under diurnal temperatures in the growth chamber and in the field.
- Use thermal models and soil water and temperature data from stations in the Great Basin to predict seedling root growth and survival for dry to wet years.

Methods

Growth Chamber Study

We have measured seedling root depths over time for six forbs, five perennial grasses, and three cheatgrass collections in relation to constant temperatures in a walk-in growth chamber (Table 1). The experiment was organized in a randomized block design of four blocks and two soil types in a walk-in growth chamber. Black plexiglass holders were constructed to hold 70 (5 replicates $\times$ 14 collections) clear plastic root tubes (7.9 inches [20 cm] long with 1 inch [2.5 cm] diameters). Each block contained two plexiglass holders, one with tubes filled with sand and the other with tubes filled with Borvant gravelly loam soil passed through a 0.2-inch (0.6 cm) screen. The holders kept the tubes slanted at a 45° angle and minimized root exposure to light. For each of six constant temperature runs (41, 50, 59, 68, 77, and 86 °F [5, 10, 15, 20, 25, and 30 °C]), three seeds of a collection were sown 0.5 cm below the soil surface against the lower side of a planting tube. Prior to sowing, Utah milkvetch seeds were scarified in sulfuric acid for 15 minutes followed by stratification at 34.7 °F (1.5 °C) for two weeks. Tubes were checked six days per week, and depth of the deepest root was recorded. Twenty-five seeds of each collection were placed in petri dishes and incubated on racks below the root experiment in the incubation chamber. Time to germination was determined for seeds in each dish. Soil temperatures were measured with six thermocouples per block placed into the ends of root tubes and attached to a Campbell Scientific, Inc. CR10X micrologger. Temperatures were read each minute, and average hourly temperatures were recorded. At the end of each temperature run, one tube of each collection per block was harvested and dry weight of root biomass was recorded. The entire experiment was also conducted at three diurnal temperatures based on cold, cool, and warm soil temperatures recorded in the field. We will compare actual root depths with root depths predicted from thermal accumulation models.

Field Experiment

The same experiment as described above was conducted at two locations in Utah for two years: one on the Brigham Young University (BYU) campus and another on the east side of the Onaqui Mountains in a Utah juniper/Wyoming big sagebrush plant community where the juniper trees had been shredded. In the first year of the field experiment, natural precipitation watered the root tubes. In the second year, root tubes were watered weekly, as needed, during the growing season. Emergence and root depth were recorded five times per week at the BYU campus and at least monthly at the Onaqui site. Thermocouples and gypsum blocks were placed in each block in the field outside of the root tubes in soil or sand surrounding the tubes. These sensors were read every minute, and hourly averages were recorded with Campbell Scientific, Inc. CR10X microloggers.

Table 1. Plant materials tested in root study

	Scientific name	Common name	Release	Source	Collection date
Forbs	<i>Achillea millefolium</i>	Eagle yarrow	Eagle	Eastern WA	2003
	<i>A. millefolium</i>	White yarrow	White-VNS	Granite Seed	2003
	<i>Agoseris heterophylla</i>	Annual agoseris	NA	USFS Shrub Laboratory	2007
	<i>Astragalus utahensis</i>	Utah milkvetch	NA	USFS Shrub Laboratory	2002
	<i>Linum perenne</i>	Blue flax	‘Appar’	UDWR	2003
	<i>Lupinus arbustus</i>	Longspur lupine	NA	Wells, NV; UDWR	2004
Perennial grasses	<i>Agropyron cristatum</i> × <i>A. desertorum</i>	Crested wheatgrass	‘Hycrest’	UDWR	2003
	<i>A. desertorum</i>	Crested wheatgrass	‘Nordan’	Granite Seed	2003
	<i>Elymus elymoides</i>	Squirreltail	Sanpete	UDWR	2003
	<i>E. wawawaiensis</i>	Snake River wheatgrass	‘Secar’	WA; Granite Seed	2003
	<i>Pseudoroegneria spicata</i> subsp. <i>spicata</i>	Bluebunch wheatgrass	Anatone	Granite Seed	2003
Weedy grasses	<i>Bromus tectorum</i>	Cheatgrass	NA	Rush Valley, UT	2005
	<i>B. tectorum</i>	Cheatgrass	NA	Skull Valley, UT	2007
	<i>B. tectorum</i>	Cheatgrass	NA	Skull Valley, UT	2008

Modeling

The first step to model or predict days to reach a 6-inch (15 cm) root depth is to model daily root depth as a function of constant temperature. A 6-inch root depth was selected because we were interested in seedling establishment, most roots are in the top portion of the soil profile, and there were already many thermocouples buried in the field at this depth. Second, solve the modeled daily root depth equation to derive the number of days to a 6-inch root depth. Third, invert the number of days to 6-inch root depth. The sum of daily inverses serves as an indicator of progress toward the goal of a 6-inch root depth. On average, the 6-inch root depth goal has been achieved when the sum of the inverses equals one. The inverse of the mean number of days to 6-inch root depth for each constant temperature is used as input into TableCurve2D software, which fits a non-linear equation to the data. This non-linear equation is the temperature response curve used to predict days to a 6-inch root depth in diurnal temperature or field root trials. Most species temperature response curves had an R^2 greater than 0.9, and all species temperature response curves had an R^2 greater than 0.7 except for Utah milkvetch with an R^2 of 0.47. Days to a 6-inch root depth are converted to degree days by summing the daily average temperatures for each day of a root trial until the 6-inch root depth has been achieved. For example, if it took a species 80 days to achieve a 6-inch root depth at a constant 45 °F (7 °C) temperature, then adding the mean daily temperature of 45 °F for 80 days would equal 560 degree days.

Results and Discussion

Growth Chamber Experiment

We have conducted all six of the constant temperature runs and all three of the diurnal temperature runs in the growth chamber. The statistical results of the experiments, so far, are as follows:

Actual vs. Predicted for Diurnal Root Trials

In comparing actual versus predicted degree days to a 6-inch root depth in the diurnal root trial at 39 to 54 °F (4-12 °C) temperatures, predicted degree days showed a slightly greater trend than actual degree days (Figure 1 and 2). In soil, Secar Snake River wheatgrass, squirreltail, and longspur lupine predicted degree days were significantly greater than actual degree days. In sand, squirreltail and Nordan crested wheatgrass predicted degree days were greater than actual. These differences among predicted and actual degree days can be used to adjust future model predictions.

In sand for the diurnal trial at 48 to 63 °F (9-17 °C) temperatures, there were no significant differences between predicted and actual degree days, except predicted degree days for squirreltail were greater than actual (Figure 3). In soil for the diurnal trial 48 to 63 °F temperatures, all of the species' predicted values were greater than actual except for 2005 cheatgrass, 2007 cheatgrass, annual agoseris, and blue flax (Figure 4).

Sand vs. Soil for Diurnal Root Trials

When comparing actual and predicted degree days for sand and soil in diurnal trial at 39 to 54 °F, grasses required more degree days to reach 6-inch root depth in sand than in soil except for Secar Snake River wheatgrass, which grew equally well in sand and soil, perhaps because of inherently slower root penetration (Figure 5). Most of the forbs did not achieve 6-inch root depths in sand. The reduced rate of root depth in sand was likely due to lower nutrient availability, although other variables probably had an influence. The texture and nutrient differences between sand and soil will be analyzed at a later date.

In the diurnal root trial at 48 to 63 °F temperatures, all grass species required more thermal time in sand than in soil except for squirreltail (Figure 6). Most of the forb roots failed to achieve 6-inch root depths in sand.

Inter-species Comparisons for Diurnal Root Trials

For inter-species comparisons in sand for the root trial at 39 to 54 °F temperatures, squirreltail required more degree days than Nordan wheatgrass and 2005 cheatgrass; otherwise, there were no inter-species differences in sand. Comparing across species in soil, blue flax required more degree days than any other species. Invasive annuals required fewer degree days than all of the forbs and the perennial wheatgrasses (Secar and Hycres). Annual agoseris required more degree days than all of the grasses except Secar and Hycres. The general trend across species in soil was that annual grasses required the least amount of thermal time, forbs required the most thermal time, and perennial grasses were intermediate, although Secar was quite slow for a grass.

For inter-species comparisons in sand for the 48 to 63 °F root trial, there were few significant differences, but 2005 cheatgrass did require fewer degree days than Anatone bluebunch wheatgrass. For inter-species comparisons in soil, blue flax required the most degree days of any species. The 2005 and 2008 cheatgrass required fewer degree days than annual agoseris, Utah milkvetch, longspur lupine, and squirreltail.

As expected, cheatgrass roots grew the fastest at cool temperatures. However, the crested wheatgrasses and Anatone bluebunch wheatgrass definitely grew well enough to compete with cheatgrass. The importance of faster root growth to establishment is suggested by comparing the heat accumulation requirement of the forbs and grasses. Forbs are known to not establish as well as grasses in rangeland revegetation projects. Blue flax, one of the most successfully-seeded forbs requires about 700 to 800 degree days to reach a 6-inch root depth, while Anatone bluebunch wheatgrass requires 250 to 350 degree days (Figure 2). Sagebrush Steppe Treatment Evaluation Project data from four Great Basin pinyon-juniper locations for 2 years were used to calculate wet degree days in spring 2008 and 2009. Degree day accumulations when the soil is wet ranged from around 300 in early spring (March and April) to around 700 in late spring (May and June). As long as soil moisture is available from March to June, robust plants of both forbs and grasses should establish because there will be sufficient wet degree days for root growth. However, if soil moisture becomes unavailable by May, even robust forbs might not establish because of insufficient wet degree days to grow their roots below the soil-drying front. The details of just how many wet degree days are available under different field conditions in relation to how many are needed for successful establishment will become better understood with specific modeling exercises and field validation tests.

What appears to be a major concern for successful establishment of forbs is the lack of robust plants. Occurrence of some vigorous forb plants indicates potential for plant improvement. Such plant improvement work could potentially increase forb establishment success.

Field Experiments

We have conducted the field root trials at both the BYU campus and the east side of Onaqui Mountain for two years. We are currently analyzing these data.

Characterization of Establishment Environment

We derived several seasonal variables to characterize the soil temperature and plant available water in seedbeds, including wet thermal time and percentage of time at five temperature ranges, frost and frost-free days, and wet period duration. Thus far, we addressed a concern that germination timing response at extremely warm (> 86 °F [30 °C]) and cool (< 41 °F [5 °C]) temperature ranges would have high variability and may require further investigation if a large sum of thermal time occurs at those temperatures. Our results indicate that a minority of time is spent at the temperature ranges of concern. As a result, germination prediction models based on the summation of thermal time should be valid (Rawlins et al. 2012b).

Future Work and Research Perspective

We have conducted all of our experimental work for this grant and continue to analyze data and prepare publications. The current research is part of an ongoing research program to better

understand how seedling establishment relates to environmental conditions and plant growth characteristics (Table 2). Additional future work will include characterization of the establishment environment using measurements from 170 soil moisture stations and predict establishment success for specific sites, weather scenarios, and plant materials using the germination and seedling root growth models we have developed.

Management Applications and/or Seed Production Guidelines

An important application of thermal accumulation modeling is to predict which seeded species are most likely to establish given site-specific soil temperatures and moisture patterns and interspecies interference. As plants have to establish in communities, rates of root depth by invasive weeds influence the duration of resource availability to other species through resource preemption as the soil dries down from spring into summer. Knowing which species are most likely to establish on a site should save money by avoiding the planting of species that are unlikely to establish on certain sites. Thermal accumulation modeling can also serve as a cultivar development tool selecting for more consistently and vigorously establishing native plants.

Presentations

Cline, N.; Roundy, B. 2013. Soil temperature and available soil water characterization of sagebrush steppe seedbeds in the Great Basin. Society for Range Management 66th Annual Meeting; 2013 February 2-8; Oklahoma City, OK.

Shakespear, W.; Roundy, B. 2013. Soil water availability in pinyon-juniper communities. Society for Range Management 66th Annual Meeting; 2013 February 2-8; Oklahoma City, OK.

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Young, K. R.; Roundy, B. A.; Egget, D. L. 2013. Tree reduction and debris from mastication of Utah juniper alter the soil climate in sagebrush steppe. *Forest Ecology and Management*. 310: 777-785.

Table 2. Schedule and status of research phases to predict seed germination and seedling establishment in the Great Basin

Research phase	Past and current work	Major findings	Published or planned publications
Characterize seedbed environment	Soil moisture and temperature measurements from 24 sagebrush/bunchgrass, pinyon-juniper, crested wheatgrass, and cheatgrass sites and 170 stations in the Great Basin	-Soil moisture and temperatures fluctuate much more at 1-3 cm in the germination zone than 13-30 cm deep in the seedling establishment zone. -Wet degree days accumulate fastest in spring, only slightly in winter, and erratically in fall as a function of timing and amount of precipitation. Number of days when the soil is wet and within certain temperature ranges has been determined for 24 sites. -Tree reduction increases time of water availability from 1-6 weeks in the spring, providing a major resource for weedy and desirable plant growth. -Wet seedbed temperatures are generally within the temperature range where germination is accurately predicted by thermal accumulation models.	Published: Chambers et al. 2007; Roundy et al. 2007; Rawlins et al. 2012b; Young et al. 2013; Roundy et al. 2014 In preparation or submitted: Cline et al. Wet-thermal time at five temperature ranges in seedbeds of the sagebrush steppe. Cline et al. Spring drying and wetting for seedling root zones in the Great Basin.
Develop models of germination and seedling growth	Roundy's laboratory developed germination models for 14 collections while Hardegree's laboratory developed models for numerous desirable and weed collections. Roundy's laboratory developed root growth models for 14 collections.	-Timing of germination can be predicted in relation to accumulated time and temperature above a threshold temperature for non-dormant seed lots. The models work best at moderate temperatures. -Seminal root growth or time for roots to reach a soil depth can be predicted similarly but will vary with other variables such as soil texture and nutrient availability.	Published: Roundy et al. 2007; Rawlins et al. 2012a; Hardegree et al. 2013 In preparation: Cline et al. Germination prediction of 31 plant materials using soil water potential and temperature at 24 Great Basin sites. Young et al. Thermal accumulation modeling of seedling root depth.

Research phase	Past and current work	Major findings	Published or planned publications
Compare modeled and actual responses in laboratory and field	Roundy's laboratory has compared predicted and actual timing of germination under simulated field seedbed temperatures in the laboratory and in field seedbeds for 2 sites and 2 years.	-Thermal accumulation tends to overestimate time required to germinate seed subpopulations, but is accurate enough for field predictions. -Wet thermal accumulation models using continuous thermal accumulation and a wet threshold of -1.5 MPa water potential predicted field germination best. Accuracy was 80% or greater for most collections in late winter to spring. -Data from field and laboratory comparisons of predicted and actual seedling root depth is being analyzed.	Published: Rawlins et al. 2012a,b In preparation: Young et al. Field prediction of seedling root depth using a wet-thermal accumulation model.
Extend predictions to a range of plant materials, environments, and land treatments	Cline has prepared a germination prediction analysis of 31 plant materials for 24 sites across a range of years and treatments, such as prescribed fire and mechanical brush or tree control. Roundy, Young, and Cline will eventually extend the germination and root growth model predictions to 24 sites across the Great Basin to predict probability of seedling mortality.	-In an analysis of cheatgrass germination potential for 9 sites and 4 years (36 site-years), Roundy et al. (2007) found that cheatgrass had high germination potential in spring, low potential in winter, and high potential in fall when rains occurred before temperatures decreased to near freezing. -Cline found that although prescribed fire increased the probability of germination, germination was predicted for most plant materials and sites in spring and fall. This suggests that germination is not generally limiting to plant establishment on similar sites and years studied.	Published: Roundy et al. 2007 In preparation: Cline et al. Germination prediction of 31 plant materials using soil water potential and temperature at 24 Great Basin sites. TBA et al. Predicting seedling mortality from thermal accumulation models of germination and root growth.

Diurnal 4-12°C - Actual vs Predicted - Sand

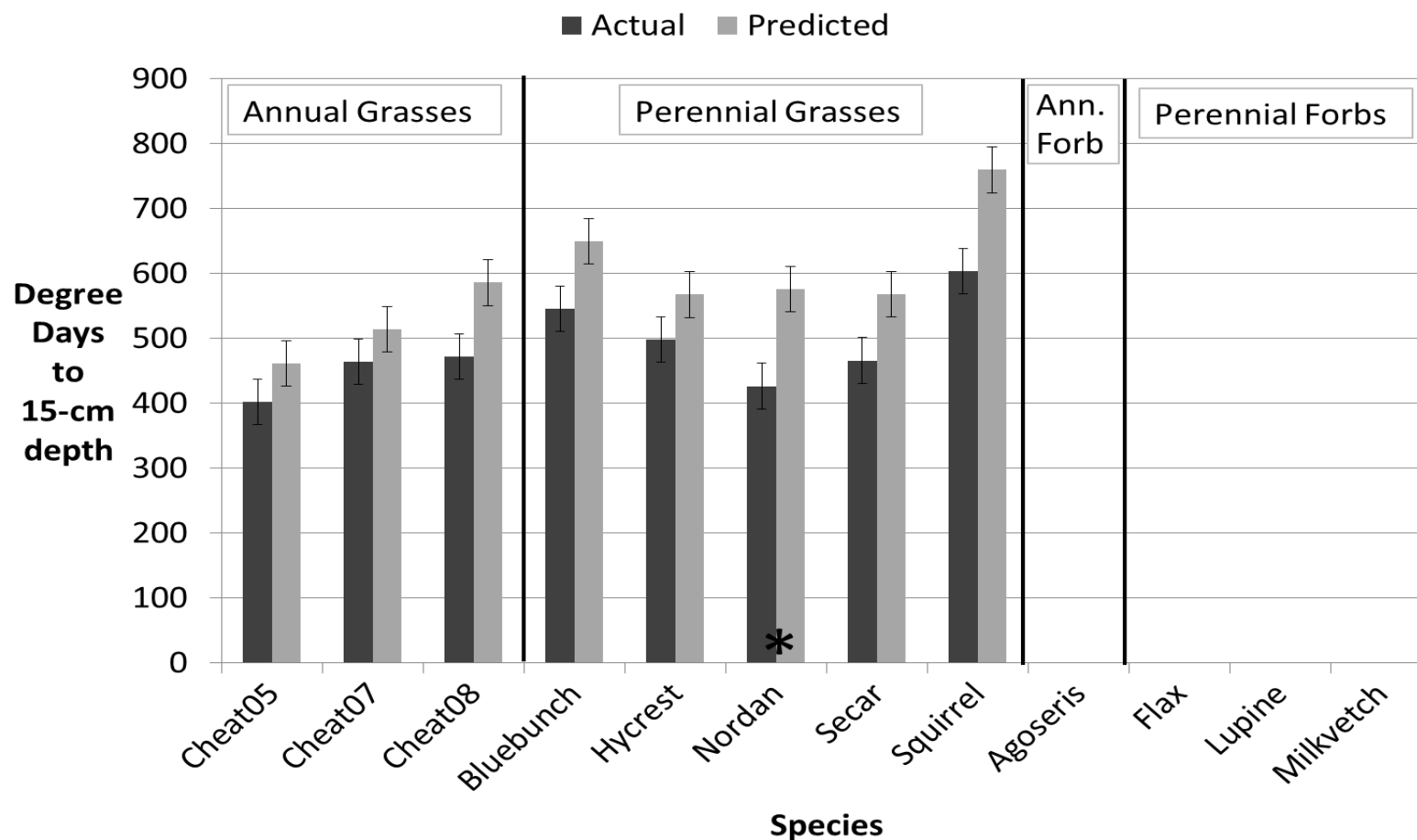


Figure 1. Actual vs. predicted degree days to a 6-inch (15 cm) root depth in sand for the growth chamber diurnal root trial at 39 to 54 °F (4-12 °C) temperatures. Asterisk indicates significant difference at the 95% confidence level.

Diurnal 4-12°C - Actual vs Predicted - Soil

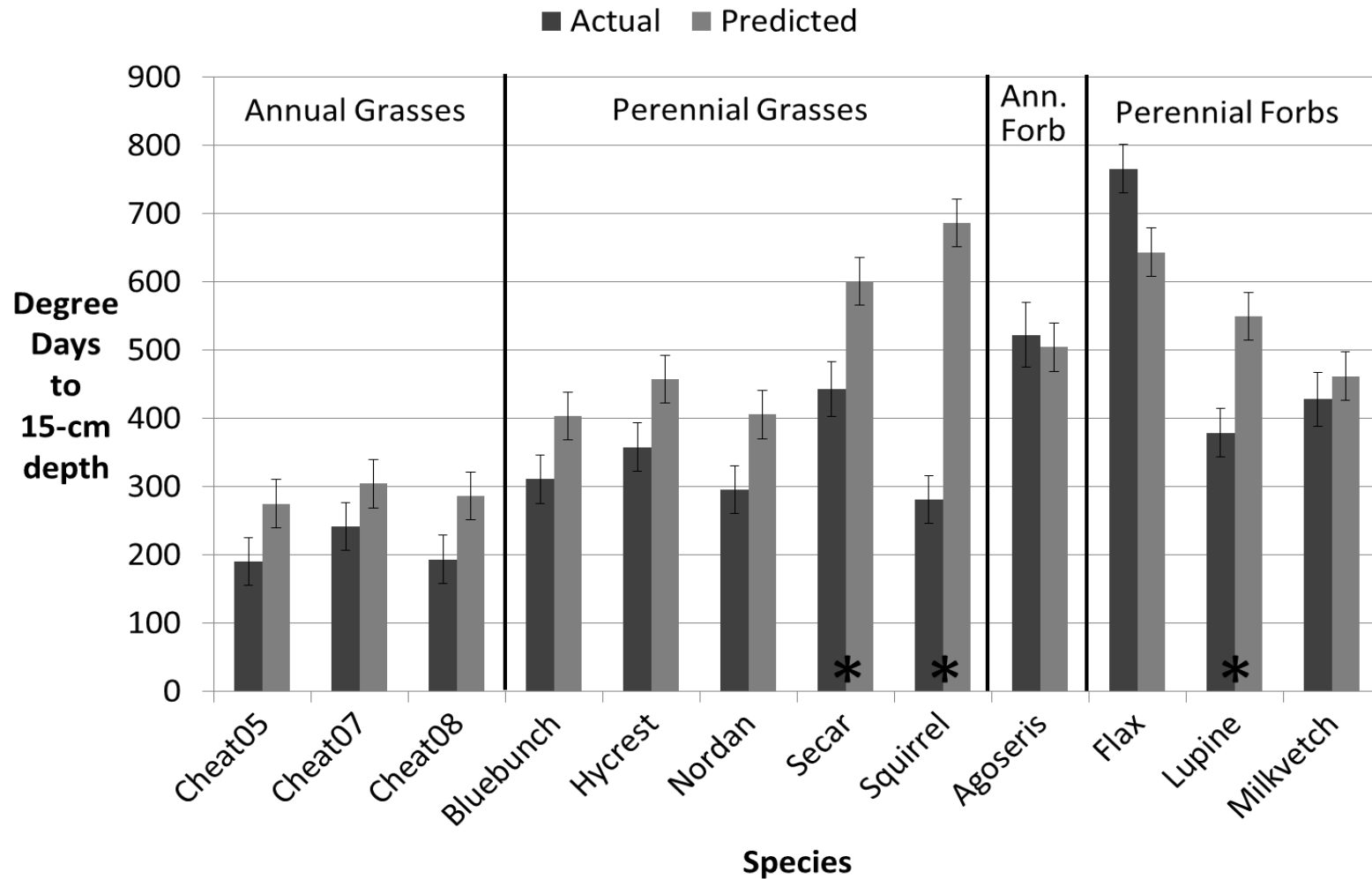


Figure 2. Actual vs. predicted degree days to a 6-inch (15 cm) root depth in soil for the growth chamber diurnal root trial at 39 to 54 °F (4-12 °C) temperatures. Asterisks indicate significant difference at the 95% confidence level.

Diurnal 9-17°C - Actual vs Predicted - Sand

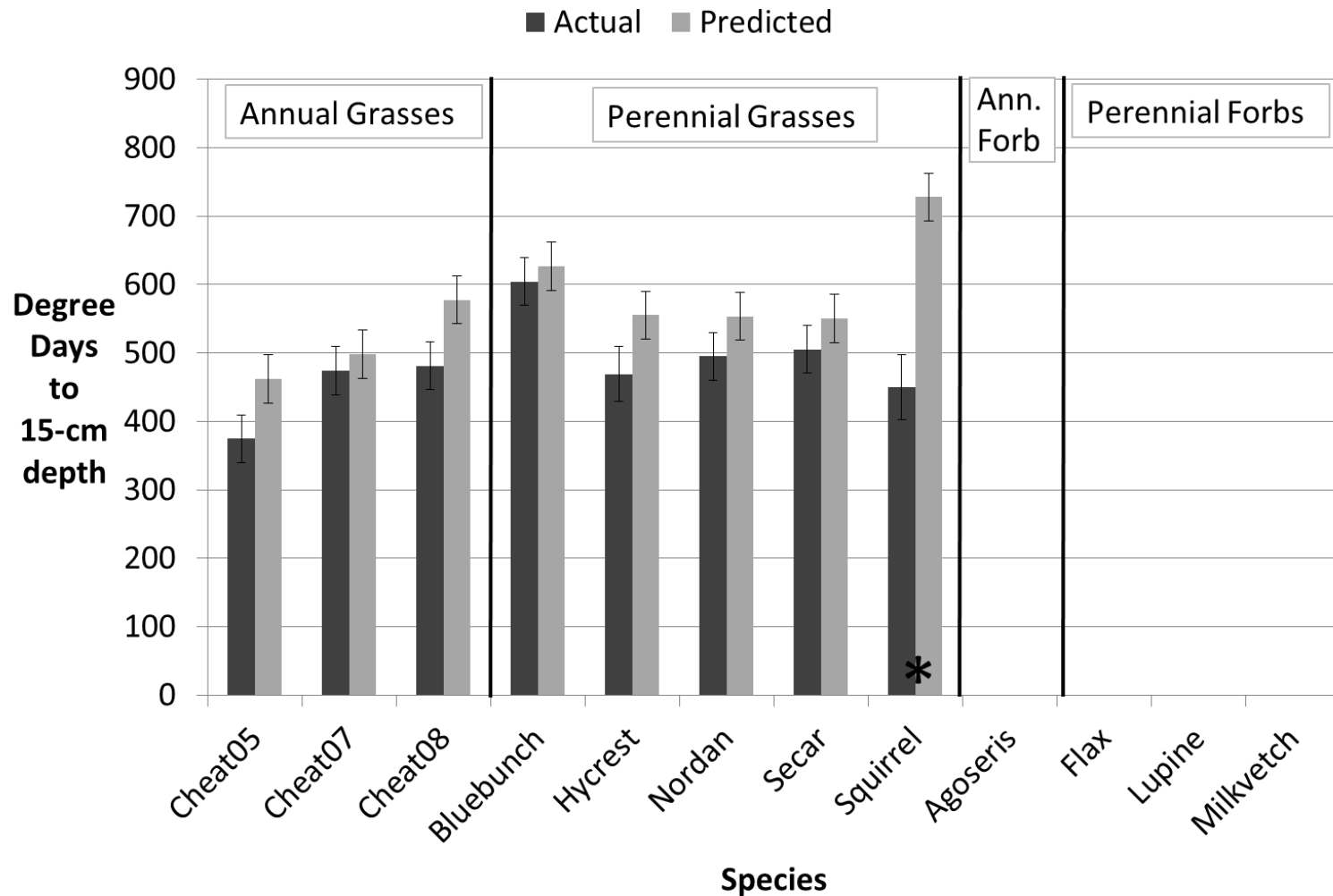


Figure 3. Actual vs. predicted degree days to a 6-inch (15 cm) root depth in sand for the growth chamber diurnal root trial at 48 to 63 °F (9-17 °C) temperatures. Asterisk indicates significant difference at the 95% confidence level.

Diurnal 9-17°C - Actual vs Predicted - Soil

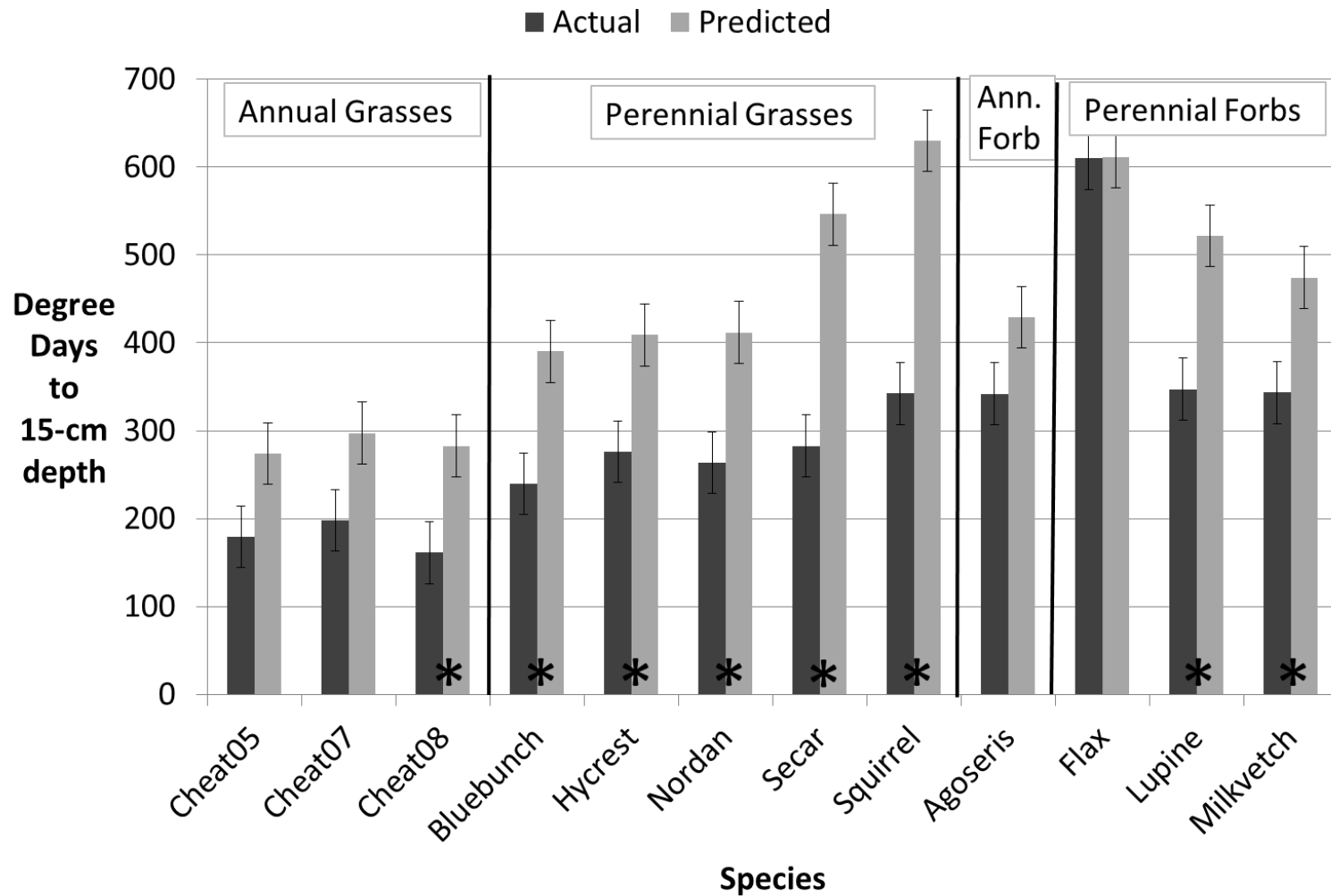


Figure 4. Actual vs. predicted degree days to a 6-inch (15 cm) root depth in soil for the growth chamber diurnal root trial at 48 to 63 °F (9-17 °C) temperatures. Asterisks indicate significant difference at the 95% confidence level.

Diurnal 4-12°C - Sand vs Soil - Actual

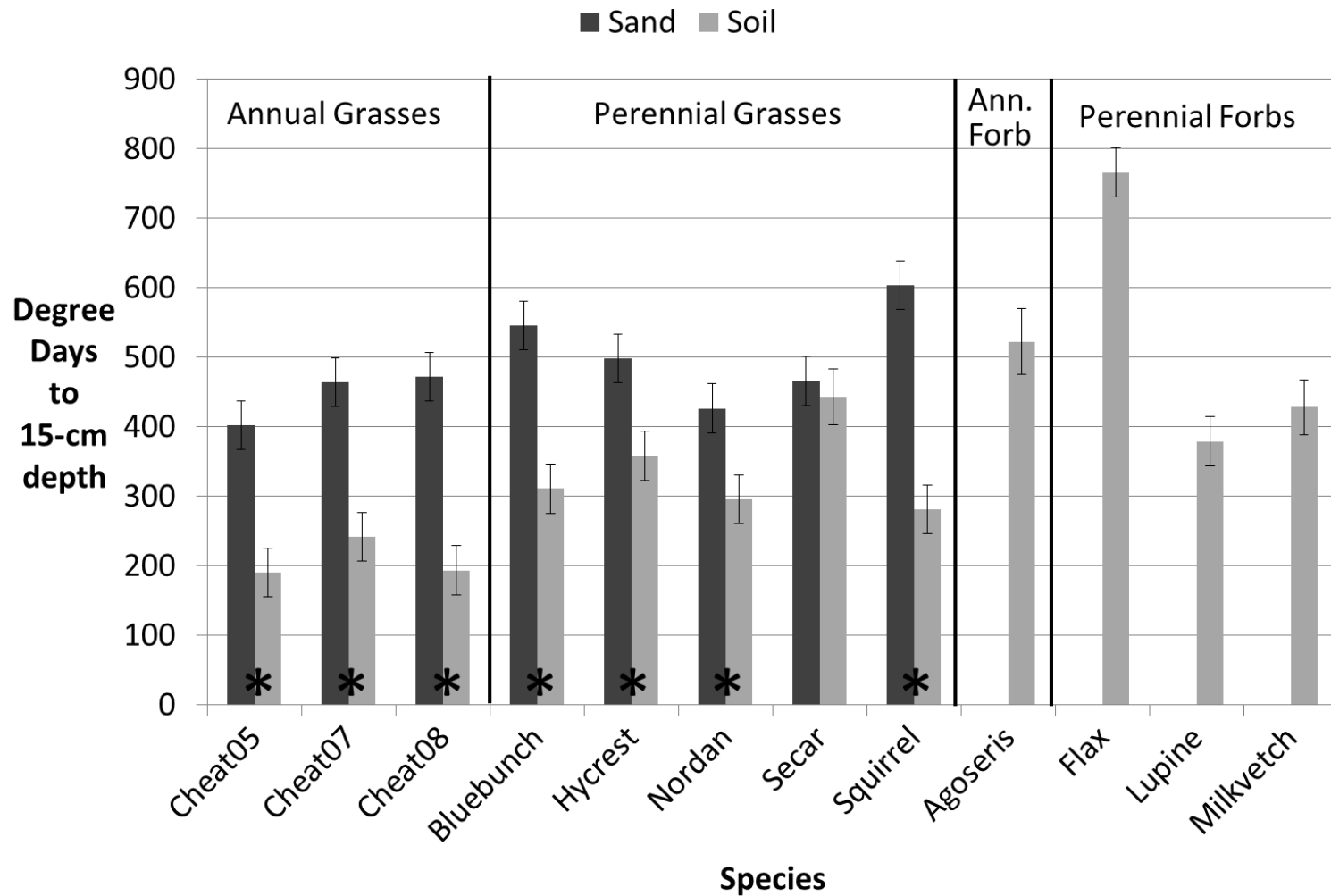


Figure 5. Actual sand vs. soil degree days to a 6-inch (15 cm) root depth for the growth chamber diurnal root trial at 39 to 54 °F (4-12 °C) temperatures. Asterisks indicate significant difference at the 95% confidence level.

Diurnal 9-17°C - Sand vs Soil - Actual

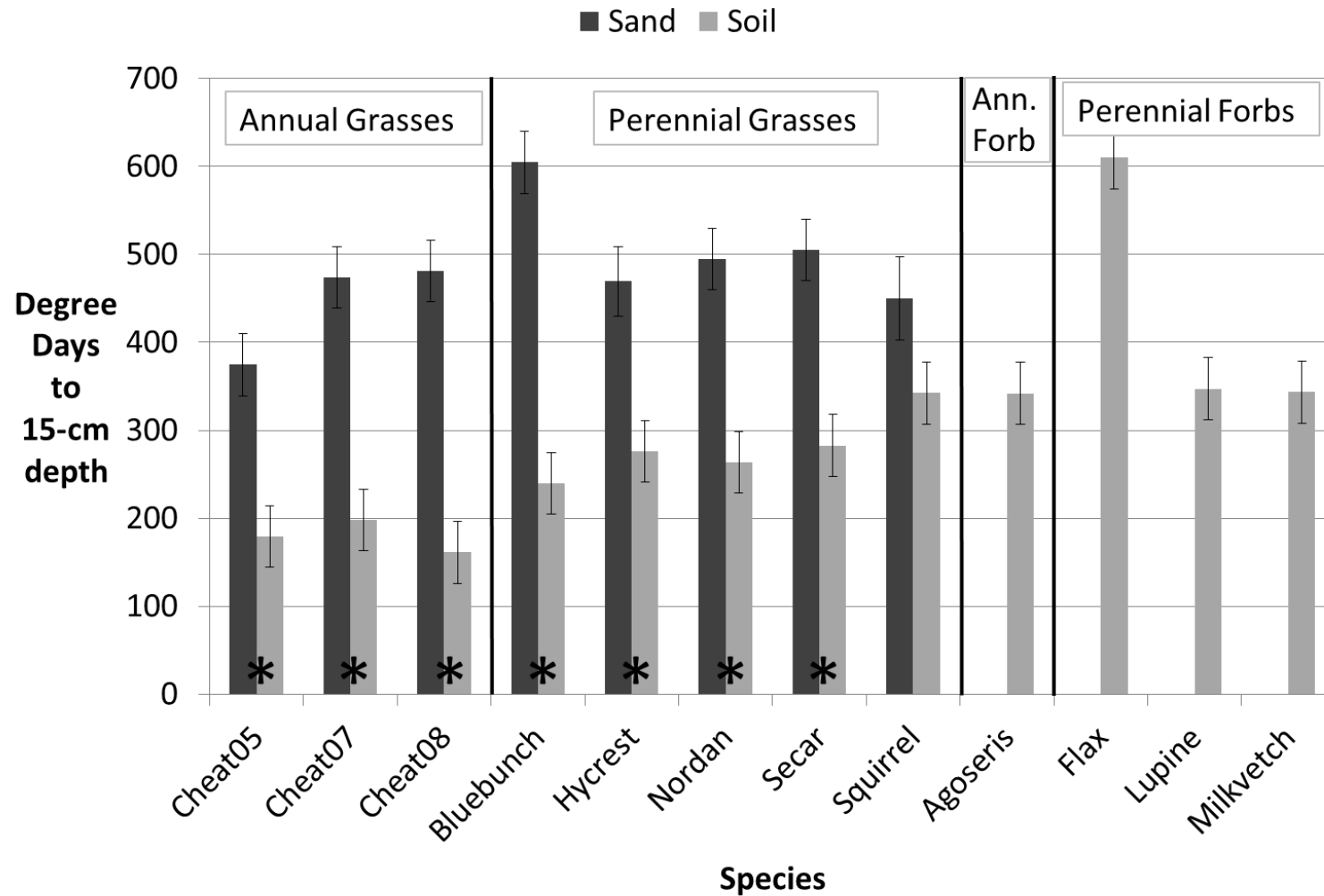


Figure 6. Actual sand vs. soil degree days to a 6-inch (15 cm) root depth for the growth chamber diurnal root trial at 48 to 63 °F (9-17 °C) temperatures. Asterisks indicate significant difference at the 95% confidence level.

Project Title Pre-inoculation of Wyoming Big Sagebrush Seedlings with Native Arbuscular Mycorrhizae: Effects on Mycorrhizal Colonization and Seedling Survival after Transplanting

Project Agreement No. 14-JV-11221632-014

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Project Description

Introduction

In semiarid steppe communities of the Intermountain West, reintroduction of Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) following fires has proven difficult. This is in large part due to high seedling mortality during summer droughts (Lambrecht et al. 2007). Mortality is also associated with the low growth rates of sagebrush seedlings. Slow growth rates decrease the plant's ability to compete for resources and may prevent seedlings from developing an adequate root system to maintain hydration during the dry summer (Stahl 1998; Lambrecht et al. 2007).

One factor that could improve the growth rates and stress tolerance of sagebrush seedlings is the establishment of symbiotic associations with arbuscular mycorrhizal fungi (AMF) (Stahl et al. 1988,1998; Klironomos et al. 1998). Mycorrhizae are known to improve nutrient uptake, particularly phosphorus, which can markedly increase plant growth (Smith et al. 2003). Colonization by AMF can also increase tolerance to water deficits (Augé 2001; Finley 2008).

Pre-inoculation of seedlings with AMF is a common practice aimed at improving seedling establishment. However, the success of this practice largely depends on the ability of the inoculum to multiply and colonize the growing root system after transplanting. In southern

Idaho, Wyoming big sagebrush is typically transplanted in the spring or early fall. At these times, the seedlings and AMF experience different edaphic and climatic conditions. Such differences may affect AMF growth after transplanting as well as the AMF impact on seedling establishment. To investigate these possibilities, we conducted two experiments at a burned site at the Morley Nelson Snake River Birds of Prey National Conservation Area. Each experiment had three treatments: non-inoculated seedlings, pre-inoculated seedlings with native soil, and pre-inoculated seedlings with pot cultures of native mycorrhizae. The three types of seedlings were transplanted in the spring and in the fall.

Objectives

- To determine whether pre-inoculation with AMF increases colonization in roots developing after transplanting.
- To evaluate if pre-inoculation causes changes in the AMF community composition of the roots.
- To characterize the effects of an increase on AMF colonization on seedling survival.

Methods

Seeds for the experiments were collected from a natural population of Wyoming big sagebrush occurring at the experiment sites before the fire (43°18'48.43"N, 116°21'48.57"W). We grew sagebrush seedlings in a greenhouse for three months under one of the three inoculation treatments: sterile soil from the field site (non-inoculated treatment), untreated soil from the field site (natural treatment), or soil from pot cultures of native mycorrhizae (inoculated treatment). One hundred seedlings per treatment were transplanted in the field; 300 were transplanted on 12 April 2012 (spring transplanting) and another 300 were transplanted on 4 October 2012 (fall transplanting).

Following transplanting, we assessed AMF colonization, AMF community composition, and seedling survival. For measurements of AMF colonization and community composition, seedlings were collected 4 and 5 months after spring and fall transplanting, respectively. Due to the laborious nature of this work, we only collected seedlings from the non-inoculated and inoculated treatments. AMF colonization was estimated by the intersection method after staining with Chlorazol Black E (McGonicle et al. 1990). The AMF phylotypes present in the roots were determined as described by Carter et al. (2013). Possible differences in AMF phylotype composition between pre-inoculated and non-inoculated seedlings were analyzed using non-metric multidimensional scaling (NMDS). NMDS is an unconstrained ordination method that arranges communities according to their similarities in species composition (Minchin 1987). Survival was monitored biweekly or monthly, and statistical differences among treatments were evaluated using a log rank test.

Results and Discussion

For the seedlings transplanted in spring, no difference in colonization was observed between non-inoculated and pre-inoculated seedlings (Figure 2). However, a significant difference in colonization was detected between roots collected in the upper 8 inches (20 cm) of soil (upper roots) and roots collected below 20 inches (50 cm) (deep roots). Upper roots had lower levels of colonization than deep roots (13% [± 3] and 41% [± 5], respectively). The most common phylotypes found in the roots were within the genus *Glomus*, while other phylotypes clustered

with *Funneliformis mosseae* or *Rhizophagus irregularis*. No clear differences in the proportion of the various phylotypes were detected between shallow and deep roots ($p = 0.3257$) or between non-inoculated and pre-inoculated seedlings ($p = 0.064$, Figure 3). No differences in seedling survival were observed between treatments (Figure 2). At the beginning of fall 2012, all treatments had similar survival rates of about 40%. No seedling mortality occurred in the fall or winter, but additional seedling losses occurred during the summer of 2013. As a result, the percent survival on 13 October 2013 was about 20%.

The results of the fall transplanting experiment were somewhat different. Five months after transplanting, most roots were within the top 12 inches (30 cm) of the soil. Consequently, no attempts were made to differentiate between upper and deep roots, but only between non-inoculated and inoculated seedlings. Inoculated seedlings had higher colonization than non-inoculated seedlings ($p = 0.03$, Figure 3), but no differences in AMF composition were observed between these treatments ($p = 0.36$, Figure 5). The most common phylotypes were again within the *Glomus* genus, followed by phylotypes that clustered with *Funneliformis mosseae* or *Rhizophagus irregularis*. In contrast to spring transplanting, survival following fall transplanting was different among the 3 treatments ($p < 0.01$). The highest survival occurred in the inoculated treatment, followed by the natural and non-inoculated treatments (Figure 4).

Losses of seedlings occurred throughout the year. Due to mortality in the fall and winter, the percent survival at the end of the winter was 44%, 62%, and 81% for non-inoculated seedlings, natural seedlings, and inoculated seedlings, respectively. Additional losses occurred in the spring and summer. As a result, the percent survival one year after transplanting was 4%, 11%, and 30% for non-inoculated seedlings, natural seedlings, and inoculated seedlings, respectively.

Our results suggest that the ability of the AMF inoculum to multiply and colonize the root system is greater in the fall than in the spring or summer. Reasons for seasonal colonization difference are unclear but may be attributed to seasonal differences in soil moisture and root system morphology. Higher soil moisture and root branching in the upper layers of the soil in the fall may facilitate propagation of the AMF inoculum.

Our results also indicate that with fall transplanting inoculation with native AMF can be beneficial. Inoculation resulted in an increase in colonization over the levels naturally occurring in the soil and increased seedling survival.

Overall, survival following spring transplanting was not significantly different from survival after fall transplanting. However, this comparison is based on data from only one year. Precipitation during fall 2011 and winter 2012 was higher than that occurring during fall 2012 and winter 2013. A wetter fall, winter, and spring in 2012 and 2013 may have favored survival of seedlings transplanted during the fall, because they were smaller and had shallower roots than those transplanted in spring. Replication of the experiments over several years is likely to provide a better understanding of the comparative advantages and disadvantages of spring versus fall transplanting.

Management Applications and/or Seed Production Guidelines

Our results indicate that pre-inoculation with native AMF can increase colonization after transplanting and pre-inoculation does not significantly alter the composition of the AMF community. Pre-inoculation prior to spring transplanting was less effective in increasing colonization and seedling survival than pre-inoculation prior to fall transplanting. Pre-inoculation with native AMF can be used to improve reestablishment of Wyoming big sagebrush, but time of application of this treatment is likely important to successful seedling establishment.

Presentations

Carter K. A.; Serpe, M. D.; Smith, J. F. 2013. Assessing the diversity of mycorrhizal communities in sagebrush steppes of southwestern Idaho. Poster presented at Botanical Society of America annual meeting; 2013 July 27-31; New Orleans, LA.

Davidson, B. E.; Serpe, M. D. 2013. Colonization of *Artemisia tridentata* subsp. *wyomingensis* by native arbuscular mycorrhizae: persistence and consequence of inoculation. Poster presented at the Great Basin Consortium Conference; 2013 December 9-10; Reno, NV.

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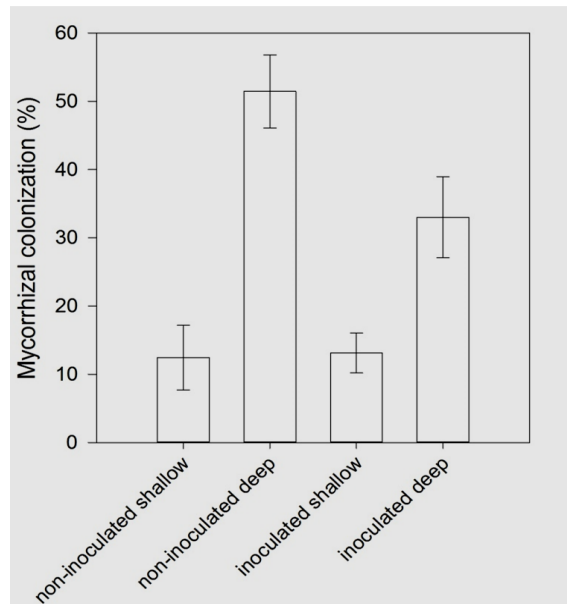


Figure 1. Mycorrhizal colonization four months after spring transplanting. Bars represent the mean ($\pm$ SE) of six seedlings. No significant differences were observed in mycorrhizal colonization between treatments ($p > 0.05$), but differences in colonization were detected between upper and deep roots ($p < 0.001$).

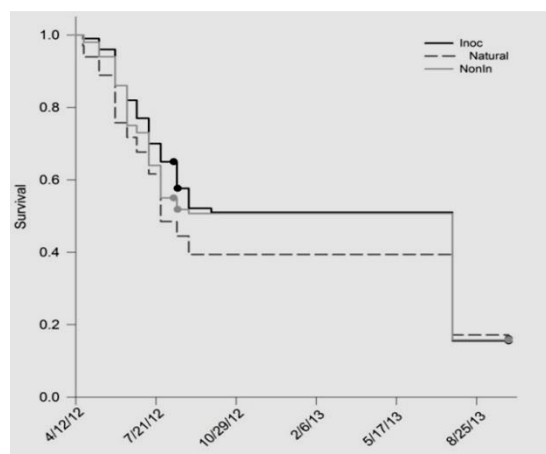


Figure 2. Seedling survival following spring transplanting. No significant differences were observed in survival between treatments ($p > 0.05$).

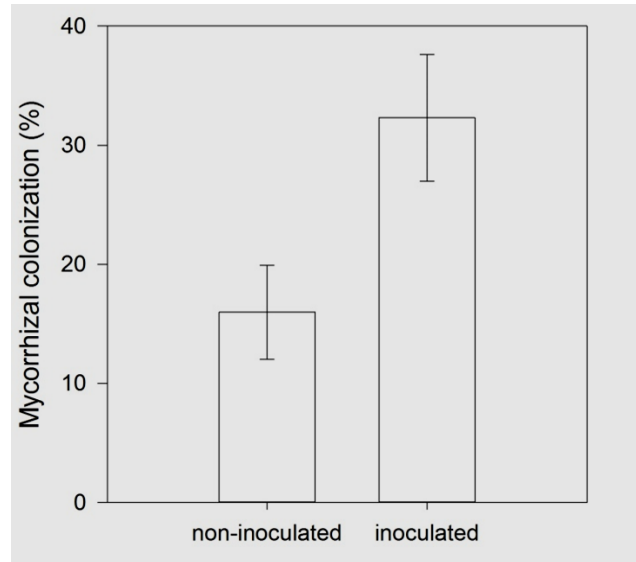


Figure 3. Mycorrhizal colonization five months following fall transplanting. Bars represent the mean ($\pm$ SE) of six seedlings. Significant differences were observed among treatments ($p < 0.05$).

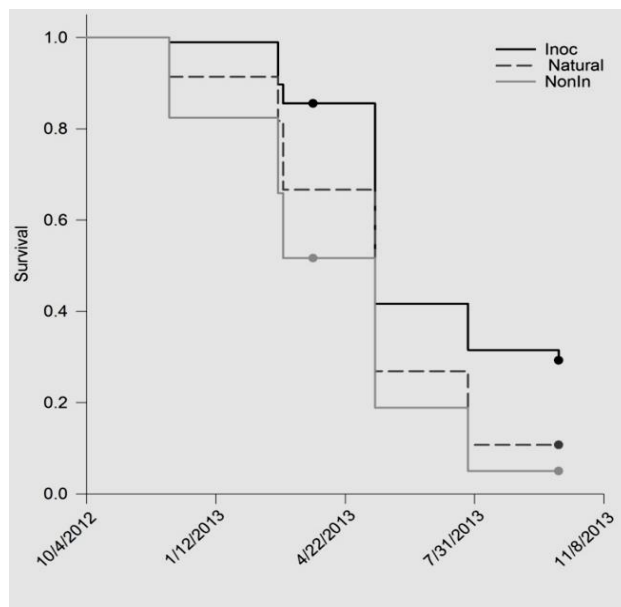


Figure 4. Seedling survival following fall transplanting. Significant differences were observed among treatments ($p < 0.05$).

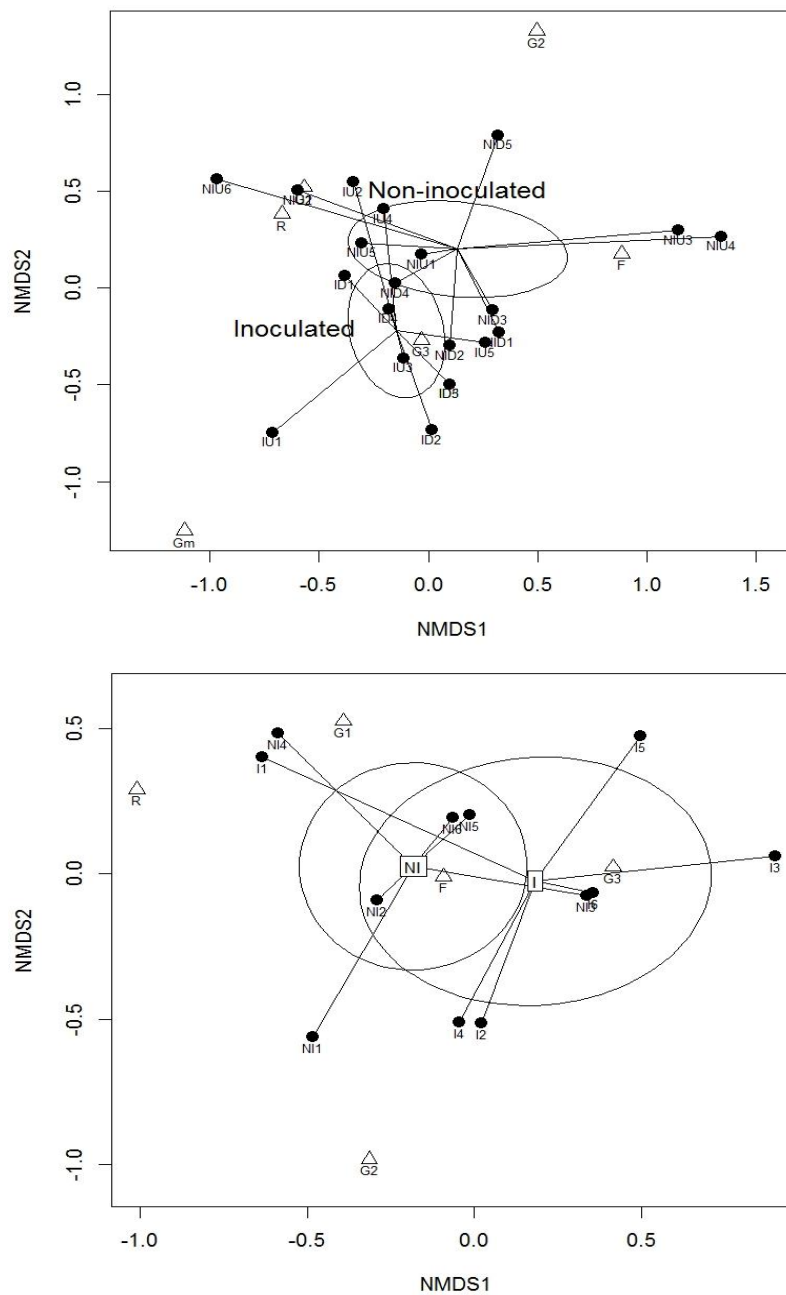


Figure 5. Similarities among arbuscular mycorrhizal communities as revealed by non-metric multidimensional scaling. Effect of inoculation on seedlings transplanted during the spring (**top**) and during the fall (**bottom**) in the ordination space of AMF communities. Phylotypes are represented by open triangles and plants by filled circles. Phylotypes: R, *Rhizophagus*; G1, *Glomus I*; G2, *Glomus II*; G3, *Glomus III*; Gm, *Glomus macrocarpum*; F, *Funneliformis*; C1, *Claroideoglomus I*, C2, *Claroideoglomus II*. Other figure abbreviations- I: inoculated seedlings, NI: non-inoculated seedlings, and when available, U: upper roots, D: deep roots. Ellipses represent 95% confident limits around centroids of each treatment.

Project Title Smoke-induced Germination of Great Basin Native Forbs

Project Agreement No. 11-CR-11221632-005

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Project Description

Objectives and Methods

We tested 11 species for germination response to smoke: Indian ricegrass (*Achnatherum hymenoides*), Thurber's needlegrass (*A. thurberianum*), common yarrow (*Achillea millefolium*), bigflower agoseris (*Agoseris grandiflora*), big sagebrush (*Artemisia tridentata*), fourwing saltbrush (*Atriplex canescens*), rubber rabbitbrush (*Ericameria nauseosa*), silverleaf phacelia (*Phacelia hastata*), king desertparsley (*Lomatium graveolens*), royal penstemon (*Penstemon speciosus*), and Sandberg bluegrass (*Poa secunda*).

For each species, there were four treatment groups that were treated with 0:1, 1:10, 1:100, and 1:1000 concentrations of smokemaster, aqueous smoke mixed with distilled water (REGEN 2000). Each treatment group had 25 treated seeds and treatments were replicated four times. Seeds were placed in plastic containers with two moist blotter sheets in a germination chamber programmed to simulate the alternating temperature and light intensity regimes required by the species. Observations were recorded for four weeks. Seeds were considered germinated when radicles extended at least 1 mm past the seed coat. Data were analyzed using a repeated measure ANOVA and JMP software to identify significant treatment effects.

Results and Discussion

Big sagebrush showed a strong negative response to a 1:10 concentration of smoke, while fourwing saltbrush demonstrated a significant positive response to smoke at a 1:1000 concentration. The other species tested did not respond to smoke.

Although sagebrush steppe grasslands generally have natural fire frequencies of 40 to 70 years, few species showed a germination response to smoke treatments. Only two of 11 species showed any significant response to smoke treatments. Big sagebrush was inhibited by high concentrations of smoke. Some species may not have exhibited a smoke response because of other germination requirements that were not met in our experimental design. Of the species tested, cold stratification is recommended by the Association of Official Seed Analysts as a pretreatment for Indian ricegrass, big sagebrush, and rubber rabbitbrush. Big sagebrush smoke has been shown to positively affect the germination of Indian ricegrass in other studies (Blank 1998), but we were not able to detect smoke treatment effects for this species.

Future Plans

We plan to continue testing species and have several tests underway at this time.

Management Applications and/or Seed Production Guidelines

When understood, the response of native seeds to smoke could be a powerful management tool to either stimulate or inhibit germination of target species. For the species tested, big sagebrush seedling emergence could be inhibited by smoke application, while fourwing saltbrush seeds could be treated with smoke to increase their germinability.

Presentations

Miller, Sarah; Pendell, Elizabeth; Chandler, Alisa; Cox, Robert. Smoke-induced seed germination of Great Basin species. Texas Tech University Undergraduate Research Conference; 2013 April 22-25; Lubbock, TX.

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

Project Agreement No. 11-IA-11221632-007

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Project Description

Rapid, uniform germination and initial stand establishment of legume species is frequently limited by hardseededness. As part of this project, we previously conducted greenhouse experiments that determined how depth of planting and seed scarification treatments (soaking in concentrated sulfuric acid for 5 minutes or mechanically scarifying with 120-grit sandpaper) affected germination and emergence of western prairie clover (*Dalea ornata*), basalt milkvetch (*Astragalus filipes*), and Searls' prairie clover (*D. searlsiae*). These studies showed that seedlings of western prairie clover and Searls' prairie clover emerged well at both the 0.6-cm (0.3 inch) and 1.9-cm (0.8 inch) planting depths. Scarification greatly improved emergence in both western and Searls' prairie clover, but much less so for basalt milkvetch. Scarification by acid was significantly better than sandpaper scarification for the two prairie clover species. For basalt milkvetch, sandpaper scarification resulted in slightly higher emergence than acid scarification; however, total emergence was still less than 40% (on a pure live seed basis) for basalt milkvetch, compared to 95% emergence for acid-scarified seedlots of western and Searls' prairie clover.

In a second greenhouse study, the effects of soil crusting (water droplet size), soil type (sand, clay/sand, and clay), and acid scarification were evaluated. Similar to the first greenhouse study, speed of emergence was greater for western prairie clover than for basalt milkvetch. All species emerged faster when seed was scarified; however, this effect was least for basalt milkvetch, which generally had a low rate of emergence. For western and Searls' prairie clover, speed of emergence was greater in sand than in soils with clay. For basalt milkvetch, emergence was

slower in sand than in soils with clay, probably because of the drying effect on seed germination and emergence for basalt milkvetch.

Seeded plots were previously established during 2011 and 2012 at three sites in Oregon (Clarno, Powell Butte, and Ontario) by cooperators, Matt Horning and Clinton Shock. Results from their first year of data indicated that early spring plantings of scarified western prairie clover seed were most successful and that scarified basalt milkvetch seed established best when seeded in the fall.

Field Seedings for 2013

Plots were again planted at the three Oregon sites in fall of 2012 and spring of 2013 to duplicate the 2011 and 2012 experiments. Because of extremely low spring and summer precipitation, seedlings failed to establish. Seedings will be conducted at these sites again in fall of 2014 and spring of 2015. Spring seedings were also made near Pleasant View, Colorado by Walter Henes and Angela Rohwer. Three ecotypes of Searls' prairie clover established successfully, and plants flowered and produced seed in their first year. Results in Colorado also confirmed that spring seeding is not good for basalt milkvetch. In another spring seeding study in Panguitch, Utah, establishment and emergence results were similar to those observed in Colorado. In Logan, Utah, a large-scale, seed-increase field of Searls' prairie clover was successfully established in spring of 2013 with supplemental irrigation, and prospects are excellent for seed production in 2014. A release of Searls' prairie clover is anticipated in 2014.

Management Applications and/or Seed Production Guidelines

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

Publications

Cane, J. H.; Johnson, C. D.; Napoles, J. R.; Johnson, D. A.; Hammon, R. 2013. Seed-feeding beetles (Bruchinae, Curculionidae, Brentidae) from legumes (*Dalea ornata*, *Astragalus filipes*) and other forbs needed for restoring rangelands of the Intermountain West. *Western North American Naturalist*. 73: 477-484.

Johnson, D. A.; Bushman, B. S.; Jones, T. A.; Bhattarai, K. 2013. Using common gardens and AFLP analyses to identify metapopulations of indigenous plant materials for rangeland revegetation in western USA. In: Michalk, D. L.; Millar, G. D.; Badgery, W. B.; Broadfoot, K. M., eds. *Proceedings of the 22nd International Grassland Congress: Revitalizing grasslands to sustain our communities*; 2013 September 15-19; Sydney, Australia. Orange, Australia: New South Wales Department of Primary Industry: 371-372.

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Bushman, B. S.; Johnson D. A.; Horning, M.; Shock, C.; Connors, K. J. 2013. Improving seedling germination and emergence of legumes native to the semi-arid western USA. 2nd Native Seed Conference; 2013 April 8-11; Santa Fe, NM.

Johnson, D. A.; Bushman, B. S.; Jones, T. A.; Bhattarai, K. 2013. Using common gardens and AFLP analyses to identify metapopulations of indigenous plant materials for rangeland revegetation in western USA. XXII International Grassland Congress; 2013 September 15-19; Sydney, Australia.

Johnson, D. A.; Bushman, B. S.; Jones, T. A.; Connors, K. J. 2013. Impact of seed scarification and soil crusting on greenhouse seedling emergence in three native legumes. Society for Range Management Annual Meeting; 2013 February 2-8; Oklahoma City, OK.

Project Title Native Forb Cultural Practices, Seed Increase, and Forb Island Plantings

Project Agreement No. 12-JV-11221632-050

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Project Description

Native Lupine Seed Production

In fall 2007, we planted cultural practice trials of four common native lupine species: silvery lupine (*Lupinus argenteus*), longspur lupine (*L. arbustus*), hairy bigleaf lupine (*L. prunophilus*), and silky lupine (*L. sericeus*) to evaluate several planting methods: seed broadcast and covered with mulch and N-sulate fabric, seed drilled in rows left uncovered, and transplants planted into weed barrier. No longspur lupine plantings established due to nutrient deficiency. Emergence and establishment have previously been reported and will not be addressed in this report. However, seed production cycles have not been reported and will be addressed.

Seed production was harvested from each treatment and analyzed for the first several years. Once the most productive plots were identified, seed production was recorded as a whole for each species. We tracked seed production as an indicator of stand health and longevity. As stands mature, seed production will eventually reach peak seed levels and then decrease. When seed

production dropped below 33.6 kg/ha (30 lb/acre) the plots were removed. This was done to imitate the actions of a private grower who is unwilling to maintain a seed increase field after it becomes unprofitable.

Silvery lupine seed production peaked in the third growing season with 66 kg/ha (59 lb/acre) on the Fountain Green WMA farm and 64 kg/ha (57 lb/acre) on the Snow Field Station farm (Figure 1 and 2). After the fourth growing season the plots were removed.

Seed production for silky lupine peaked in the fourth growing season with 93 kg/ha (83 lb/acre) on the Fountain Green WMA farm and 116 kg/ha (104 lb/acre) on the Snow Field Station farm (Figure 1 and 2). In 2013 all plots except the broadcast and covered treatments were removed. We believe that the decreased seed production in 2012 and 2013 was due to the drought conditions during the winter and spring.

Hairy bigleaf lupine exhibited signs of iron deficiency chlorosis shortly after emergence. One of our three treatment groups became established, however, it suffered from iron deficiency chlorosis each year and did not flower and set seed until 2011, 4 years after planting. Seed production for hairy bigleaf lupine peaked in the sixth growing season with 43 kg/ha (38 lb/acre) on the Fountain Green Wildlife Management Area (WMA) farm and 338 kg/ha (302 lb/acre) on the Snow Field Station Farm (Figures 1 and 2).

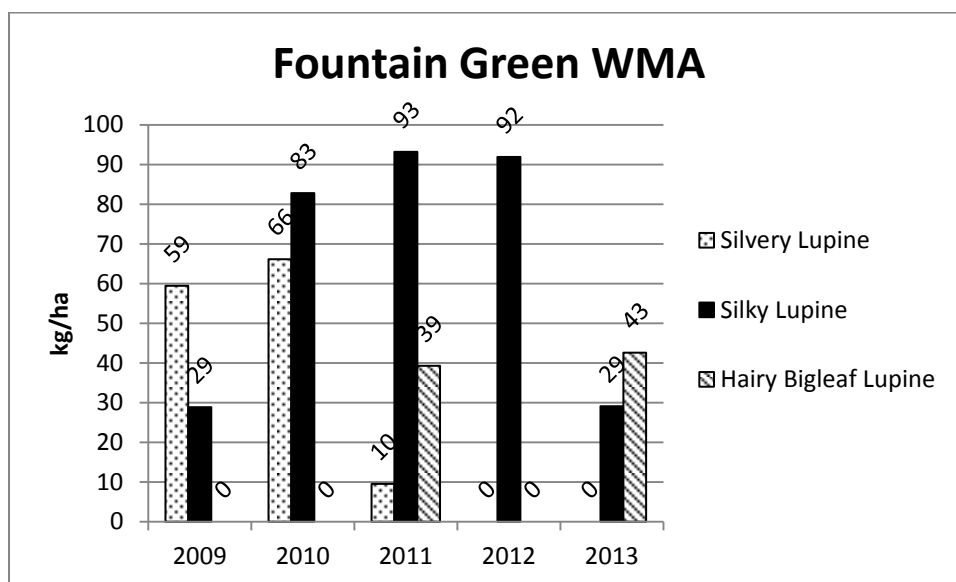


Figure 1. Seed production of three native lupine species over a five-year period at the Fountain Green WMA common garden site.

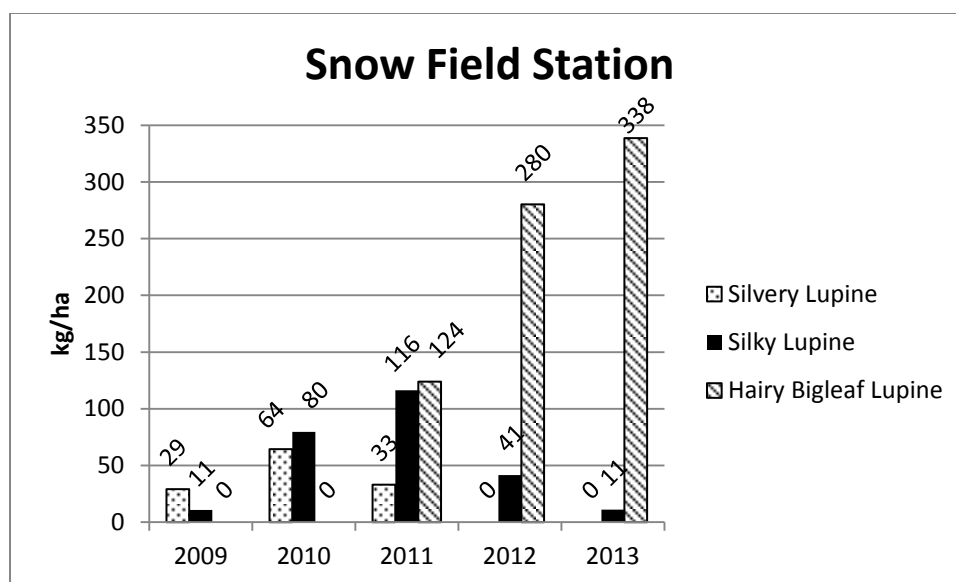


Figure 2. Seed production of three native lupine species over a five-year period at the Snow Field Station common garden site.

Lupine Iron Deficiency Chlorosis Treatments

In our early cultural practices, lupine crops were typically failures because of iron deficiency chlorosis (IDC). In fall 2011, two common gardens (randomized complete block design) were planted at the Fountain Green WMA and Snow Field Station Research Farm to study the effects of iron fertilizer treatments. The treatments of EDDHA chelated iron fertilizer were: seed-applied iron, foliar-applied iron, a combined seed- and foliar-applied iron, and no iron fertilization (Table 1). These were applied to three lupine species: longspur lupine, hairy bigleaf lupine, and silky lupine.

Table 1. Iron fertilizer treatments

Code	Treatment Type	Application Timing
Control	No fertilizer application	N/A
Foliar	Foliar-applied fertilizer	1 lb/acre applied twice in the spring of 2012
Seed	Seed-applied fertilizer	1 lb/acre applied before planting fall 2011
Combined	Seed- and foliar-applied fertilizer	Seed and foliar

In spring 2012, we sampled seedling density by randomly sampling five 0.8-foot (0.25 m) sections of each 16-foot (5 m) row in each plot to calculate emergence and to use as a baseline to calculate establishment in 2013. We also took chlorophyll content meter readings to quantify the efficiency of each treatment. Silky lupine was the only species to flower and set seed in 2013. We took the following additional measurements for silky lupine: plant height at maturity, seed yield, and 1,000 count seed weight.

In spring 2013, we sampled plant establishment using the same method described for emergence. We used emergence sampling data from 2012 to determine the baseline for survival. We calculated survival and establishment percentages, comparing our sampling counts to the emergence counts. The data were analyzed by ANOVA and Tukey HSD. Although no significance was reported, there were qualitative differences in the data. Establishment of longspur lupine was greatest for the combined treatments at Snow Field Station and Fountain Green WMA, 58% and 54%, respectively. These establishment rates are 25 points higher than the control (33%) and foliar (29%) treatments at Snow Field Station and at Fountain Green WMA, respectively. Hairy bigleaf lupine had establishment rates of 61% and 70% for the seed treatment at Snow Field Station and the combined treatment at Fountain Green WMA, respectively. These establishment rates are 15 and 32 points greater than the control (46%) and foliar (38%) treatments at Snow Field Station and Fountain Green WMA, respectively. Silky lupine had establishment rates of 80% for both the seed treatment at Snow Field Station and the foliar treatment at Fountain Green WMA. These establishment rates are 15 points greater than the combined (65%) treatments at both Snow Field Station and Fountain Green WMA. For all establishment rates, see Figure 3.

Chlorophyll content (CC) readings were taken in the spring of 2013 with a CCM-300 (Optisciences, Hudson, NH) to verify the long term effects of the fertilizer treatments on each species. Two separate analyses were done. The first was a one-way ANOVA and Tukey HSD to compare the significance of 2012 and 2013 CC readings. The second was a two-way ANOVA with interaction and Tukey HSD to compare the significance of treatments and locations for the 2013 CC readings.

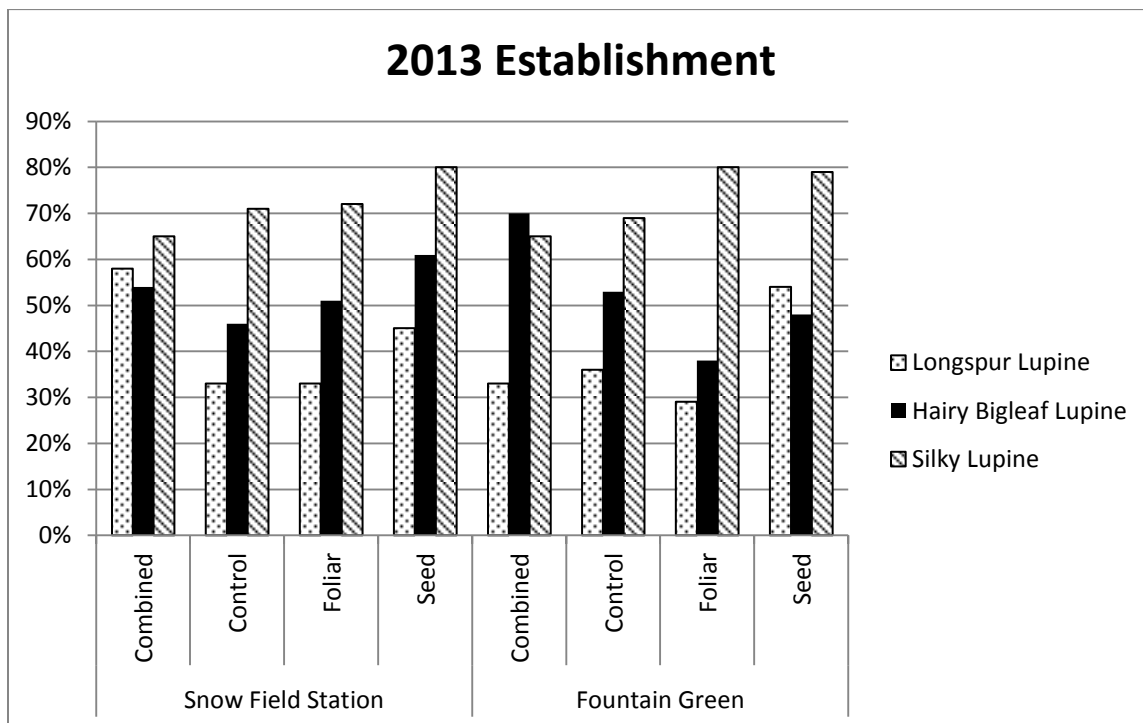


Figure 3. Plant establishment (%) in 2013 based on 2012 seedling emergence.

Longspur Lupine

When CC readings for 2012 and 2013 were compared with those from 2012, there were no significant treatment differences in 2013, but there were significant treatment differences in 2012 and between treatments in 2012 and 2013 (i.e. control 2013 and control 2012). All *p*-values are listed in Table 2 and Figure 4. There were some significant findings in the 2013 CC reading analysis, where treatments and locations were compared. However, there was no clear difference between locations. All significant differences are listed in Table 4 and Figure 5.

Table 2. Multiple comparisons of means: Tukey contrasts for longspur lupine two-year chlorophyll content (treatment vs. year)

Comparison	Estimate	Std. Error	t value	Pr(> t)
Combined 2013 - Combined 2012	85.5392	11.6451	7.346	<0.01
Control 2012 - Combined 2012	-130.0271	10.7912	-12.049	<0.01
Control 2013 - Combined 2012	60.1687	11.2907	5.329	<0.01
Foliar 2013 - Combined 2012	85.6706	11.3012	7.581	<0.01
Seed 2012 - Combined 2012	-46.6807	10.7912	-4.326	<0.01
Seed 2013 - Combined 2012	51.9200	11.5164	4.508	<0.01
Control 2012 - Combined 2013	-215.5664	10.0025	-21.551	<0.01
Foliar 2012 - Combined 2013	-109.4365	11.6018	-9.433	<0.01
Seed 2012 - Combined 2013	-132.2199	10.0025	-13.219	<0.01
Seed 2013 - Combined 2013	-33.6192	10.7809	-3.118	0.0465
Wild Population - Combined 2013	-50.2342	15.7591	-3.188	0.0368
Control 2013 - Control 2012	190.1958	9.5876	19.838	<0.01
Foliar 2012 - Control 2012	106.1298	10.7445	9.878	<0.01
Foliar 2013 - Control 2012	215.6977	9.5998	22.469	<0.01
Seed 2012 - Control 2012	83.3464	8.9939	9.267	<0.01
Seed 2013 - Control 2012	181.9471	9.8524	18.467	<0.01
Wild Population - Control 2012	165.3321	15.1391	10.921	<0.01
Foliar 2012 - Control 2013	-84.0660	11.2461	-7.475	<0.01
Seed 2012 - Control 2013	-106.8494	9.5876	-11.145	<0.01
Foliar 2013 - Foliar 2012	109.5678	11.2565	9.734	<0.01
Seed 2013 - Foliar 2012	75.8173	11.4727	6.609	<0.01
Wild Population - Foliar 2012	59.2023	16.2402	3.645	<0.01
Seed 2012 - Foliar 2013	-132.3512	9.5998	-13.787	<0.01
Seed 2013 - Foliar 2013	-33.7505	10.4084	-3.243	0.0313
Wild Population - Foliar 2013	-50.3655	15.5067	-3.248	0.0309
Seed 2013 - Seed 2012	98.6007	9.8524	10.008	<0.01
Wild Population - Seed 2012	81.9857	15.1391	5.416	<0.01

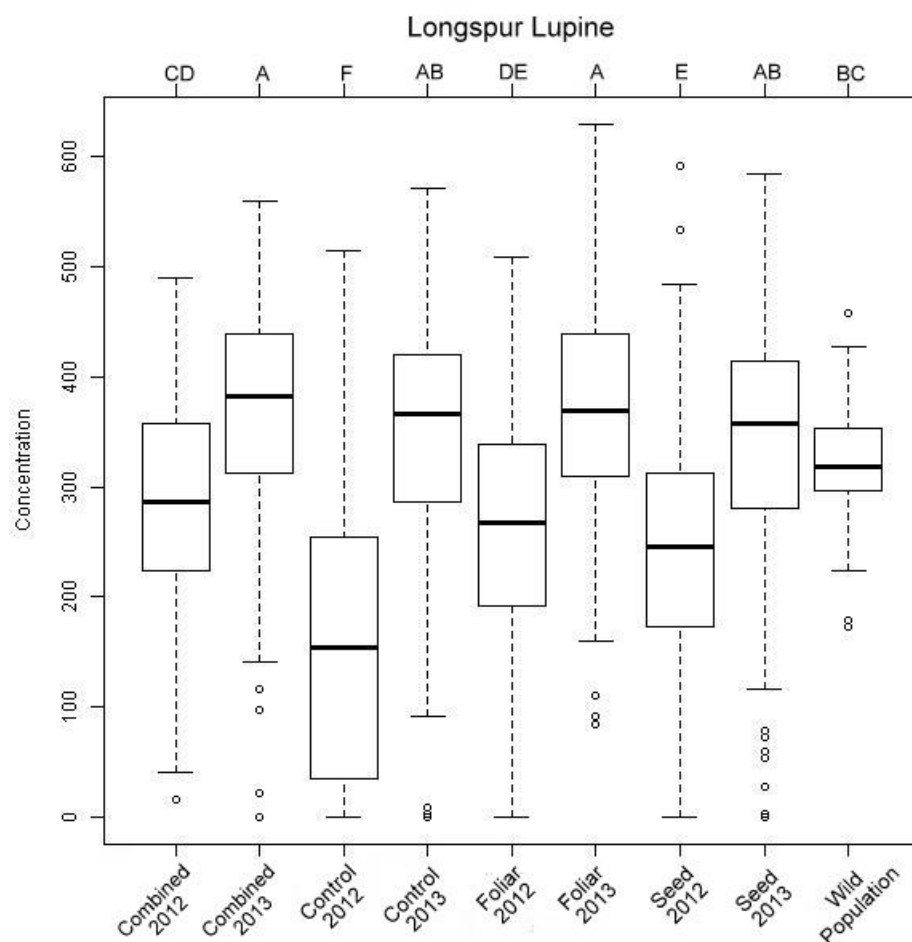


Figure 4. Box-and-whisker plots of longspur lupine chlorophyll concentrations (mg/m^2), comparing treatments in 2012 and 2013. Treatments with the same letter are not significantly different ($p>0.05$).

Table 3. Mean chlorophyll concentrations (mg/m^2) for longspur lupine by treatments in 2012 and 2013; treatments groups are identified in Figure 4; means with the same letter are not significantly different ($p>0.05$)

Groups	Treatments	Means
A	Foliar 2013	369.4
A	Combined 2013	369.3
AB	Control 2013	343.9
AB	Seed 2013	335.7
BC	Wild Population	319.0
CD	Combined 2012	283.7
DE	Foliar 2012	259.8
E	Seed 2012	237.1
F	Control 2012	153.7

Table 4. Multiple comparisons of means: Tukey contrasts longspur lupine 2013 chlorophyll content (treatment vs. location)

Comparison	Estimate	Std. Error	t value	Pr(> t)
Combined.Snow Field - Control.Ft. Green	48.065	14.022	3.428	0.0148
Foliar.Snow Field - Control.Ft. Green	72.427	14.048	5.156	<0.001
Foliar.Snow Field - Foliar.Ft. Green	65.747	14.048	4.680	<0.001
Foliar.Snow Field - Seed.Ft. Green	68.087	14.972	4.548	<0.001
Foliar.Snow Field - Control.Snow Field	41.437	13.397	3.093	0.0423
Seed.Snow Field - Foliar.Snow Field	-60.895	13.397	-4.545	<0.001

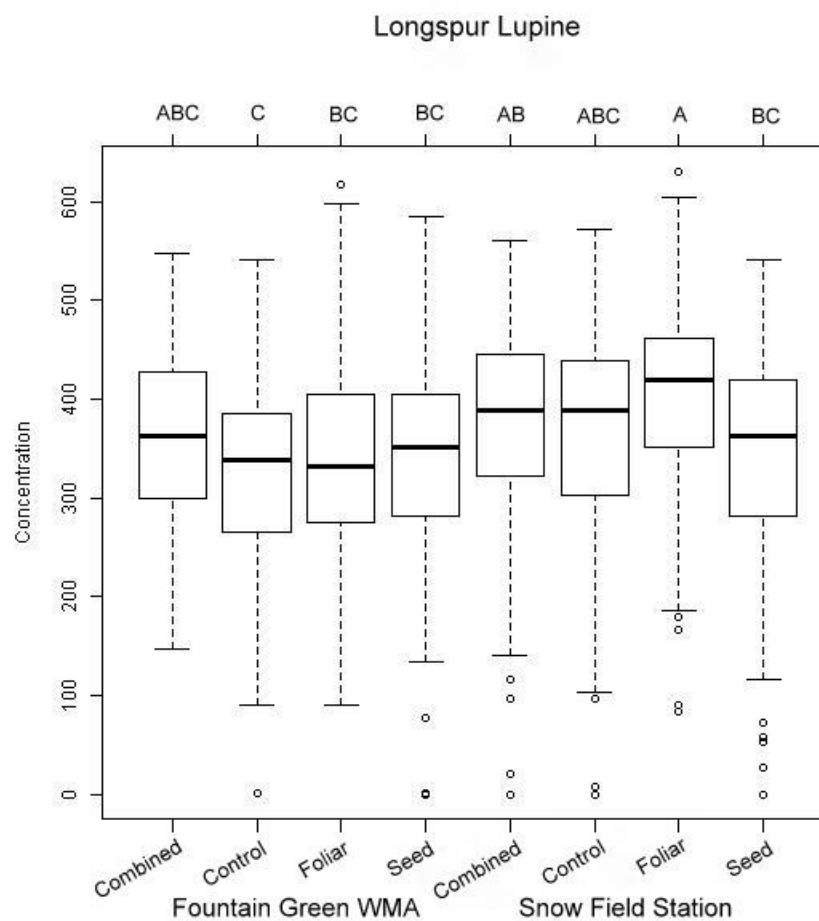


Figure 5. Box-and-whisker plots of longspur lupine chlorophyll concentrations (mg/m⁻²), comparing treatments and common garden locations in 2013. Treatments with the same letter are not significantly different ($p>0.05$).

Table 5. Mean chlorophyll concentrations (mg/m-2) for longspur lupine by treatment and location in 2013; treatments groups are identified in Figure 5; means with the same letter are not significantly different ($p>0.05$)

Groups	Treatments	Means
A	Foliar—Snow Field	399.4
AB	Combined—Snow Field	375.1
ABC	Combined—Ft. Green	359.4
ABC	Control—Snow Field	358.0
BC	Seed—Snow Field	338.5
BC	Foliar—Ft. Green	333.7
BC	Seed—Ft. Green	331.4
C	Control—Ft. Green	327.0

Hairy Bigleaf Lupine

Results of the CC reading analysis comparing 2012 and 2013 CC readings are shown in Table 6 and Figure 6. In general, 2013 CC readings were significantly higher than 2012 CC readings with the exception of the combined treatments. Results of the 2013 CC reading analysis comparing treatments and locations are shown in Table 8 and Figure 7. Generally, the CC readings from Snow Field Station were significantly higher than the readings from Fountain Green WMA with the exception of the Fountain Green WMA seed treatment that was not significantly different from control and seed treatments at the Snow Field Station.

Table 6. Multiple comparisons of means: Tukey contrasts for hairy bigleaf lupine two-year chlorophyll content (treatment vs. year)

Comparison	Estimate	Std. Error	t value	Pr(> t)
Control 2012 - Combined 2012	-106.961	12.338	-8.669	< 0.001
Foliar 2013 - Combined 2012	66.996	12.893	5.196	< 0.001
Control 2012 - Combined 2013	-137.902	10.966	-12.576	< 0.001
Foliar 2012 - Combined 2013	-46.766	12.868	-3.634	0.00864
Foliar 2013 - Combined 2013	36.055	11.587	3.112	0.04689
Seed 2012 - Combined 2013	-67.397	10.948	-6.156	< 0.001
Control 2013 - Control 2012	115.170	10.980	10.489	< 0.001
Foliar 2012 - Control 2012	91.136	12.312	7.402	< 0.001
Foliar 2013 - Control 2012	173.957	10.966	15.864	< 0.001
Seed 2012 - Control 2012	70.505	10.289	6.852	< 0.001
Seed 2013 - Control 2012	127.127	10.898	11.666	< 0.001
Wild Population - Control 2012	119.282	17.299	6.895	< 0.001
Foliar 2013 - Control 2013	58.787	11.600	5.068	< 0.001
Seed 2012 - Control 2013	-44.665	10.962	-4.074	0.00146
Foliar 2013 - Foliar 2012	82.821	12.868	6.436	< 0.001
Seed 2012 - Foliar 2013	-103.452	10.948	-9.449	< 0.001
Seed 2013 - Foliar 2013	-46.830	11.522	-4.064	0.00161
Seed 2013 - Seed 2012	56.622	10.880	5.204	< 0.001

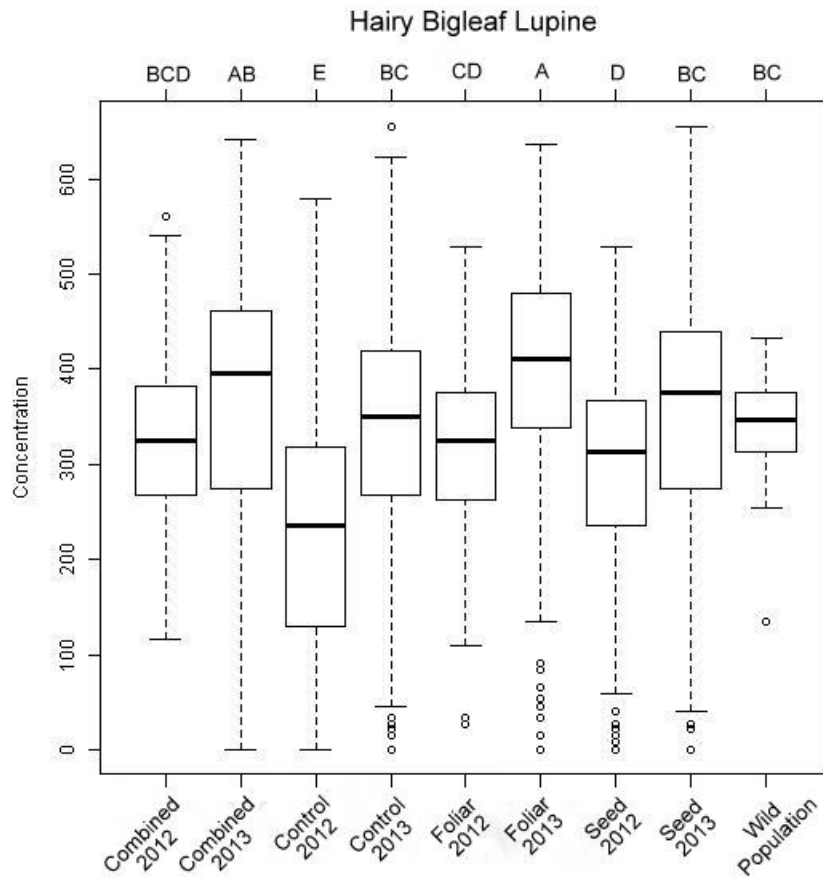


Figure 6. Box-and-whisker plots of hairy bigleaf lupine chlorophyll concentrations (mg/m^{-2}), comparing treatments in 2012 and 2013. Treatments with the same letter are not significantly different ($p>0.05$).

Table 7. Mean chlorophyll concentrations (mg/m^{-2}) for longspur lupine by treatments in 2012 and 2013; treatments groups are identified in Figure 6; means with the same letter are not significantly different ($p>0.05$)

Groups	Treatments	Means
A	Foliar 2013	395.7
AB	Combined 2013	359.7
BC	Seed 2013	348.9
BC	Wild Population	341.1
BC	Control 2013	337.0
BCD	Combined 2012	328.7
CD	Foliar 2012	312.9
D	Seed 2012	292.3
E	Control 2012	221.8

Table 8. Multiple comparisons of means: Tukey contrasts for hairy bigleaf lupine 2013 chlorophyll content (treatment vs. location)

Comparison	Estimate	Std. Error	t value	Pr(> t)
Control.Ft. Green - Combined.Ft. Green	59.047	17.679	3.340	0.01975
Foliar.Ft. Green - Combined.Ft. Green	72.410	17.634	4.106	0.00114
Combined.Snow Field - Combined.Ft. Green	174.270	16.884	10.322	< 0.001
Control.Snow Field - Combined.Ft. Green	83.278	16.884	4.932	< 0.001
Foliar.Snow Field - Combined.Ft. Green	180.028	16.884	10.663	< 0.001
Seed.Snow Field - Combined.Ft. Green	114.578	16.884	6.786	< 0.001
Combined.Snow Field - Control.Ft. Green	115.223	16.930	6.806	< 0.001
Foliar.Snow Field - Control.Ft. Green	120.982	16.930	7.146	< 0.001
Seed.Snow Field - Control.Ft. Green	55.532	16.930	3.280	0.02363
Combined.Snow Field - Foliar.Ft. Green	101.860	16.884	6.033	< 0.001
Foliar.Snow Field - Foliar.Ft. Green	107.618	16.884	6.374	< 0.001
Combined.Snow Field - Seed.Ft. Green	124.614	16.663	7.479	< 0.001
Foliar.Snow Field - Seed.Ft. Green	130.373	16.663	7.824	< 0.001
Seed.Snow Field - Seed.Ft. Green	64.923	16.663	3.896	0.00252
Control.Snow Field - Combined.Snow Field	-90.992	16.098	-5.652	< 0.001
Seed.Snow Field - Combined.Snow Field	-59.692	16.098	-3.708	0.00528
Foliar.Snow Field - Control.Snow Field	96.750	16.098	6.010	< 0.001
Seed.Snow Field - Foliar.Snow Field	-65.450	16.098	-4.066	0.00132

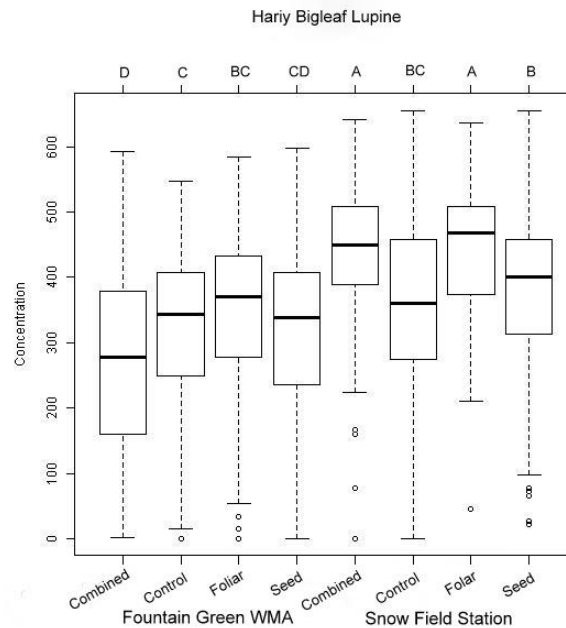


Figure 7. Box-and-whisker plot of hairy bigleaf lupine chlorophyll concentrations (mg/m²), comparing treatments and common garden locations in 2013. Treatments with the same letter are not significantly different ($p>0.05$).

Table 9. Mean chlorophyll concentrations (mg/m²) for hairy bigleaf lupine by treatment and location in 2013; treatments groups are identified in Figure 7; means with the same letter are not significantly different ($p>0.05$)

Groups	Treatments	Means
A	Foliar—Snow Field	444.7
A	Combined—Snow Field	438.9
B	Seed—Snow Field	379.2
BC	Control—Snow Field	347.9
BC	Foliar—Ft. Green	337.0
C	Control—Ft. Green	323.7
CD	Seed—Ft. Green	314.3
D	Combined—Ft. Green	264.6

Silky Lupine-Chlorophyll Content

Chlorophyll content readings taken of the silky lupine treatments in 2013 were all significantly greater than those taken in 2012 (Figure 8, all p -values are listed in Table 10). Treatment and location comparisons from the 2013 CC readings showed no significant treatment differences (Figure 9), however, CC readings from Fountain Green WMA were significantly higher than those from Snow Field Station (p -values are listed in Table 12).

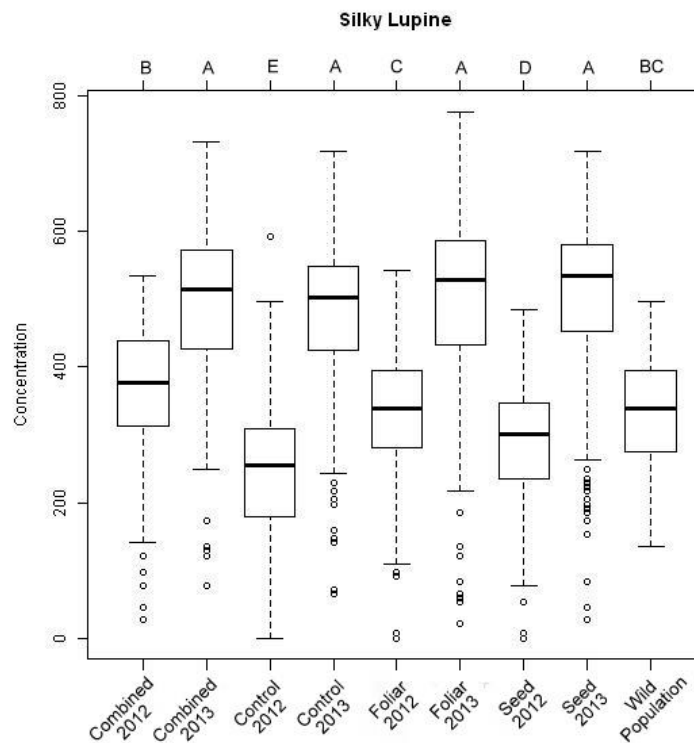


Figure 8. Box-and-whisker plots of silky lupine chlorophyll concentrations (mg/m²), comparing treatments in 2012 and 2013. Treatments with the same letter are not significantly different ($p > 0.05$).

Table 10. Tukey contrasts for silky lupine two-year chlorophyll contents (treatment vs. year)

Comparison	Estimate	Std. Error	t value	Pr(> t)
Combined 2013 - Combined 2012	126.3325	11.5991	10.892	< 0.001
Control 2012 - Combined 2012	-129.7337	11.0887	-11.700	< 0.001
Control 2013 - Combined 2012	108.0279	11.5991	9.313	< 0.001
Foliar 2013 - Combined 2012	129.2098	11.5991	11.140	< 0.001
Seed 2012 - Combined 2012	-79.3136	11.0817	-7.157	< 0.001
Seed 2013 - Combined 2012	129.6734	11.5991	11.180	< 0.001
Control 2012 - Combined 2013	-256.0662	9.8963	-25.875	< 0.001
Foliar 2012 - Combined 2013	-165.1585	11.6220	-14.211	< 0.001
Seed 2012 - Combined 2013	-205.6461	9.8885	-20.796	< 0.001
Wild Population - Combined 2013	-156.1985	15.9856	-9.771	< 0.001
Control 2013 - Control 2012	237.7617	9.8963	24.025	< 0.001
Foliar 2012 - Control 2012	90.9077	11.1126	8.181	< 0.001
Foliar 2013 - Control 2012	258.9435	9.8963	26.166	< 0.001
Seed 2012 - Control 2012	50.4201	9.2846	5.431	< 0.001
Seed 2013 - Control 2012	259.4071	9.8963	26.213	< 0.001
Wild Population - Control 2012	99.8677	15.6192	6.394	< 0.001
Foliar 2012 - Control 2013	-146.8539	11.6220	-12.636	< 0.001
Seed 2012 - Control 2013	-187.3416	9.8885	-18.945	< 0.001
Wild Population - Control 2013	-137.8939	15.9856	-8.626	< 0.001
Foliar 2013 - Foliar 2012	168.0358	11.6220	14.458	< 0.001
Seed 2012 - Foliar 2012	-40.4876	11.1057	-3.646	0.00828
Seed 2013 - Foliar 2012	168.4994	11.6220	14.498	< 0.001
Seed 2012 - Foliar 2013	-208.5234	9.8885	-21.087	< 0.001
Wild Population - Foliar 2013	-159.0758	15.9856	-9.951	< 0.001
Seed 2013 - Seed 2012	208.9870	9.8885	21.134	< 0.001
Wild Population - Seed 2012	49.4476	15.6142	3.167	0.03948
Wild Population - Seed 2013	-159.5394	15.9856	-9.980	< 0.001

Table 11. Mean chlorophyll concentrations (mg/m²) for silky lupine by treatments in 2012 and 2013; treatments groups are identified in Figure 8; means with the same letter are not significantly different (p>0.05)

Groups	Treatments	Means
A	Seed 2013	497.8
A	Foliar 2013	497.3
A	Combined 2013	494.4
A	Control 2013	476.1
B	Combined 2012	368.1
BC	Wild Population	338.2
C	Foliar 2012	329.3
D	Seed 2012	288.8
E	Control 2012	238.4

Table 12. Tukey contrasts for silky lupine 2013 chlorophyll contents (treatment vs. location)

Comparison	Estimate	Std. Error	t value	Pr(> t)
Combined.Snow Field - Combined.Ft. Green	-76.318	15.762	-4.842	< 0.001
Control.Snow Field - Combined.Ft. Green	-95.635	15.762	-6.067	< 0.001
Foliar.Snow Field - Combined.Ft. Green	-71.277	15.762	-4.522	< 0.001
Seed.Snow Field - Combined.Ft. Green	-69.960	15.762	-4.438	< 0.001
Combined.Snow Field - Control.Ft. Green	-59.228	15.762	-3.758	0.00472
Control.Snow Field - Control.Ft. Green	-78.545	15.762	-4.983	< 0.001
Foliar.Snow Field - Control.Ft. Green	-54.187	15.762	-3.438	0.01430
Seed.Snow Field - Control.Ft. Green	-52.870	15.762	-3.354	0.01880
Combined.Snow Field - Foliar.Ft. Green	-76.598	15.762	-4.860	< 0.001
Control.Snow Field - Foliar.Ft. Green	-95.915	15.762	-6.085	< 0.001
Foliar.Snow Field - Foliar.Ft. Green	-71.557	15.762	-4.540	< 0.001
Seed.Snow Field - Foliar.Ft. Green	-70.240	15.762	-4.456	< 0.001
Combined.Snow Field - Seed.Ft. Green	-76.038	15.762	-4.824	< 0.001
Control.Snow Field - Seed.Ft. Green	-95.355	15.762	-6.050	< 0.001
Foliar.Snow Field - Seed.Ft. Green	-70.997	15.762	-4.504	< 0.001
Seed.Snow Field - Seed.Ft. Green	-69.680	15.762	-4.421	< 0.001

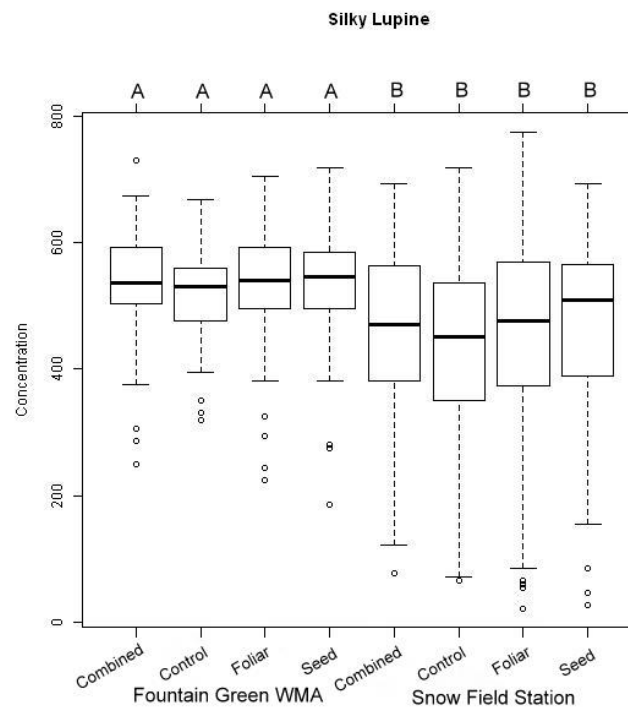


Figure 9. Box-and-whisker plots of silky lupine chlorophyll concentrations (mg/m^2), comparing treatments and common garden locations in 2013. Treatments with the same letter are not significantly different ($p > 0.05$).

Table 13. Mean chlorophyll concentrations (mg/m²) for silky lupine by treatment and location in 2013; treatments groups are identified in Figure 9; means with the same letter are not significantly different ($p>0.05$)

Groups	Treatments	Means
A	Foliar—Ft. Green	536.3
A	Combined—Ft. Green	536.1
A	Seed—Ft. Green	535.8
A	Control—Ft. Green	519
B	Seed—Snow Field	466.1
B	Foliar—Snow Field	464.8
B	Combined—Snow Field	459.7
B	Control—Snow Field	440.4

Silky Lupine-Plant Height at Maturity

We randomly selected ten plants per treatment and measured plant height before seed was harvested. We compared height means by treatments and locations using a two-way ANOVA with interaction and Tukey HSD to assess significance (Figure 10). In general, all of the Snow Field Station plant heights were significantly greater than those from Fountain Green WMA, with the exception of the foliar treatment from Fountain Green WMA which had only a significant difference with the foliar treatment from Snow Field Station. All p -values are listed in Table 14.

Table 14. Multiple comparisons of means: Tukey contrasts for silky lupine plant height at maturity (treatment vs. location)

Comparison	Estimate	Std. Error	t value	Pr(> t)
Combined.Snow Field - Combined.Ft. Green	3.6875	0.8877	4.154	<0.01
Control.Snow Field - Combined.Ft. Green	3.5205	0.9059	3.886	<0.01
Foliar.Snow Field - Combined.Ft. Green	4.6542	0.8877	5.243	<0.01
Seed.Snow Field - Combined.Ft. Green	3.9375	0.8877	4.436	<0.01
Combined.Snow Field - Control.Ft. Green	3.2075	0.8877	3.613	<0.01
Control.Snow Field - Control.Ft. Green	3.0405	0.9059	3.356	0.0190
Foliar.Snow Field - Control.Ft. Green	4.1742	0.8877	4.702	<0.01
Seed.Snow Field - Control.Ft. Green	3.4575	0.8877	3.895	<0.01
Foliar.Snow Field - Foliar.Ft. Green	3.0244	0.8877	3.407	0.0162
Combined.Snow Field - Seed.Ft. Green	3.5075	0.8877	3.951	<0.01
Control.Snow Field - Seed.Ft. Green	3.3405	0.9059	3.688	<0.01
Foliar.Snow Field - Seed.Ft. Green	4.4742	0.8877	5.040	<0.01
Seed.Snow Field - Seed.Ft. Green	3.7575	0.8877	4.233	<0.01

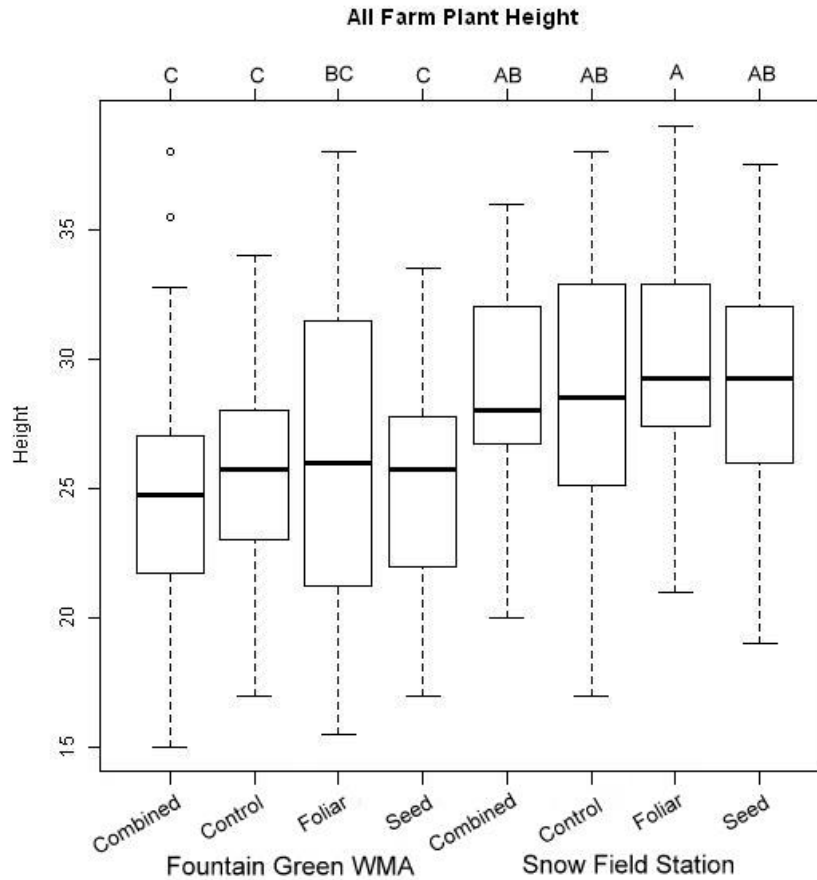


Figure 10. Box-and-whisker plots of silky lupine chlorophyll concentrations (mg/m^{-2}), comparing treatments and common garden locations in 2013. Treatments with the same letter are not significantly different ($p > 0.05$).

Table 15. Mean chlorophyll concentrations (mg/m^{-2}) for silky lupine by treatment and location in 2013; treatments groups are identified in Figure 10; means with the same letter are not significantly different ($p > 0.05$)

Groups	Treatments	Means
A	Foliar—Snow Field	29.63
AB	Seed—Snow Field	28.91
AB	Combined—Snow Field	28.66
AB	Control—Snow Field	28.5
BC	Foliar—Ft. Green	26.6
C	Control—Ft. Green	25.46
C	Seed—Ft. Green	25.16
C	Combined—Ft. Green	24.98

Silky Lupine-Seed Production

When approximately 50% of the seedpods were ripe or nearly ripe, a single silky lupine seed harvest was made with a custom push-cart harvester from each block and treatment individually. Seed was air dried, cleaned, weighed, and analyzed using a two-way ANOVA with an interaction between treatment and location and Tukey's HSD to assess significance. The only notable significant difference in seed production was for the combined treatment seed yield at Snow Field Station, which was significantly greater than the combined treatment seed yield at Fountain Green WMA ($p=0.0262$, Figure 11).

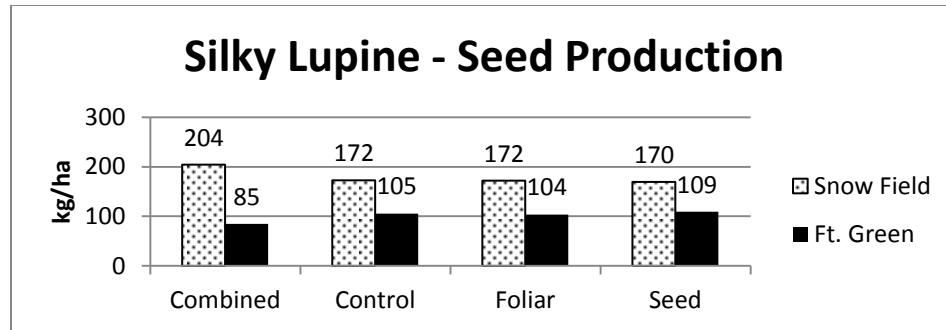


Figure 11. Silky lupine seed production, the only statistically significant difference in seed production was with combined treatments.

Table 16. Tukey multiple comparisons of means for silky lupine seed production, comparison of treatments and common garden locations in 2013; means with the same letter are not significantly different ($p>0.05$)

Groups	Treatments	Means
A	Combined—Snow Field	204
AB	Control—Snow Field	172.4
AB	Foliar—Snow Field	171.8
AB	Seed—Snow Field	169.5
AB	Seed—Ft. Green	109.2
AB	Control—Ft. Green	105.4
AB	Foliar—Ft. Green	103.7
B	Combined—Ft. Green	84.62

Silky Lupine-1,000 Count Seed Weight

Using the harvested seed from each treatment, block, and common garden we counted 1,000 seeds and weighed them. We ran a two-way ANOVA with interaction between treatment and location, and Tukey's HSD to assess significance and found no significant differences in the data. In general, seed from Fountain Green WMA had greater mass than that from Snow Field Station with the exception of the foliar treatment which had the lowest overall mass in the study. Means of the 1,000 count seed weight are presented in Figure 12.

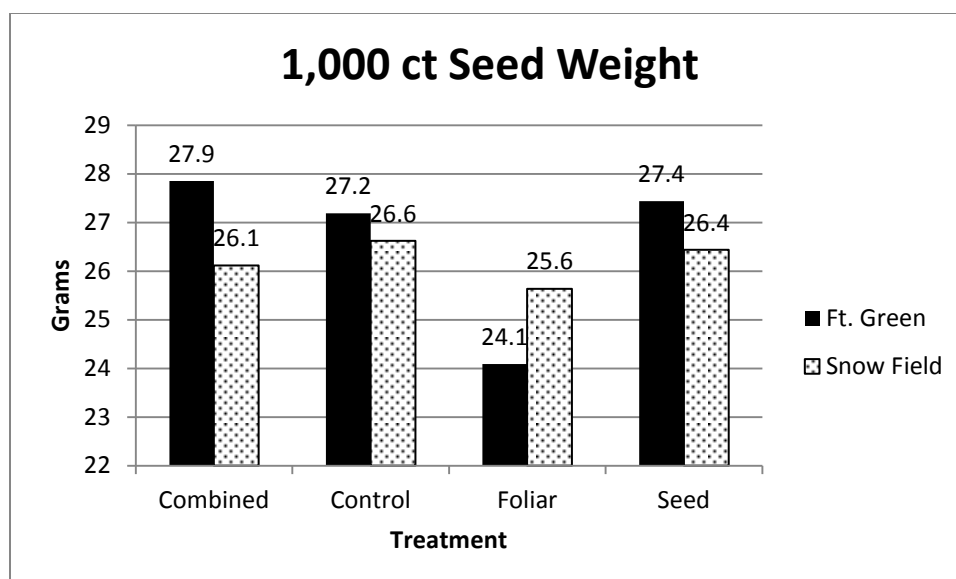


Figure 12. Silky lupine 1,000-count weight means. Typically seed weight was greater at Fountain Green WMA than Snow Field Station.

Wildland Germplasm Collection

This year we primarily focused our efforts on penstemon species, specifically firecracker penstemon (*Penstemon eatonii*) and Palmer's Penstemon (*P. palmeri*). We wanted to identify, collect, and evaluate germplasm from these two species for improved drought and heat tolerance in firecracker penstemon and tolerance to growth in heavy soils in Palmer's penstemon. However, we did not limit ourselves to these species. We made 89 germplasm collections from 22 species (Table 17). These collections were primarily from the Central Basin and Range of eastern Nevada and western Utah. However, several collections were made from the Wasatch and Uintah mountains and from the Colorado Plateau of eastern Utah (Figure 13).

Table 17. New populations found and germplasm collections made in 2013

Code	Species	Common Name	New Sites	Collections
CHAN9	<i>Chamerion angustifolium</i>	Fireweed	1	1
LOUT3	<i>Lotus utahensis</i>	Utah bird's-foot trefoil	0	1
PEAC	<i>Penstemon acuminatus</i>	Sharpleaf penstemon	1	1
PECO	<i>Penstemon confusus</i>	Owens Valley beardtongue	3	4
PEDE4	<i>Penstemon deustus</i>	Scabland penstemon	1	1
PEEA	<i>Penstemon eatonii</i>	Firecracker penstemon	29	19
PEIM2	<i>Penstemon immanifestus</i>	Steptoe Valley beardtongue	1	1
PELE7	<i>Penstemon leiophyllus</i>	Smoothleaf beardtongue	0	1
PENA3	<i>Penstemon nanus</i>	Dwarf beardtongue	2	2
PENST	<i>Penstemon sp.</i>	Penstemon species	2	2
PEPA6	<i>Penstemon pachyphyllus</i>	Thickleaf beardtongue	5	6
PEPA8	<i>Penstemon palmeri</i>	Palmer's penstemon	40	32

Code	Species	Common Name	New Sites	Collections
PEPL4	<i>Penstemon platyphyllus</i>	Broadleaf beardtongue	1	1
PEPR2	<i>Penstemon procerus</i>	Littleflower penstemon	0	1
PERO10	<i>Penstemon rostriflorus</i>	Bridge penstemon	1	1
PERY	<i>Penstemon rydbergii</i>	Rydberg's penstemon	1	2
PESP	<i>Penstemon speciosus</i>	Royal penstemon	1	1
PEUT	<i>Penstemon utahensis</i>	Utah penstemon	2	2
PEWA	<i>Penstemon watsonii</i>	Watson's penstemon	3	3
SPCO	<i>Sphaeralcea coccinea</i>	Scarlet globemallow	2	3
SPGR2	<i>Sphaeralcea grossulariifolia</i>	Gooseberryleaf globemallow	2	3
SPMU2	<i>Sphaeralcea munroana</i>	Munro's globemallow	1	1
Total			99	89

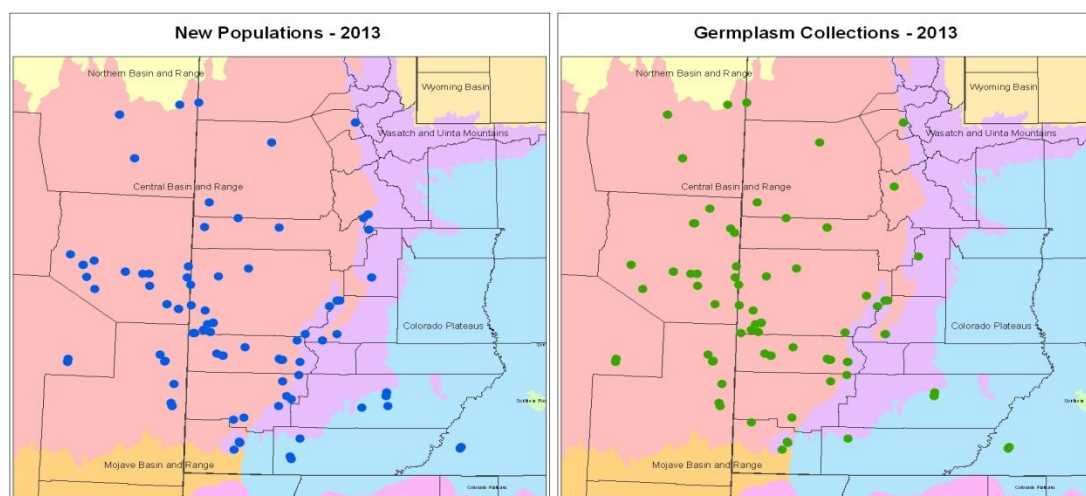


Figure 13. New populations recorded and germplasm collections in 2013.

Ecological Niche Modeling

A common difficulty with native plant materials development research is identifying sufficient germplasm sources to be used in species evaluation trials. Diverse germplasm from many sources from throughout a species' geographic range is needed in the native plant materials development process to identify germplasm adapted to the areas where the released germplasm will be used for restoration work. Current methods for identifying germplasm sources involve using historical records obtained from online herbaria databases, and sources identified by happenstance while doing fieldwork. Another approach to identifying germplasm sources is through the use of ecological niche models (ENMs).

In an effort to identify additional populations of Palmer's penstemon and firecracker penstemon throughout the Great Basin, ENMs were developed and field tested for these two native forb species. We used 19 climatic envelopes, which include temperature and precipitation variables and elevation data to develop the ENM in Maximum Entropy (Maxent, 3.3.3e). The ENM found "hotspots" where there would be relatively high probabilities for each species to grow. Although

there may not be populations growing in all locations, we believe that the habitat is suitable for the species to grow if there was at least a 75% probability in the models. In general, the ENMs showed the predicted distribution for firecracker penstemon to be on middle to upper elevations in mountain ranges primarily within 62 miles (100 km) of the Utah-Nevada border (Figure 14). The predicted distribution for Palmer's penstemon appeared to be primarily within the sagebrush (*Artemisia* spp.) steppe foothills at mid-elevations of mountain ranges primarily within 62 miles (100 km) of the Utah-Nevada border (Figure 15).

There were 19 test sites identified for Palmer's penstemon and 16 test sites identified for firecracker penstemon. A 3.1-mile (5 km) buffer was placed around each test site for two purposes: applying a search area or zone for each species and eliminating sites with historic records in the area. The model-predicting distribution for Palmer's penstemon was more accurate with plants being present in 15 out of the 19 test sites, one of which was eliminated due to its proximity to a historic site. The model for firecracker penstemon was less accurate with plants being present in less than half of the sites (7 of 16), two of which were eliminated due to proximity to historic sites. All test site information can be found in Table 18.

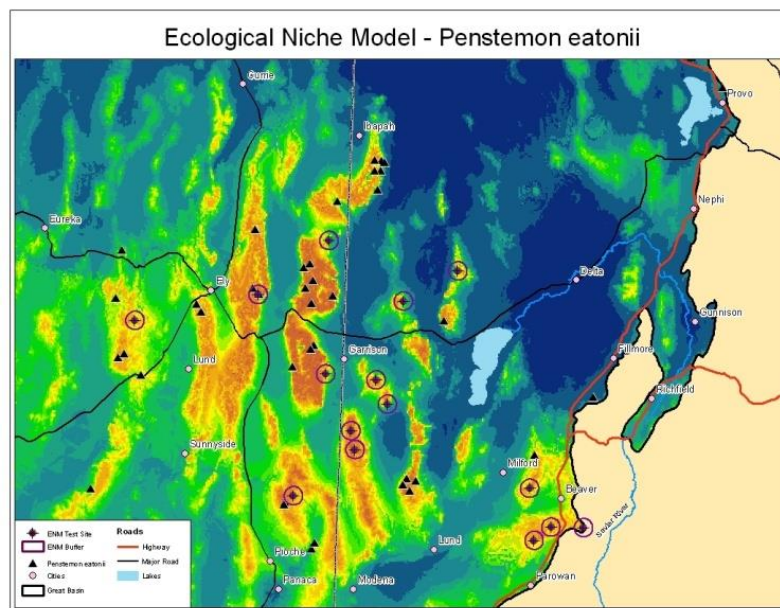


Figure 14. Distribution model for firecracker penstemon.

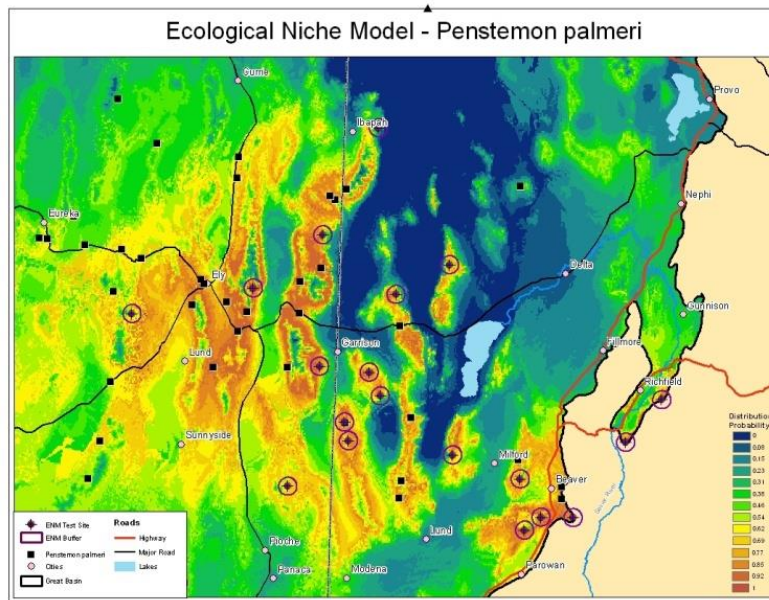


Figure 15. Distribution model for Palmer’s penstemon.

Presentations

Stettler, J. 2013. Agronomic production of native lupine species. 2nd National Native Seed Conference; 2013 April 8-11; Santa Fe, NM.

Stettler, J. 2013. Enhancing germination of mountain hollyhock. Poster presented at the 2nd National Native Seed Conference; 2013 April 8-11; Santa Fe, NM.

Stettler, J. 2013. Agronomic production of native lupine species. Intermountain Native Plant Summit VII; 2013 March 26-27; Boise, ID.

Management Applications and/or Seed Production Guidelines

The development and use of Ecological Niche Modeling maps will be extremely useful in identifying new populations for use in plant materials development and delineating areas of adaptability for restoration and land management.

Additional Products

Seed Increase

- Gooseberryleaf globemallow (*Sphaeralcea grossulariifolia*)-1,800 g
- Scarlet globemallow (*S. coccinea*)-1,300 g
- Limestone hawksbeard (*Crepis intermedia*)- 810 g
- Tapertip hawksbeard (*C. acuminata*) 8 g
- Hairy bigleaf lupine-6,350 g
- Silky lupine-6,100 g
- 89 wildland seed collections made from 22 forb species
- 11 seed allocations made to two private growers

Project Title: Plant Material Evaluations at the Shrub Sciences Laboratory

Project Agreement No. 13-IA-11221632-161

Principal Investigators and Contact Information

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Project Description

Wildland Seed Collection

Seed collection efforts in 2013 focused on identifying and harvesting new populations of thickleaf penstemon (*Penstemon pachyphyllus*) and collecting additional sources of promising species underrepresented in existing provisional seed zone collections (Table 1).

Table 1. Species and number of sources collected in 2013

Name	Common Name	Family	Collections
<i>Enceliopsis nudicaulis</i>	nakedstem sunray	Asteraceae	5
<i>Ipomopsis aggregata</i>	scarlet gilia	Polemoniaceae	1
<i>Linum lewisii</i>	Lewis flax	Linaceae	4
<i>Penstemon pachyphyllus</i>	thickleaf penstemon	Scrophulariaceae	18
<i>Sphaeralcea grossulariifolia</i>	gooseberryleaf globemallow	Malvaceae	4

Evaluating Emergence from Increasing Planting Depth for 20 Native Forbs

Objectives

Evaluate the effect of increasing planting depth on seedling emergence for 20 native forb species planted in loam soils at three locations (Table 2).

Methods

Each species was sown at four depths from just beneath the soil surface to 1 inch (3 cm) deep in a randomized block design with 10 blocks per site. Seeding rates were adjusted for viability and purity to 25 pure live seed (PLS)/ft. Five blocks were covered with N-Sulate fabric, and five were left uncovered. The study was replicated at three sites: Orovada, Nevada; Wells, Nevada; and Fountain Green, Utah. Planting occurred in 2013 and will be repeated in 2014. Emergence and short-term persistence data will be collected from 2014 to 2016.

Table 2. Forbs seeded in the increased planting depth study

Scientific Name	Common Name	Family
<i>Achillea millefolium</i>	common yarrow	Asteraceae
<i>Agoseris grandiflora</i>	bigflower agoseris	Asteraceae
<i>Agoseris heterophylla</i>	annual agoseris	Asteraceae
<i>Arenaria macradenia</i> subsp. <i>ferrisiae</i>	Ferris' sandwort	Caryophyllaceae
<i>Astragalus filipes</i>	basalt milkvetch	Fabaceae
<i>Balsamorhiza hookeri</i>	Hooker's balsamroot	Asteraceae
<i>Enceliopsis nudicaulis</i>	nakedstem sunray	Asteraceae
<i>Eriogonum umbellatum</i>	sulphur-flower buckwheat	Polygonaceae
<i>Heliomeris multiflora</i> var. <i>nevadensis</i>	Nevada showy goldeneye	Asteraceae
<i>Ipomopsis aggregata</i>	scarlet gilia	Polemoniaceae
<i>Lomatium nudicaule</i>	barestem biscuitroot	Apiaceae
<i>Lupinus argenteus</i>	silvery lupine	Fabaceae
<i>Lupinus prunophilus</i>	hairy bigleaf lupine	Fabaceae
<i>Machaeranthera canescens</i>	hoary tansyaster	Asteraceae
<i>Penstemon acuminatus</i>	sharp-leaf penstemon	Scrophulariaceae
<i>Penstemon pachyphyllus</i>	thick-leaf penstemon	Scrophulariaceae
<i>Penstemon speciosus</i>	royal penstemon	Scrophulariaceae
<i>Sphaeralcea grossulariifolia</i>	gooseberry-leaf globemallow	Malvaceae
<i>Sphaeralcea munroana</i>	Munro's globemallow	Malvaceae
<i>Stanleya pinnata</i> var. <i>integrifolia</i>	golden prince's plume	Brassicaceae

Testing the Provisional Seed Zone Concept with Basin Wildrye (Leymus cinereus)

Objectives

With increasing focus on genecological-based plant development techniques, provisional seed zones have been proposed as an intermediary option for identifying seed source populations until genecological zones are delineated. Competing with these two options is the agronomic plant development model that has brought most of the cultivar materials currently available in the marketplace. Each approach has its strengths and proponents.

The agricultural model can be generally defined as a genetically narrow-based approach founded on selection for a superior source or breeding for specific traits. The genecological model is a broad genetically-based approach focused on pooling similar germplasm within data-derived seed zones. The agricultural model typically results in the development of a few cultivars recommended for use over large areas, whereas the genecological approach relies on species-specific data to determine an appropriate number of seed zones, each necessitating its own pooled seed source. The agricultural model typically selects sources with good seedling establishment through direct comparison or indirect breeding line observation and vigor measurements, whereas the genecological model incorporates no selection for seedling

establishment, relying on correlation between measured plant parameters and source-site characteristics to predict a zone of adaptation.

The genecological model is growing in popularity, in part because of the perceived benefit that a broader genetic base material has a higher likelihood of adapting to invasive species, altered fire frequencies, climate change, and other anthropogenic impacts. The antagonistic counter is that any real or perceived benefit can only be realized if the material first establishes on site, an advocated advantage of the agronomic model.

The provisional seed zone approach shortcuts the genecological model by including only climate parameters in zone development without any species-specific data. Some have argued that even this shortcut approach improves upon the agronomic model by identifying broad genetic base source materials tied to reasonable climatic brackets.

Intriguing research questions abound relating to differential success between approaches from establishment through plant community composition years into the future. The genecological model is sufficiently new that while development is underway for three species common to the Great Basin, bluebunch wheatgrass (*Pseudoroegneria spicata*), Sandberg's bluegrass (*Poa secunda*), and Indian ricegrass (*Achnatherum hymenoides*) verification of the initial empirical seed zones is not complete, thus final model recommendations are not available, so seed source materials have not been designated.

Provisional seed zones are complete nationwide. Following the provisional seed zone concept, source populations for any species can be identified, harvested, and pooled to initiate zone-based stock seed supplies. For species where cultivar materials do not exist, this seems a logical approach, but where cultivar materials have been developed following the agronomic model, the question arises, are cultivar materials or provisional seed zone materials a better fit? This study is intended to evaluate one aspect of this fitness, short-term establishment. We chose basin wildrye as a test species. This study will compare initial establishment of basin wildrye cultivar materials and provisional seed zone materials across four Great Basin climate envelopes common to the species.

Methods

Seed from four basin wildrye cultivars, Magnar, Trailhead, Continental, and Tetra was procured through local vendors, and 27 wildland seed sources representing four provisional zones were collected from native stands. Individual sources were sampled for seed weight, viability, and ploidy. Seeding at 25 PLS/ft occurred in a randomized block design with ten blocks per site and four sites, each representing a different provisional seed zone. Five blocks were covered with N-Sulate fabric and 5 blocks were left uncovered. Plots were seeded in 2013 and will be replicated in 2014. Emergence and persistence data will be collected from 2014 to 2016.

Provisional Seed Zone-Based Stock Seed Production

Objectives

Our seed increase efforts follow the model described by Johnson et al. (2010) to develop locally adapted and regionally appropriate native seed sources. Johnson et al. (2010) recommends seed sources be composed of more than 50 parents from at least five populations from the same

ecosystem. We selected Bower's (Bower et al. 2010) provisional seed zone (PSZ) map as our surrogate for genecological-derived seed zones (ecosystems), because empirical zones have not been developed for any species currently in our increase program. Our wildland seed collection protocol restricts seed gathering to populations with more than 25 individual plants thus retaining a broad genetic base, though most collections represent hundreds of plants. We assign each species collection site a PSZ based on its mapped location. Seed sources from the same PSZ of the same species are increased without regard for isolation. Sources from different zones are increased at different farms to prevent cross-pollination.

In 2009, we began establishing seed increase and evaluation plantings at farm facilities in Juab and Sanpete counties in Utah. Information generated from these plantings provides a better understanding of appropriate cultural practices necessary to grow specific plant materials and dramatically increase the quantity of seed available for distribution to researchers and private sector seed producers. In 2013, we harvested seed from 14 species representing 53 different sites (Table 3). This seed is currently being cleaned. In most cases, additional quantities are needed before volumes are adequate to permit commercial seed production.

Table 3. Seed was harvested from these species at Fountain Green, Utah in 2013

Scientific Name	Number of Sources	Provisional Seed Zone v1.0
		Precipitation (in) / °F
<i>Arenaria macradenia</i> subsp. <i>ferrisea</i>	1	Outside Great Basin
<i>Cleome serrulata</i>	2	<10 / > 80
<i>Cryptantha rugulosa</i>	1	10-14 / 70-80
<i>Enceliopsis nudicaulis</i>	4	<10 / <80
<i>Erigeron speciosus</i>	1	14-24 / <70
<i>Frasera albomarginata</i>	2	10-14 / 70-80
<i>Heliomeris multiflora</i> var. <i>nevadensis</i>	4	10-14 / 80-90
<i>Hesperostipa comata</i>	7	<10 / <80
<i>Linum lewisii</i> var. <i>lewisii</i>	12	10-14 / 70-80
<i>Linum subteres</i>	1	<10 / <80
<i>Penstemon pachyphyllus</i>	5	14-24 / <70
<i>Stanleya pinnata</i> var. <i>integrifolia</i>	1	<10 / > 80
<i>Thelypodium milleflorum</i>	1	<10 / <80

Presentations

Anderson, Val; Jensen, Scott. 2013. Plant materials for ecological restoration. Local ecotypes; both sides of the story. Society for Range Management 66th Annual Meeting; 2013 February 2-8; Oklahoma City, OK.

Jensen, Scott. Approaches to deciphering local ecotype issues in the Great Basin, developing plant materials in the absence of verified genecological data. Plant materials development, production, and use in habitat restoration. 2nd National Native Seed Conference; 2013 April 8-11; Santa Fe, NM.

Jensen, Scott; Stettler, Jason. Incorporating technology in plant material collecting tasks. Poster presented at 2nd National Native Seed Conference; 2013 April 8-11; Santa Fe, NM.

Jensen, Scott; Stettler, Jason. Applying provisional seed zones to native forb development in the Great Basin, USA. National Native Seed Conference; 2013 April 8-11; Santa Fe, NM. (Poster)

References

Bower, A.; St. Clair, J. B.; Erickson, V. J. 2010. Provisional seed zones for native plants. [Online]. Available: http://www.fs.fed.us/wwetac/threat_map/SeedZones_Intro.html

Johnson, Randy; Stritch, Larry; Olwell, Peggy; Lambert, Scott; Horning, Mathew E.; Cronn, Richard. 2010. What are the best seed sources for ecosystem restoration on BLM and USFS lands? *Native Plants Journal*. 11(2): 117-131.

Project Title Aberdeen Plant Materials Center Report of Activities

Project Agreement No 11-1A-11221632-004

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Project Description

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

Plant Guides

The Aberdeen PMC is gathering information on selected plant species to create Natural Resources Conservation Service Plant Guides. Plant guides offer the most up-to-date information on plant establishment, management, and seed and plant production information on a given species. General information including potential uses, ethnobotanical significance, adaptation, pests and potential production problems can also be found in the Plant Guides. In 2013, Plant Guides were completed or revised for Palmer's penstemon (*Penstemon palmeri*), thistleleaf penstemon (*P. pachyphyllus*), Rydberg's penstemon (*P. rydbergii*), Columbia needlegrass (*Achnatherum nelsonii*), bigflower Agoseris (*Agoseris grandiflora*), showy goldeneye (*Heliomeris multiflora*), and limestone hawksbeard (*Crepis intermedia*). Plant guides are available at the PLANTS database, www.plants.usda.gov and at the Aberdeen PMC website, www.id.nrcs.usda.gov/programs/plant.html.

Plant Materials Development

Douglas' dustymaiden

Fifteen accessions of Douglas' dustymaiden (*Chaenactis douglasii*) were evaluated at the Aberdeen PMC from 2009 to 2010. The accessions were evaluated for establishment, growth, and seed production. Following evaluation, accession 9076577 was chosen for selected class release. Accession 9076577 was originally collected in Boise County, Idaho near Arrow Rock

and Lucky Peak Reservoirs, approximately 0.5 mile (0.8 km) west of the dam on Forest Service Road 268. The site is a mountain big sagebrush-bitterbrush (*Artemisia tridentata* subsp. *vaseyana*-*Purshia tridentata*) community in coarse granitic soils at 3,150-foot (960 m) elevation. Accession 9076577 ranked at or near the top in percent establishment, plant vigor, height, flower production, and seed yield.

Seed increase plots have been established at the Aberdeen PMC for early generation Certified seed production. In fall 2013, we planted a total of 0.18 acres (0.07 ha) of weed barrier fabric to G-0 seed. Release documentation is being developed and official release will occur once the PMC has produced a sufficient amount of early generation seed.

Hoary tansyaster

Nine accessions of hoary tansyaster (*Machaeranthera canescens*) were evaluated from 2009 through 2011 for establishment, plant growth, and seed production. Accession 9076670 had the best establishment and stands in 2009 and 2010, and had the highest rated vigor in 2010. This accession also produced the tallest plants in the study. The population for 9076670 is located near the St. Anthony Sand Dunes in Fremont County, Idaho at 5,000-foot (1,520 m) elevation. The site has sandy soils and supports a bitterbrush, Indian ricegrass (*Achnatherum hymenoides*), yellow rabbitbrush (*Chrysothamnus viscidiflorus*), and lemon scurfpea (*Psoralidium lanceolatum*) community. The location receives on average between 10 and 15 inches (254-381 mm) of annual precipitation.

Several strips of weed barrier fabric have been planted to hoary tansyaster for initial seed bulking. An additional 0.6 acres (0.2 ha) of hoary tansyaster was drill seeded in spring 2012 to investigate agronomics without using weed barrier fabric.

We made comparisons between using a small-plot combine in a single combine harvest and multiple vacuum harvests from a jet harvester. The single combining method takes less time in the field; however, this method yields less seed and the collected seed requires significantly more time to clean than the vacuum harvested seed. The 2010 drill seeded 0.6 acres (0.2 ha) was harvested twice in 2013 using a Flailvac harvester. The field was harvested on the 3rd and the 23rd of September. The first harvest yielded 4.5 lb clean seed and the second harvest yielded 2.8 lbs for a total of 7.3 lbs (equivalent to 12.2 lbs/ac).

Release documentation is being developed and official release will occur once the PMC has produced a sufficient amount of early generation seed.

Wyeth and sulphur-flower buckwheat

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

In fall 2011, two 500-foot (150 m) rows of weed barrier fabric were planted to accession 9076546. Accession 9076546 was originally collected in Caribou County, Idaho northeast of Soda Springs in an area receiving 18 to 20 inches (457-508 mm) of annual precipitation and

supporting mountain big sagebrush, threetip sagebrush (*Artemisia tripartita*), bluebunch wheatgrass (*Pseudoroegneria spicata*), and basin wildrye (*Leymus cinereus*). Germination in the weed barrier fabric in 2012 was poor, likely due to drier and warmer than normal winter and early spring conditions. Plants were propagated in the greenhouse in winter/spring 2013 and transplanted to the fabric in summer 2013.

In the summer of 2013, 520 feet (160 m) of weed barrier fabric was planted to approximately 700 greenhouse-grown transplants. Establishment was excellent, and survival was good. First seed harvest should occur in 2014. Release documentation is being developed and official release will occur once the PMC has produced a sufficient amount of early generation seed.

Publications

Ogle, D.; Peterson, S.; St. John, L. 2013. Plant Guide for Palmer's penstemon (*Penstemon palmeri*). Aberdeen, ID: U.S. Department of Agriculture, Natural Resources Conservation Service, Aberdeen Plant Materials Center. 4 p. (Revised October 2013). Available: http://plants.usda.gov/plantguide/pdf/pg_pepap9.pdf [2014, March 3].

Ogle, D.; Peterson, S.; St. John, L. 2013. Plant Guide for mucronate penstemon (*Penstemon pachyphyllus* var. *mucronatus*). Aberdeen, ID: U.S. Department of Agriculture, Natural Resources Conservation Service, Aberdeen Plant Materials Center. 4 p. Available: http://plants.usda.gov/plantguide/pdf/pg_pepam5.pdf [2014, March 3].

Ogle, D.; Peterson, S.; St. John, L. 2013. Plant Guide for Rydberg's penstemon (*Penstemon rydbergii*). Aberdeen, ID: U.S. Department of Agriculture, Natural Resources Conservation Service, Aberdeen Plant Materials Center. 4 p. Available: http://plants.usda.gov/plantguide/pdf/pg_pery.pdf [2014, March 3].

St. John, L.; Tilley, D. 2012. Plant Guide for limestone hawksbeard (*Crepis intermedia*). Aberdeen, ID: U.S. Department of Agriculture, Natural Resources Conservation Service, Aberdeen Plant Materials Center. 3 p. Available: http://plants.usda.gov/plantguide/doc/pg_crin4.docx [2014, March 3].

Tilley, D.; St. John, L. 2013. Plant guide for Columbia needlegrass (*Achnatherum nelsonii*). Aberdeen, ID: U.S. Department of Agriculture, Natural Resources Conservation Service, Aberdeen Plant Materials Center. 3 p. Available: http://plants.usda.gov/plantguide/pdf/pg_acne9.pdf [2014, March 3].

Tilley, D. 2013. Plant Guide for bigflower agoseris (*Agoseris grandiflora*). Aberdeen, ID: U.S. Department of Agriculture, Natural Resources Conservation Service, Aberdeen Plant Materials Center. 2 p. Available: http://plants.usda.gov/plantguide/pdf/pg_aggr.pdf [2014, March 3].

Tilley, D. 2012. Plant Guide for showy goldeneye (*Helioeris multiflora*). Aberdeen, ID: U.S. Department of Agriculture, Natural Resources Conservation Service, Aberdeen Plant Materials Center. 2 p. Available: http://plants.usda.gov/plantguide/pdf/pg_hemu3.pdf [2014, March 3].

Additional Products

Early generation certified seed of hoary tansyaster, Douglas' dustymaiden and Wyeth buckwheat is being produced and will be available through Utah Crop Improvement and the University of Idaho Foundation Seed Program when release is approved.

Project Title Bee Pollination and Breeding Biology Studies

Project Agreement No. 11-IA-11221632-010

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Project Description

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

Breeding Biology and Pollination Needs of Silverleaf Phacelia (Phacelia hastata)

In 2012, established transplants (n=50) of silverleaf phacelia successfully survived the winter. Silverleaf phacelia plants were caged before bloom and manually pollinated (selfed and outcrossed) to establish the species' breeding biology. Bloom was spectacular, with enough flowers to obscure foliage. However, the flowers are small, and worse, their stigmas were miniscule, with only enough surface area to receive a few dozen pollen grains. Even with magnifying visors, we could not confidently see the stigmas when applying self- or outcross pollen. Probably as a consequence, many hours of daily manual pollinations were rarely effective. From 937 hand-pollinated flowers on 19 plants and 76 racemes, we only obtained 54 plump seeds. Out of 3,748 ovules seed set was a paltry 1.4%. Clearly, the species does require a pollinator's visit, but we do not yet know its need for outcrossing.

Floral visitors were sampled at a half dozen wild populations of silverleaf phacelia in northern Utah and Nevada. Visitors were exclusively bees except for one pollen specialist wasp. Silverleaf phacelia attracts a diversity of native bees, which is promising for fostering Great Basin bee communities that fly in the late spring/early summer.

Concentrating Seed Weevils of Wild Forbs for Practical Control on Seed Farms

We explored a novel trap-cropping technique for seed beetle control to help growers avoid broadcast insecticide sprays that kill pollinators when applied while plants are in flower. We tried advancing bloom on short cultivated rows of basalt milkvetch (*Astragalus filipes*) and prairie clover (*Dalea ornata*) at our common garden in Logan, Utah. A small patch of blooming plants at a field's edge could be used as a trap-crop that concentrates emerging specialist seed weevils for control (adults feed and mate at host flowers, then oviposit). A month before bloom, a 10-foot (3-m) row was covered with a portable grow tunnel made of regularly perforated clear

plastic. Plants grew well under the plastic, but we failed to advance bloom, perhaps because the plants were grown in black fabric weed barrier, which we had seen advance bloom by several weeks.

Fire Impact on Forb Survival

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

To examine the individual plant's response to wildfire, six common Great Basin perennial forb species were experimentally burned in 2012 at increasing intensities using a custom portable propane burner designed to mimic wildfire attributes. The plants were growing at the Malheur Experiment Station in Ontario, Oregon in adjacent 200-foot (60-m) monoculture rows. Soils were uniform. Plants were mature and of the same age. All members of a species received the same controlled sub-irrigation and pest management. Individuals of basalt milkvetch, prairie clover, sulphur-flower buckwheat (*Eriogonum umbellatum*), fernleaf biscuitroot (*Lomatium dissectum*), blue penstemon (*Penstemon cyaneus*), and gooseberryleaf globemallow (*Sphaeralcea grossulariifolia*) were chosen for their prevalence, contrasting life histories and morphological traits, and their importance to native bees. Prior to treatments, 11-ft² (1-m²) plots were marked, and the number of plants in each plot to be burned was counted. Any dead material was trimmed to 4 inches (10 cm); loose dead vegetation was cleared from the burn zone to equalize combustibles. Thermocouples were put at the soil surface to monitor temperatures and standardize heating. Six propane-fueled prescription treatments were conducted at varying heat intensities and durations (Table 1). After burning, each plot was sprayed with a liter of water to extinguish any embers.

In spring 2013, survival data were collected along with a number of characteristics thought to be important for bees in a postfire environment (e.g., numbers of flowers, numbers of flowering stalks, and/or the lengths of racemes). Initial analyses for mortality are shown in Figure 1, except for gooseberryleaf globemallow, which is pending resolution of protocols for reliably distinguishing age classes.

Table 1. Propane burn treatments used on native plants

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

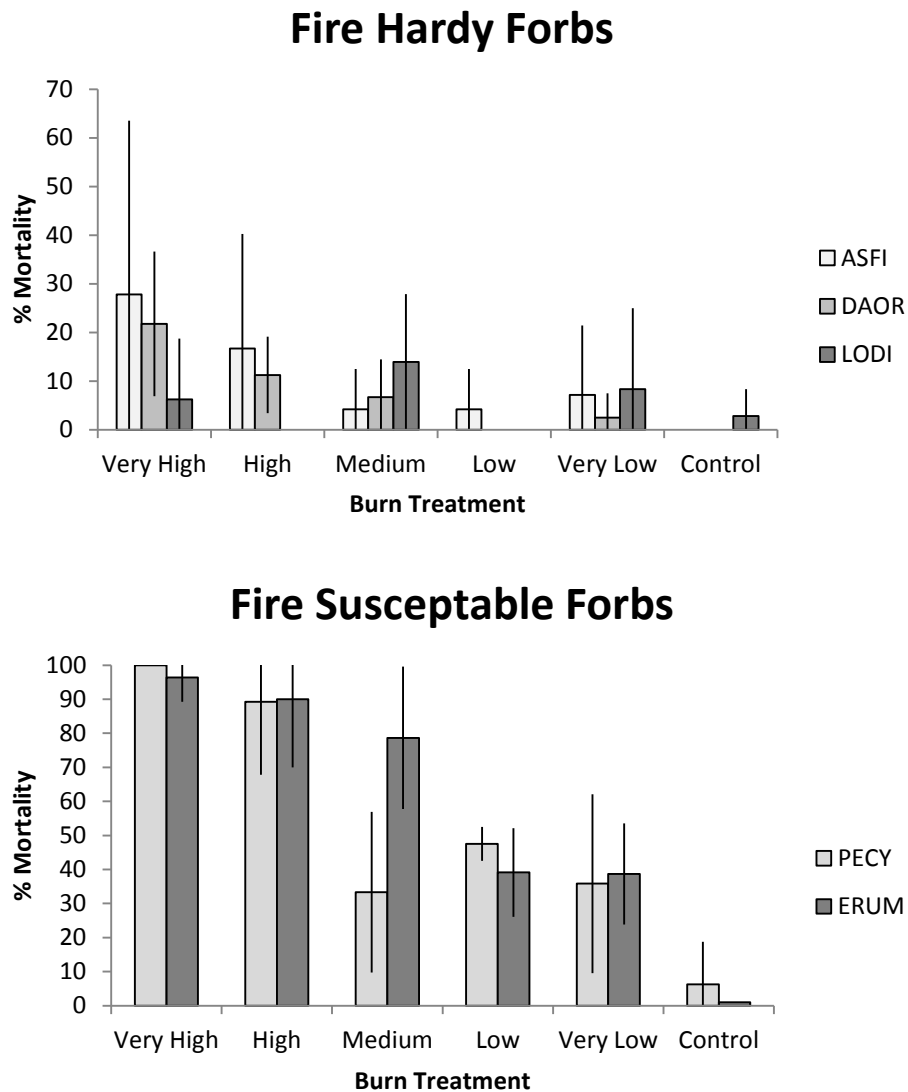


Figure 1. Percent mortality ($\pm$ standard deviation) of forbs subjected to various propane-fueled burn treatments. Species codes: ASFI – *Astragalus filipes*; DAOR – *Dalea ornata*; LODI – *Lomatium dissectum*; PECY – *Penstemon cyaneus*; ERUM – *Eriogonum umbellatum*.

Future plans

- 1) Complete analyses and a manuscript for the forb burning study. Two other manuscripts are planned that detail recently completed investigations of the responses of native forbs and bees to fire in Great Basin sagebrush steppe.
- 2) Improve our novel trap-cropping technique for seed beetle control. Attempt to find local plantings with a dirt surface, rather than the hot black fabric weed barrier, and again try this strategy to advance bloom as bait for beetles.

3) Find a new method for documenting the breeding biology of silverleaf phacelia. We can grow the plants from seed for transplanting. Next we will use resident bees to provide the pollinations. We are lining up cooperating xeriscape gardeners, as well as suitable campus gardens for outplantings. At each site, we will plant one isolated silverleaf phacelia and, at a distance, a close-set trio of plants. The former should be primarily selfed by resident bees, whereas the trio should have considerable outcrossing. We will collect seeds per umbel of counted flowers to evaluate seed production with these naturally pollinated plants.

Publications

Cane, J. H.; Johnson, C.; Romero Napoles, J.; Johnson, D.; Hammon, B. 2013. Seed-feeding beetles (Bruchidae, Curculionidae, Brentidae) from legumes (*Dalea ornata*, *Astragalus filipes*) and other forbs needed for restoring rangelands of the Intermountain West. *Western North American Naturalist*. 73(4): 477-484.

Cane, J. H.; Love, B.; Swoboda, K. A. 2012. Breeding biology and bee guild of Douglas' dustymaiden, *Chaenactis douglasii* (Asteraceae, Helenieae). *Western North American Naturalist*. 72(4): 563-568.

Additional Products

Wrote and aired a program for "Wild About Utah", a weekly nature series produced for Utah Public Radio, entitled: "Great Basin Defined". Program aired December 5, 2013. Available: <http://www.bridgerlandaudubon.org/wildaboututah/archive.htm>

Project Title Etiology, Epidemiology, and Management of Diseases of Native Wildflower Seed Production

Project Agreement No. 10-CR-11221632-073

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Project Description

Disease problems may cause serious losses of native plants in nurseries and losses of seed in production fields. The major objective of this project in 2013 was to identify potentially important diseases, with an emphasis on powdery mildews. Specifically we surveyed seed production plots at Oregon State's Malheur Experiment Station (MES), collected samples, and identified powdery mildew species present.

Seed production and maintenance plots for various native wildflowers at the MES were surveyed during September, 2013. Any plants showing powdery mildew-like symptoms were sampled and studied at the plant pathology laboratory at the University of Idaho's Parma Research and Extension Center. Samples were critically examined for presence of typical symptoms and signs of the disease. A total of 15 plant samples were collected. Laboratory examinations revealed that Douglas' dustymaiden (*Chaenactis douglasii*), silverleaf phacelia (*Phacelia hastata*), and common woolly sunflower (*Eriophyllum lanatum*) samples were not infected with powdery mildew. The other 12 samples were confirmed to be infected with different powdery mildews. The identity of the powdery mildew species and whether or not the host plant is a new record to the United States and /or to the literature were confirmed by Dr. Uwe Braun (Martin-Luther-Universität, Institut für Biologie, Halle, Germany) who is the foremost world authority on powdery mildews, their host plants, and worldwide distribution. The results are shown in Table 1.

Table 1. Powdery mildews identified on wildflower plants at MES (2013 September 11)

Scientific name	Common name	Result
<i>Astragalus filipes</i>	basalt milkvetch	<i>Leveillula papilionacearum</i> (new host)
<i>Chaenactis douglasii</i>	Douglas' dustymaiden	No powdery mildew detected
<i>Cleome lutea</i>	yellow spiderflower	<i>Leveillula cleomes</i> (new host, new to US)
<i>Cleome serrulata</i>	Rocky Mountain beeplant	<i>Leveillula cleomes</i> (new host, new to US)
<i>Cucurbita maxima</i>	winter squash	<i>Leveillula taurica</i> (sens. lat.) (new to US on this host)
<i>Dalea ornata</i>	Blue Mountain prairie clover	<i>Leveillula papilionacearum</i> (new host)
<i>Dalea searlsiae</i>	Searles' prairie clover	<i>Leveillula papilionacearum</i> (new host)
<i>Enceliopsis nudicaulis</i>	nakedstem sunray	<i>Leveillula picridis</i> (new host, new to US)
<i>Eriophyllum lanatum</i>	common woolly sunflower	No powdery mildew confirmed
<i>Heliomeris multiflora</i>	showy goldeneye	<i>Leveillula picridis</i> (new host, new to US)
<i>Heliomeris multiflora</i> var. <i>nevadensis</i>	Nevada goldeneye	<i>Leveillula picridis</i> (new host, new to US)
<i>Machaeranthera canescens</i>	hoary tansyaster	<i>Leveillula picridis</i> (new host)
<i>Phacelia hastata</i>	silverleaf phacelia	No powdery mildew detected
<i>Sphaeralcea grossulariifolia</i>	gooseberryleaf globemallow	<i>Leveillula</i> spp.
<i>Trifolium fragiferum</i>	strawberry clover	<i>Erysiphe trifoliorum</i>

These findings will provide useful information to seed producers, researchers, and other specialists about the identification and management of powdery mildews.

Publication

Braun, U.; Mohan, S. K. 2013. New records and new host plants of powdery mildews (*Erysiphales*) from Idaho and Oregon (USA). *Schlechtendalia*. 27: 7-10.

Project Title Seed Production of Great Basin Native Forbs

Project No. 12-JV-11221632-014

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Management Applications and Seed Production Guidelines

Amount of subsurface drip irrigation for maximum native wildflower seed yield, years to seed set, and life span; a summary of multi-year research findings from Oregon State University-Malheur Experiment Station, Ontario, OR, 2013.

Species	Optimum amount of irrigation	Years to first seed set	Life span
	inches/season	from fall planting	years
<i>Eriogonum umbellatum</i>	0 in wet years, 6 to 8 in dry years	1	7+
<i>Lomatium dissectum</i>	5 to 8	4	7+
<i>Lomatium grayi</i>	0 in wet years, 6 to 8 in dry years	2	7+
<i>Lomatium triternatum</i>	4 to 8 depending on precipitation	2	7+
<i>Penstemon acuminatus</i>	no response	1	3
<i>Penstemon speciosus</i>	0 in wet years, 4 to 8 in dry years	1	3
<i>Sphaeralcea coccinea</i>	no response	1	5
<i>Sphaeralcea grossulariifolia</i>	no response	1	5
<i>Sphaeralcea parvifolia</i>	no response	1	5

Amount of subsurface drip irrigation for maximum native wildflower seed yield of new plantings; a summary of multi-year research findings, OSU-MES, Ontario, OR, 2013.

Species	Optimum amount of irrigation inches/season
<i>Astragalus filipes</i>	no response in 2011, 2012, and 2013
<i>Cleome lutea</i>	no response in 2012 ^a
<i>Cleome serrulata</i>	8 inches in 2011, no response in 2012 ^a
<i>Dalea ornata</i>	0 inches in 2011 (wet year), 7.7 & 8 inches in 2012 & 2013 (dry years)
<i>Dalea searlsiae</i>	0 inches in 2011 (wet year), 6.6 & 8 inches in 2012 & 2013 (dry years)
<i>Eriogonum heracleoides</i>	no response in 2012, 4.9 inches in 2013 (dry year)
<i>Lomatium nudicaule</i>	no response in 2012, 4 inches in 2013 (dry year)
<i>Penstemon cyaneus</i>	no response in 2011 (wet year), 8 & 2 inches in 2012 & 2013 (dry years)
<i>Penstemon deustus</i>	0 inches in 2011 (wet year), no response in 2012 (dry year)
<i>Penstemon pachyphyllus</i>	no response in 2012, 8 inches in 2013 (dry year)

^a Results might be compromised due to poor flowering and seed set in 2012.

A. Direct Surface Seeding Systems for Successful Establishment of Native Wildflowers

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Project Description

Seed of native plants is needed to restore rangelands of the Intermountain West. Reliable commercial seed production is desirable to make seed readily available. Direct seeding of native range plants can be problematic, especially for certain species. Fall planting is important for many species, because their seed requires a period of cold to break dormancy (vernalization).

Fall planting of native seed has resulted in poor stands in some years at the Malheur Experiment Station (MES). Loss of soil moisture, soil crusting, and bird damage are some detrimental factors hindering emergence of fall planted seed. Previous trials at the MES have examined effects of seed pelleting, planting depth, and soil anti-crustants on seedling establishment (Shock et al. 2010). Planting wildflower seeds at a shallow depth with the addition of a soil anti-crustant increased seedling emergence compared to surface planting. Seed pelleting did not improve emergence. Despite these positive results, emergence was extremely poor for all treatments, due to soil crusting and bird damage.

In rangelands and in established native perennial fields at the MES, we have observed prolific natural emergence from seed that falls on the soil surface and is covered by thin layers of organic debris. This trial tested the effect of seven planting systems on the establishment of 15 native wildflower species (Table 1). Row cover can be a protective barrier against soil desiccation and bird damage. Sawdust can mimic the protective effect of organic debris. Sand can help hold the seed in place. Fungicide seed treatments can protect the emerging seedlings from fungal pathogens that might cause decomposition or damping off. Hydroseeding mulch could be a low cost replacement for row cover. Treatments did not test all possible combinations of factors, but tested the combinations that could provide systems that would result in adequate stand establishment. In previous trials, we demonstrated the importance of row cover in the establishment of native wildflower stands (Shock et al. 2012).

This trial tested seven plant systems that included combinations of seed cover, row cover, seed treatment, and hydroseeding mulch for stand establishment of 15 important wildflower species that are native to Malheur County and surrounding areas.

Methods

Fourteen species for which stand establishment may be problematic were chosen. A fifteenth species, royal penstemon (*Penstemon speciosus*), was chosen as a check, because of its reliable production of stands in Ontario, Oregon. Seed weights for all species were determined. 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 liter of water). Seed weights of the treated seeds were determined after fungicide treatments. The seed weights of untreated and treated seed were used to make seed packets containing close to 300 seeds each. The seed packets were assigned to one of seven treatments (Table 1). The trial was planted manually on 15 November 2012. The experimental design was a

randomized complete block with six replicates. Plots were one bed 30 inches (76 cm) wide and 5 feet (1.5 m) long. Two seed rows were planted in each bed.

Tetrazolium tests were conducted to determine seed viability of each species (Table 2). The tetrazolium results were used to correct the plant stands to a percent of viable seed planted.

At planting, treatments receiving sawdust had sawdust applied in a narrow band over the seed row at 558 pounds/acre of row (0.26 oz/ft). For the treatments receiving both sawdust and sand, the sand was applied at 1,404 pounds/acre (0.65 oz/ft) of row as a narrow band over the sawdust. Following planting and sawdust and sand applications, some of the treatments had row cover installed over the beds. The row cover (N-sulate, DeWitt Co., Inc., Sikeston, MO) covered four rows (two beds) and was applied with a mechanical plastic mulch layer. For the simulated hydroseeding mulch treatments, hydroseeding mulch (Hydrostraw LLC, Manteno, IL) was applied dry at 7.5 g/ft of row in a 1-inch (3 cm) band over the seed row. The mulch was applied dry and sprayed with water using a backpack sprayer to simulate hydroseeding.

On 15 March 2013, the row cover was removed and plant stand counts were made in each plot. Plant stands were counted again on the 2nd and 18th of April.

Data were analyzed using analysis of variance (General Linear Models Procedure, NCSS, Kaysville, UT). Means separation was determined using Fisher's least significant difference test at the 5 percent probability level, LSD (0.05).

Results and Discussion

By the first plant count on 15 March 2013, all species were emerging. Between the second count on 2 April and the third count on 18 April, most species showed no increase in stand density and some species showed a decline in stand density. Even by 18 April the stands of threadleaf phacelia (*Phacelia linearis*), coyote tobacco (*Nicotiana attenuata*), and cleftleaf wildheliotrope (*P. crenulata*) were too poor to draw meaningful conclusions.

Direct planting of the seed without other aids was among the least successful plant system (Tables 3, 4, and 5). Row cover was beneficial to plant stand establishment. For the 12 species where there were statistical differences among planting systems, the planting systems with greatest plant establishment included row cover. The most effective system for plant establishment for each species varied somewhat by the date that the evaluations were made. Since plant stands later in the growing season are critical to seed yield, the discussion that follows is based on the last stand count on 18 April (Table 5).

Overall seedling plant stands were lower with simulated hydroseeding mulch plus seed treatment than with row cover plus seed treatment. Actual hydroseeding may result in better stand establishment than our simulated application.

Seedlings of scarlet gilia (*Ipomopsis aggregata*) established best using a system of row cover plus sawdust, and this system was among the most favorable system for seven other species. Row cover plus seed treatment was among the most favorable systems for 8 of the species, while row cover plus seed treatment plus sawdust was among the most favorable system for six of the

species. The system using row cover plus sawdust plus sand was among the best systems for ten of the twelve species where significant differences between planting systems were found.

References

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Table 1. Seven planting systems evaluated for the establishment of 15 native wildflower species. Mouse bait packs were scattered over the trial area at Oregon State University (OSU)-MES, Ontario, Oregon in 2013

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

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

Table 2. Seed weights and tetrazolium test (seed viability) for 15 native wildflower species submitted to seven planting systems in the fall of 2012 at OSU-MES, Ontario, OR

Species	Common name	Untreated seed weight (seeds/g)	Tetrazolium test (%)
<i>Chaenactis douglasii</i>	Douglas' dustymaiden	787	72
<i>Enceliopsis nudicaulis</i>	nakedstem sunray	127	92
<i>Eriophyllum lanatum</i>	common woolly sunflower	1,634	88
<i>Heliomeris multiflora</i>	showy goldeneye	1,700	85
<i>Ipomopsis aggregata</i>	scarlet gilia	656	76
<i>Ligusticum canbyi</i>	Canby's licorice-root	238	63
<i>Ligusticum porteri</i>	Porter's licorice-root	158	93
<i>Machaeranthera canescens</i>	hoary tansyaster	2,321	84
<i>Mentzelia albicaulis</i>	whitestem blazingstar	1,130	84
<i>Nicotiana attenuata</i>	coyote tobacco	13,000	25
<i>Penstemon speciosus</i>	showy penstemon	710	88
<i>Phacelia crenulata</i>	cleftleaf wildheliotrope	942	94
<i>Phacelia hastata</i>	silverleaf phacelia	1,471	100
<i>Phacelia linearis</i>	threadleaf phacelia	2,843	100
<i>Thelypodium milleflorum</i>	many flower thelypody	3,650	96
<i>Machaeranthera canescens</i>	hoary tansyaster	2,321	84

Table 3. Plant stands of 15 native plant species on 15 March 2013 in response to seven planting systems used at the time of planting (fall 2012). Plant stand for each species was corrected to the percent based on the number of viable seed planted at OSU-MES, Ontario, Oregon.

Species	Row cover, seed treatment, sawdust	Row cover, seed treatment	Row cover, sawdust	Seed treatment, sawdust	Row cover, seed treatment, sawdust, sand	Seed treatment, mulch	Untreated check	LSD (0.05)
	----- % stand -----							
<i>Chaenactis douglasii</i>	22.2	21.9	17.8	1.6	45.6	9.2	0.3	13.6
<i>Enceliopsis nudicaulis</i>	12.1	12.6	5.5	0.1	5.5	0.3	4.0	NS
<i>Eriophyllum lanatum</i>	47.9	55.1	31.8	1.6	45.8	14.5	2.0	21.9
<i>Heliomeris multiflora</i>	5.8	15.0	9.5	0.4	15.9	0.5	0.3	6.7
<i>Ipomopsis aggregata</i>	0.3	0.3	9.4	0.3	0.1	0.1	0.5	3.8
<i>Ligusticum canbyi</i>	0.4	9.3	0.4	0.1	0.3	0.7	0.0	NS
<i>Ligusticum porteri</i>	0.1	0.8	1.7	0.0	5.8	0.0	1.3	NS
<i>Machaeranthera canescens</i>	69.6	54.5	53.0	20.7	61.6	18.1	21.7	23.1
<i>Mentzelia albicaulis</i>	18.9	22.5	16.7	3.1	22.2	5.6	3.4	10.8
<i>Nicotiana attenuata</i>	1.6	0.2	0.2	0.9	6.9	7.8	0.0	NS
<i>Penstemon speciosus</i>	25.7	25.1	7.8	0.1	34.0	0.4	0.1	13.9
<i>Phacelia crenulata</i>	0.1	1.1	4.1	0.0	1.1	0.0	0.0	NS
<i>Phacelia hastata</i>	7.4	10.2	18.5	0.3	12.2	0.2	1.3	9.2
<i>Phacelia linearis</i>	2.8	0.1	0.2	0.0	2.4	0.1	0.1	NS
<i>Thelypodium milleflorum</i>	29.7	41.0	31.5	4.6	21.2	2.7	3.1	20.4

Table 4. Plant stands of 15 native plant species on 2 April 2013 in response to seven planting systems used at the time of planting (fall 2012). Plant stand for each species was corrected to the percent based on the number of viable seed planted at OSU-MES, Ontario, Oregon.

Species	Row cover, seed treatment, sawdust	Row cover, seed treatment	Row cover, sawdust	Seed treatment, sawdust	Row cover, seed treatment, sawdust, sand	Seed treatment, mulch	Untreated check	LSD (0.05)
	----- % stand -----							
<i>Chaenactis douglasii</i>	21.5	28.6	18.7	4.2	46.5	13.1	2.5	11.8
<i>Enceliopsis nudicaulis</i>	13.8	12.5	7.1	0.2	8.9	0.6	4.1	NS
<i>Eriophyllum lanatum</i>	44.8	52.1	29.2	4.2	47.5	14.6	3.9	23.4
<i>Heliomeris multiflora</i>	7.5	19.0	12.3	1.0	17.6	0.1	0.3	7.5
<i>Ipomopsis aggregata</i>	0.5	0.4	13.5	0.4	0.9	0.0	0.3	3.0
<i>Ligusticum canbyi</i>	4.1	20.2	6.4	0.2	10.1	0.0	0.0	8.8
<i>Ligusticum porteri</i>	3.6	7.6	11.8	0.0	12.5	0.0	2.5	7.2
<i>Machaeranthera canescens</i>	70.5	46.2	61.6	18.5	61.4	21.3	21.4	28.8
<i>Mentzelia albicaulis</i>	19.3	21.4	17.2	3.4	19.9	6.5	3.3	11.3
<i>Nicotiana attenuata</i>	0.4	10.4	1.6	0.4	4.2	16.4	6.0	NS
<i>Penstemon speciosus</i>	31.4	27.3	11.2	0.1	43.0	0.6	0.4	15.5
<i>Phacelia crenulata</i>	0.4	5.6	4.4	0.0	2.1	0.0	0.1	NS
<i>Phacelia hastata</i>	12.1	26.4	20.9	1.1	15.8	0.4	3.2	14.9
<i>Phacelia linearis</i>	2.8	0.1	0.2	0.1	2.8	0.1	0.2	NS
<i>Thelypodium milleflorum</i>	28.0	40.5	34.8	3.9	23.1	3.6	3.9	20.7

Table 5. Plant stands of 15 native plant species on 18 April 2013 in response to seven planting systems used at the time of planting (fall 2012). Plant stand for each species was corrected to the percent based on the number of viable seed planted at OSU-MES, Ontario, Oregon.

Species	Row cover, seed treatment, sawdust	Row cover, seed treatment	Row cover, sawdust	Seed treatment, sawdust	Row cover, seed treatment, sawdust, sand	Seed treatment, mulch	Untreated check	LSD (0.05)
	----- % stand -----							
<i>Chaenactis douglasii</i>	18.8	26.5	17.5	4.2	39.1	12.2	5.4	12.2
<i>Enceliopsis nudicaulis</i>	10.9	11.5	6.4	0.1	7.8	0.0	3.7	8.6
<i>Eriophyllum lanatum</i>	38.8	46.6	25.6	4.7	44.0	14.6	3.9	22.9
<i>Heliomeris multiflora</i>	8.0	14.2	11.2	0.3	17.4	0.1	0.3	8.2
<i>Ipomopsis aggregata</i>	0.3	1.1	14.3	0.0	1.0	0.0	0.7	3.2
<i>Ligusticum canbyi</i>	5.3	16.1	6.3	0.0	8.8	0.8	0.1	7.6
<i>Ligusticum porteri</i>	3.4	7.7	10.6	0.0	12.1	0.1	2.5	7.1
<i>Machaeranthera canescens</i>	67.3	47.4	48.8	18.7	57.7	19.1	22.1	26.3
<i>Mentzelia albicaulis</i>	18.7	20.3	15.7	3.3	17.5	7.1	2.9	10.5
<i>Nicotiana attenuata</i>	4.4	11.8	1.8	0.0	4.2	12.2	0.0	NS
<i>Penstemon speciosus</i>	27.0	27.0	7.6	0.0	33.1	0.7	0.1	14.6
<i>Phacelia crenulata</i>	0.6	3.4	4.3	0.1	2.0	0.0	0.1	NS
<i>Phacelia hastata</i>	10.6	23.6	19.9	1.0	14.2	0.7	1.9	13.9
<i>Phacelia linearis</i>	2.6	0.1	0.1	0.0	2.7	0.0	0.1	NS
<i>Thelypodium milleflorum</i>	23.2	37.0	28.5	1.7	19.7	2.4	2.0	17.5

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

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Project Description

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

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

Native wildflower plants are not well adapted to croplands. They often are not competitive with crop weeds in cultivated fields. Poor competitiveness with weeds could also limit wildflower seed production. Both sprinkler and furrow irrigation could provide supplemental water for seed production, but these irrigation systems risk further encouraging weeds. Also, sprinkler and furrow irrigation can lead to the loss of plant stand and seed production due to fungal pathogens. By burying drip tapes at a 12-inch (30 cm) depth and avoiding wetting the soil surface, we hoped to assure flowering and seed set without undue encouragement of weeds or opportunistic diseases. The trials reported here tested the effects of three low rates of irrigation on the seed yield of 13 native wildflower species.

Methods

Plant Establishment

Seed of seven Intermountain West wildflower species (sulphur-flower buckwheat [*Eriogonum umbellatum*], biscuitroot species [*Lomatium* spp.], and penstemon species [*Penstemon* spp.]) was received in late November 2004 from the Rocky Mountain Research Station (RMRS) in Boise, Idaho. See Table 6 for all wildflower species evaluated. 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, seed was cold stratified. Seed was soaked overnight in distilled water on 26 January 2005 then the water was drained and seed was soaked for 20 minutes in a 10 percent by volume solution of 13 percent bleach in distilled water. The bleach-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 (1 °C). 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 (*Lomatium grayi*) and nineleaf biscuitroot (*L. triternatum*) had started to sprout.

In late February 2005, drip tape (T-Tape TSX 515-16-340) was buried at 12-inch (30 cm) depths between two 30-inch (76 cm) rows of a Nyssa silt loam with a pH of 8.3 and 1.1 percent organic

matter. The drip tape was buried in alternating inter-row spaces (5 ft [1.5 m] apart). The flow rate for the drip tape was 0.34 gal/min/100 ft at 8 psi with emitters spaced 16 inches (41 cm) apart, resulting in a water application rate of 0.066 inch/hour.

On 3 March 2005, seed of sulphur-flower buckwheat, lomatium species, and penstemon species (Table 6) was planted in 30-inch rows using a custom-made plot grain drill with disc openers. All seed was planted at 20 to 30 seeds/foot of row. Sulphur-flower buckwheat and the penstemon species were planted at 0.25-inch (0.6 cm) depths and the biscuitroot species at 0.5-inch (1.3 cm) depths. The trial was irrigated with a mini sprinkler system (R10 Turbo Rotator, Nelson Irrigation Corp., Walla Walla, WA) for even stand establishment from 4 March to 29 April. Risers were spaced 25 feet (8 m) apart along the flexible polyethylene hose laterals that were spaced 30 feet (9 m) apart and the water application rate was 0.10 inch/hour. A total of 1.72 inches (43.7 mm) of water was applied with the mini sprinkler system. Sulphur-flower buckwheat, nineleaf biscuitroot, and Gray's biscuitroot started emerging on 29 March. All other species except fernleaf biscuitroot (*L. dissectum*) emerged by late April. Starting 24 June, the field was irrigated with the drip system. A total of 3.73 inches (9.47 cm) of water was applied with the drip system from 24 June to 7 July. The field was not irrigated further in 2005.

Plant stands for sulphur-flower buckwheat, nineleaf biscuitroot, Gray's biscuitroot, and penstemon species 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. Empty lengths of row were replanted by hand in the sulphur-flower buckwheat and penstemon species plots. The biscuitroot species plots had the entire row lengths replanted using the planter. Seed was replanted on 26 October 2005. In the spring of 2006, stands of the replanted species were excellent, except for scabland penstemon (*P. deustus*).

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

Irrigation for Seed Production

In April 2006, each planted strip of each wildflower species was divided into plots 30 feet (9 m) long. Each plot contained four rows of each species. The experimental designs were randomized complete blocks with four replicates. The three treatments were a non-irrigated check, 1 inch (25 mm) of water applied per irrigation, and 2 inches (50 mm) of water applied per irrigation. Each treatment received 4 irrigations that were applied approximately every 2 weeks starting with the flowering of each species. 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 of the irrigations, the amount of water applied was read on a water meter and recorded to ensure correct water applications.

Table 6. Wildflower species planted in the drip irrigation trials at the Oregon State University-Malheur Experiment Station (OSU-MES), Ontario, OR

Species	Common names
<i>Astragalus filipes</i>	basalt milkvetch
<i>Dalea ornata</i>	Blue Mountain prairie clover, western prairie clover
<i>Dalea searlsiae</i>	Searls' prairie clover
<i>Eriogonum umbellatum</i>	sulphur-flower buckwheat
<i>Lomatium dissectum</i>	fernleaf biscuitroot
<i>Lomatium grayi</i>	Gray's biscuitroot, Gray's lomatium
<i>Lomatium triternatum</i>	nineleaf biscuitroot, nineleaf desert parsley
<i>Penstemon acuminatus</i>	sharpleaf penstemon, sand-dune penstemon
<i>Penstemon deustus</i>	scabland penstemon, hotrock penstemon
<i>Penstemon speciosus</i>	royal penstemon, sagebrush penstemon
<i>Sphaeralcea coccinea</i>	scarlet globemallow, red globemallow
<i>Sphaeralcea grossulariifolia</i>	gooseberryleaf globemallow
<i>Sphaeralcea parvifolia</i>	smallflower globemallow

In March of 2007, the drip-irrigation system was modified to allow separate irrigation of the species due to differences in flowering timing. The three biscuitroot species were irrigated together and scabland and royal penstemon (*P. speciosus*) were irrigated together, but separately from the others. Sharpleaf penstemon (*P. acuminatus*) and sulphur-flower buckwheat were irrigated individually. In early April 2007, the three globemallow species, two prairie clover species, and basalt milkvetch were divided into plots with a drip-irrigation system to allow the same irrigation treatments that were received by the other wildflowers.

Irrigation dates are found in Table 7. In 2007, irrigation treatments were inadvertently continued after the fourth irrigation. Irrigation treatments for all species were continued until the last irrigation on 24 June 2007.

Soil volumetric water content was measured by neutron probe. The neutron probe was calibrated by taking soil samples and probe readings at 8-, 20-, and 32-inch (20, 51, and 81 cm) depths during installation of the access tubes. Soil water content was determined volumetrically from the soil samples and regressed against the neutron probe readings separately for each soil depth. Regression equations were then used to transform the neutron probe readings into volumetric soil water content.

Flowering, Harvesting, and Seed Cleaning

Flowering dates for each species were recorded (Table 7). Sulphur-flower buckwheat and penstemon species plots produced seed in 2006, in part because they had emerged in spring 2005. Each year, the middle two rows of each plot were harvested when seed of each species was mature (Table 7), using the methods listed in Table 8. The plant stand for *P. deustus* was too poor to result in reliable seed yield estimates. Replanting of *P. deustus* in the fall of 2006 did not result in adequate plant stand in the spring of 2007.

Sulphur-flower buckwheat seeds did not separate from the flowering structures in the combine; the unthreshed seed was taken to the United States Forest Service, Lucky Peak Nursery in Boise, Idaho

and run through a dewinger to separate the seed, which was further cleaned in a small clipper seed cleaner.

Scabland penstemon seed pods were too hard to be opened by 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. Seed was then cleaned again in the small clipper seed cleaner.

Sharpleaf and royal penstemon were threshed in the combine, and seed was further cleaned using a small clipper seed cleaner.

Cultural Practices in 2006

On 27 October 2006, 50 lb phosphorus (P)/acre and 2 lb zinc (Zn)/acre were injected through the drip tape to all plots of sulphur-flower buckwheat, penstemon species, and biscuitroot species. On 11 November, 100 lb nitrogen (N)/acre as urea was broadcast to all biscuitroot species plots. On 17 November, all plots of sulphur-flower buckwheat, penstemon species (except scabland), and biscuitroot species had Prowl[®] at 1 lb active ingredient (ai)/acre broadcast on the soil surface. Irrigations for all species were initiated on 19 May and terminated on 30 June. Harvesting and seed cleaning methods for each species are listed in Table 8.

Cultural Practices in 2007

Sharpleaf and royal penstemon were sprayed with Aza-Direct[®] at 0.0062 lb ai/acre on 14 and 29 May for lygus bug control. Irrigations for each species were initiated and terminated on different dates (Table 7). Harvesting and seed cleaning methods for each species are listed in Table 8. All plots of the globemallow species were flailed on 8 November 2007.

Cultural Practices in 2008

On 9 November 2007 and on 15 April 2008, Prowl at 1 lb ai/acre was broadcast on all plots for weed control. Capture[®] 2EC at 0.1 lb ai/acre was sprayed on all plots of sharpflea and royal penstemon on 20 May for lygus bug control. Irrigations for each species were initiated and terminated on different dates (Table 7). Harvesting and seed cleaning methods for each species are listed in Table 8.

Cultural Practices in 2009

On 18 March, Prowl at 1 lb ai/acre and Volunteer[®] at 8 oz/acre were broadcast on all plots for weed control. On 9 April, 50 lb N/acre and 10 lb P/acre were applied through the drip irrigation system to the three biscuitroot species. The flowering, irrigation timing, and harvest timing were recorded for each species (Table 7). Harvesting and seed cleaning methods for each species are listed in Table 8. On 4 December 2009, Prowl at 1 lb ai/acre was broadcast for weed control on all plots.

Cultural Practices in 2010

The flowering, irrigation, and harvest timing of the established wildflowers were recorded for each species (Table 7). Harvesting and seed cleaning methods for each species are listed in Table 8. On 17 November, Prowl at 1 lb ai/acre was broadcast on all plots for weed control.

Cultural Practices in 2011

On 3 May, 50 lb N/acre was applied to all biscuitroot species plots and Uran (urea ammonium nitrate) was injected through the drip tape. Timing of flowering, irrigations, and harvests varied by species, see Table 7. Harvesting and seed cleaning methods for each species are listed in Table 8. On November 9, Prowl at 1 lb ai/acre was broadcast on all plots for weed control.

Cultural Practices in 2012

Soil volumetric water content was very low in 2012 prior to the onset of irrigation for each species. Iron deficiency symptoms were prevalent in 2012. On 13 April, 50 lb N/acre, 10 lb P/acre, and 5 lb iron (Fe)/acre was applied to all biscuitroot species plots as liquid fertilizer injected through the drip tape. On 7 November, Prowl at 1 lb ai/acre was broadcast on all plots of sulphur-flower buckwheat and Gray's, fernleaf, and nineleaf biscuitroot for weed control.

Cultural Practices in 2013

On 29 March, 20 lb N/acre, 25 lb P/acre, and 5 lb Fe/acre were applied through the drip tape to all plots of Gray's, fernleaf, and nineleaf biscuitroot. On 3 April, Select Max at 32 oz/acre was broadcast for grass weed control on all plots of sulphur-flower buckwheat, royal penstemon, and Gray's, fernleaf, and nineleaf biscuitroot.

Results and Discussion

Precipitation from January through April in 2013 was only 1.4 inches (36 mm), substantially lower than average. The accumulated growing degree-days (50-86 °F [10-30 °C]) from January through June in 2013 were higher than average (Table 9, Figures 1 and 2).

Flowering and Seed Set

Sharpleaf 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 [11 °C] base) are accumulated. Data collected by an AgriMet weather station adjacent to the field indicated that annual first lygus bug hatches occurred on 14 May 2006, 1 May 2007, 18 May 2008, 19 May 2009, and 29 May 2010. The average (1995-2010) lygus bug hatch date was 18 May. Sharpleaf and royal penstemon start flowering in early May. The earlier lygus bug hatch in 2007 probably resulted in harmful levels of lygus bugs present during a larger part of the penstemon species flowering period than normal. Poor seed set for sharpleaf and royal penstemon in 2007 also was related to poor vegetative growth compared to 2006 and 2008. In 2009, all plots of sharpleaf 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 in the wettest treatment (2 inches [50 mm] of water per irrigation). Root rot affected the wetter plots of royal penstemon in 2009, but the stand partially recovered due to natural reseeding.

Table 7. Native wildflower flowering, irrigation, and seed harvest dates by species in 2006-2013 at OSU-MES, Ontario, OR

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

Table 7, continued. Native wildflower flowering, irrigation, and seed harvest dates by species in 2006-2013 at OSU-MES, Ontario, OR

	Flowering				Irrigation		
Species	start	peak	end		start	end	Harvest
	2009						
<i>Eriogonum umbellatum</i>	31-May		15-Jul		19-May	24-Jun	28-Jul
<i>Lomatium dissectum</i>	10-Apr		7-May		20-Apr	28-May	16-Jun
<i>Lomatium grayi</i>	10-Mar		7-May		20-Apr	28-May	16-Jun
<i>Lomatium triternatum</i>	10-Apr	7-May	1-Jun		20-Apr	28-May	26-Jun
<i>Penstemon acuminatus</i>	2-May		10-Jun		8-May	12-Jun	10-Jul
<i>Penstemon deustus</i>					19-May	24-Jun	
<i>Penstemon speciosus</i>	14-May		20-Jun		19-May	24-Jun	10-Jul
<i>Sphaeralcea coccinea</i>	1-May		10-Jun		22-May	24-Jun	14-Jul
<i>Sphaeralcea grossulariifolia</i>	1-May		10-Jun		22-May	24-Jun	14-Jul
<i>Sphaeralcea parvifolia</i>	1-May		10-Jun	22-May	24-Jun	14-Jul	
	2010						
<i>Eriogonum umbellatum</i>	4-Jun	12-19 Jun	15-Jul		28-May	8-Jul	27-Jul
<i>Lomatium dissectum</i>	25-Apr		20-May		15-Apr	28-May	21-Jun
<i>Lomatium grayi</i>	15-Mar		15-May		15-Apr	28-May	22-Jun
<i>Lomatium triternatum</i>	25-Apr		15-Jun		15-Apr	28-May	22-Jul
<i>Penstemon speciosus</i>	14-May		20-Jun		12-May	22-Jun	22-Jul
<i>Sphaeralcea coccinea</i>	10-May	4-Jun	25-Jun		28-May	8-Jul	20-Jul
<i>Sphaeralcea grossulariifolia</i>	10-May	4-Jun	25-Jun		28-May	8-Jul	20-Jul
<i>Sphaeralcea parvifolia</i>	10-May	4-Jun	25-Jun		28-May	8-Jul	20-Jul
	2011						
<i>Eriogonum umbellatum</i>	8-Jun	30-Jun	20-Jul		20-May	5-Jul	1-Aug
<i>Lomatium dissectum</i>	8-Apr	25-Apr	10-May		21-Apr	7-Jun	20-Jun
<i>Lomatium grayi</i>	1-Apr	25-Apr	13-May		21-Apr	7-Jun	22-Jun
<i>Lomatium triternatum</i>	30-Apr	23-May	15-Jun		21-Apr	7-Jun	26-Jul
<i>Penstemon speciosus</i>	25-May	30-May	30-Jun		20-May	5-Jul	29-Jul
<i>Sphaeralcea coccinea</i>	26-May	15-Jun	14-Jul		20-May	5-Jul	29-Jul
<i>Sphaeralcea grossulariifolia</i>	26-May	15-Jun	14-Jul		20-May	5-Jul	29-Jul
<i>Sphaeralcea parvifolia</i>	26-May	15-Jun	14-Jul		20-May	5-Jul	29-Jul
	2012						
<i>Eriogonum umbellatum</i>	30-May	20-Jun	4-Jul		30-May	11-Jul	24-Jul
<i>Lomatium dissectum</i>	9-Apr	16-Apr	16-May		13-Apr	24-May	4-Jun
<i>Lomatium grayi</i>	15-Mar	25-Apr	16-May		13-Apr	24-May	14-Jun
<i>Lomatium triternatum</i>	12-Apr	17-May	6-Jun		13-Apr	24-May	21-Jun
<i>Penstemon speciosus</i>	2-May	20-May	25-Jun		2-May	13-Jun	13-Jul
	2013						
<i>Eriogonum umbellatum</i>	8-May	27-May	27-Jun		8-May	19-Jun	9-Jul
<i>Lomatium dissectum</i>	10-Apr		25-Apr		4-Apr	16-May	4-Jun
<i>Lomatium grayi</i>	15-Mar		30-Apr		4-Apr	16-May	10-Jun
<i>Lomatium triternatum</i>	18-Apr		10-May		4-Apr	16-May	4-Jun
<i>Penstemon speciosus</i>	2-May	10-May	20-Jun		2-May	12-Jun	11-Jul

Table 8. Native wildflower seed harvest and cleaning by species at OSU-MES, Ontario, OR

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

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

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

^c Clipper seed cleaner.

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

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

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

The three globemallow species had a long flowering period (early May through September) in 2007. Multiple manual harvests were necessary because seed falls out of the capsules once they mature. The flailing of the three globemallow species starting in fall 2007 was done annually to induce a more concentrated flowering, allowing only one mechanical harvest. Precipitation in June of 2009 (2.27 inches [58 mm]) and 2010 (1.95 inches [50 mm]) was substantially higher than average (0.76 inches [19 mm]). Rust (*Puccinia sherardiana*) infected all three globemallow species in June 2009 and 2010, causing substantial leaf loss and reduced vegetative growth. Stands of all three species deteriorated in 2011, and plots were disked out in 2012.

Seed Yields

Sulphur-flower Buckwheat

In 2006, seed yield of sulphur-flower buckwheat increased with increasing water application, up to 8 inches (20 cm), the highest amount tested (Tables 10 and 12). From 2007 to 2009, seed yield showed a quadratic response to irrigation rate (Tables 11 and 12). Seed yields were maximized by 8.1 inches (206 mm), 7.2 (183 mm) inches, and 6.9 inches (175 mm) of water applied in 2007, 2008, and 2009, respectively. In 2010, there was no significant difference in yield between irrigation treatments. In 2011, seed yield was highest with no irrigation. The 2010 and 2011 seasons had unusually cool and wet weather (Table 9, Figure 2). Accumulated precipitation in April through June of 2010 and 2011 was highest of all years of the trial (Table 9). Relatively high seed yield of sulphur-flower buckwheat in non-irrigated treatments in 2010 and 2011 seemed to be related to high

levels of spring precipitation. The negative effect of irrigation on seed yield in 2011 might have been related to the presence of rust. Irrigation could have exacerbated the rust and resulted in lower yields. In 2012, seed yield of sulphur-flower buckwheat increased with increased water application, up to 8 inches (200 mm), the highest amount tested (Tables 11 and 12). In 2013, seed yield showed a quadratic response to irrigation rate. Seed yield was maximized at 5.6 inches (142 mm) of water applied in 2013. Averaged over 8 years, seed yield of sulphur-flower buckwheat increased with increasing water applied. Shape of the quadratic seed yield responses in most years suggests that additional irrigation above 8 inches would not be beneficial.

Sharpleaf Penstemon

There was no significant difference in seed yield between irrigation treatments for sharpleaf penstemon in 2006 (Table 10). Precipitation from March through June was 6.4 inches (163 mm) in 2006. The 64-year average precipitation from March through June is 3.6 inches (91 mm). 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 (102 mm) of water applied in 2007. In 2008, seed yield showed a linear response to applied water. In 2009, there was no significant difference in seed yield between treatments (Table 12). However, because root rot affected all plots in 2009, seed yield results were compromised. By 2010, substantial lengths of row contained only dead plants. Measurements in each plot showed that plant death increased with increasing irrigation rate. The stand loss was 51.3%, 63.9%, and 88.5% for the 0, 4-inch (102 mm), and 8-inch (203 mm) 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.

Royal Penstemon

From 2006 to 2009, seed yield of royal penstemon showed a quadratic response to irrigation rates (Tables 10, 11, and 12). Seed yields were maximized by 4.3, 4.2, 5.0, and 4.3 inches (109, 107, 127, and 109 mm) of water applied in 2006, 2007, 2008, and 2009, respectively. In 2010, 2011, and 2012, there was no difference in seed yield between irrigation treatments. Seed yield was low in 2007 due to lygus bug damage, as discussed previously. Seed yield in 2009 was low due to stand loss from root rot. The plant stand recovered somewhat in 2010 and 2011, due in part to natural reseeding, especially in non-irrigated plots. In 2013, seed yield increased with increasing water application, up to 8 inches (203 mm), the highest amount tested. Averaged over 8 years, seed yield was maximized by 4.9 inches (125 mm) of water applied.

Nineleaf Biscuitroot

Nineleaf biscuitroot showed a trend for increasing seed yield with increasing irrigation in 2007 (Table 10). The highest irrigation rate resulted in significantly higher seed yield than the non-irrigated checks in seven of the last eight years. Seed yields of nineleaf biscuitroot were substantially higher from 2008 to 2011 than in other years (Tables 11 and 12). From 2008 to 2011 seed yields of nineleaf biscuitroot showed a quadratic response to irrigation rate. Seed yields were estimated to be maximized by 8.4, 5.4, 7.8, and 4.1 inches (213, 137, 198, and 104 mm) of water applied in 2008, 2009, 2010, and 2011, respectively. In 2012 and 2013, seed yield increased linearly with increasing water applied up to the highest amount, 8 inches (203 mm). Over 7 years, seed yield of nineleaf biscuitroot was estimated to be maximized by 6.4 inches (163 mm) of applied water (Table 12).

Gray's Biscuitroot

Gray's biscuitroot showed a trend for increasing seed yield with increasing irrigation in 2007 (Table 10). The highest irrigation rate resulted in significantly higher seed yield than non-irrigated checks in six of the last eight years. Seed yields of Gray's biscuitroot were substantially higher in 2008 and 2009. In 2008, seed yields showed a quadratic response to irrigation rate. Seed yields were estimated to be maximized by 6.9 inches (175 mm) of water applied in 2008. In 2009, seed yield showed a linear response to irrigation rate (Tables 11 and 12). Seed yield with the 4-inch (102 mm) irrigation rate was significantly higher than in the non-irrigated check, but the 8-inch (203 mm) irrigation rate did not result in a significant increase above the 4-inch rate. In 2010, seed yield was not responsive to irrigation, possibly because of the unusually wet spring of 2010. A further complicating factor in 2010 that compromised seed yields was rodent damage. Extensive rodent (vole) damage occurred over the 2009-10 winter. Affected areas were transplanted with 3-year-old Gray's biscuitroot plants from an adjacent area in spring 2010. To reduce their attractiveness to voles, plants were mowed after becoming dormant in early fall 2010 and in each subsequent year. In 2011, seed yield again did not respond to irrigation. Spring 2011 was unusually cool and wet. In 2012, seed yields of Gray's biscuitroot showed a quadratic response to irrigation, with a maximum seed yield at 5.5 inches of applied water. In 2013, seed yield increased linearly with increasing water application, up to 8 inches, the highest amount applied. Over 7 years, seed yield of Gray's biscuitroot was estimated to be maximized by 5.5 inches (140 mm) of applied water. Most appropriately, irrigation probably should be varied with precipitation.

Fernleaf Biscuitroot

Fernleaf biscuitroot had very little vegetative growth from 2006 to 2008 and produced very few flowers in 2008. In 2009, vegetative growth and flowering for fernleaf biscuitroot were greater. Seed yield of fernleaf biscuitroot showed a linear response to irrigation rate in 2009 (Figure 14). Seed yield with the 4-inch (102 mm) irrigation rate was significantly higher than the non-irrigated check, but the 8-inch (203 mm) irrigation rate did not result in a significant increase above the 4-inch rate. In 2010 and 2011, seed yields of fernleaf biscuitroot showed a quadratic response to irrigation rate. Seed yields were estimated to be maximized by 5.4 and 5.1 inches (137 and 130 mm) of applied water in 2010 and 2011, respectively. In 2012, seed yields of fernleaf biscuitroot were not responsive to irrigation rates. In 2013, seed yield increased linearly with increasing irrigation rate up to 8 inches (203 mm), the highest amount applied. Over 5 years, seed yield showed a quadratic response to irrigation rate and was estimated to be maximized by 5.5 inches (140 mm) of applied water.

All the biscuitroot species tested were affected by *Alternaria* fungus, but the infection was greatest on fernleaf biscuitroot. This infection delayed fernleaf biscuitroot plant development.

Globemallow Species

From 2007 to 2011, there were no significant differences in seed yield among irrigation treatments for the three globemallow species (Tables 10 and 11). Stand development for the globemallow species was poor in 2012, and plantings were eliminated.

Conclusions

Subsurface drip irrigation systems were tested for native seed production because they have two potential strategic advantages: low water use and buried drip tape provides water to plants at a depth that precludes irrigation-induced germination of weed seed and keeps water away from native plant tissues not adapted to a wet environment.

Due to the arid environment, supplemental irrigation may often be required for successful flowering and seed set because soil water reserves may be exhausted before seed formation. Total irrigation requirements for these arid-land species were low and varied by species (Table 12). Globemallow species and sharpleaf penstemon did not respond to irrigation in these trials. Natural rainfall was sufficient to maximize seed production in the absence of weed competition.

Fernleaf biscuitroot required approximately 6 inches (152 mm) of irrigation. Gray's biscuitroot, nineleaf biscuitroot, and sulphur-flower buckwheat responded quadratically to irrigation with the optimum varying by year. Scabland penstemon had insufficient plant stands to reliably evaluate its response to irrigation over multiple years.

Table 9. Early season precipitation and growing degree-days at OSU-MES, Ontario, OR, 2006-2013

Year	Precipitation (inches)		Growing degree-days (50-86°F)
	Jan-June	April-June	Jan-June
2006	9.0	3.1	1120
2007	3.1	1.9	1208
2008	2.9	1.2	936
2009	5.8	3.9	1028
2010	8.3	4.3	779
2011	8.3	3.9	671
2012	5.8	2.3	979
2013	2.6	1.4	1118
70-year average	5.8	2.7	1026 ^a

^a27-year average.

Table 10. Native wildflower seed yield response to irrigation rate (inches/season) in 2006, 2007, and 2008 at OSU-MES, Ontario, OR

	2006					2007					2008			
Species	0 inches	4 inches	8 inches	LSD (0.05)		0 inches	4 inches	8 inches	LSD (0.05)		0 inches	4 inches	8 inches	LSD (0.05)
	----- lb/acre -----													
<i>Eriogonum umbellatum</i> ^a	155.3	214.4	371.6	92.9		79.6	164.8	193.8	79.8		121.3	221.5	245.2	51.7
<i>Lomatium dissectum</i> ^d	---- no flowering ----					--- no flowering ---					--- very little flowering ---			
<i>Lomatium grayi</i> ^d	---- no flowering ----					36.1	88.3	131.9	77.7 ^b		393.3	1287.0	1444.9	141.0
<i>Lomatium triternatum</i> ^d	---- no flowering ----					2.3	17.5	26.7	16.9 ^b		195.3	1060.9	1386.9	410.0
<i>Penstemon acuminatus</i> ^a	538.4	611.1	544.0	NS		19.3	50.1	19.1	25.5 ^b		56.2	150.7	187.1	79.0
<i>Penstemon deustus</i> ^c	1246.4	1200.8	1068.6	NS		120.3	187.7	148.3	NS		--- very poor stand ---			
<i>Penstemon speciosus</i> ^a	163.5	346.2	213.6	134.3		2.5	9.3	5.3	4.7 ^b		94.0	367.0	276.5	179.6
<i>Sphaeralcea coccinea</i> ^e						279.8	262.1	310.3	NS		298.7	304.1	205.2	NS
<i>Sphaeralcea grossulariifolia</i> ^e						442.6	324.8	351.9	NS		275.3	183.3	178.7	NS
<i>Sphaeralcea parvifolia</i> ^e						1062.6	850.7	957.9	NS		436.2	569.1	544.7	NS

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

^b Values within the same row and year are significantly different $p=0.10$.

^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 a very poor and uneven stand.

^d Planted March 2005, whole area replanted in October 2005.

^e Planted spring 2006, whole area replanted in November 2006.

Table 11. Native wildflower seed yield in response to irrigation rate (inches/season) from 2009 to 2013 and for 2- to 8-year yield averages at OSU-MES, Ontario, OR.

	2009					2010					2011			
Species	0 inches	4 inches	8 inches	LSD (0.05)		0 inches	4 inches	8 inches	LSD (0.05)		0 inches	4 inches	8 inches	LSD (0.05)
	----- lb/acre -----													
<i>Eriogonum umbellatum</i> ^a	132.3	223	240.1	67.4		252.9	260.3	208.8	NS		248.7	136.9	121.0	90.9
<i>Lomatium dissectum</i> ^d	50.6	320.5	327.8	196.4 ^b		265.8	543.8	499.6	199.6		567.5	1342.8	1113.8	180.9
<i>Lomatium grayi</i> ^d	359.9	579.8	686.5	208.4		1035.7	1143.5	704.8	NS		570.3	572.7	347.6	NS
<i>Lomatium triternatum</i> ^d	181.6	780.1	676.1	177		1637.2	2829.6	3194.6	309.4		1982.9	2624.5	2028.1	502.3 ^b
<i>Penstemon acuminatus</i> ^a	20.7	12.5	11.6	NS		-- Stand disked out --								
<i>Penstemon speciosus</i> ^a	6.8	16.1	9.0	6.0 ^b		147.2	74.3	69.7	NS		371.1	328.2	348.6	NS
<i>Sphaeralcea coccinea</i> ^e	332.2	172.1	263.3	NS		385.7	282.6	372.5	NS		89.6	199.6	60.5	NS
<i>Sphaeralcea grossulariifolia</i> ^e	270.7	298.9	327.0	NS		310.5	351	346.6	NS		224.0	261.9	148.1	NS
<i>Sphaeralcea parvifolia</i> ^e	285.9	406.1	433.3	NS		245.3	327.3	257.3	NS		81.6	142.5	141.2	NS
	2012					2013					2- to 8-year averages			
		4	8					8						
Species	0 inches	inches	inches	LSD (0.05)		0 inches	4 inches	inches	LSD (0.05)		0 inches	4 inches	8 inches	LSD (0.05)
	----- lb/acre -----													
<i>Eriogonum umbellatum</i> ^a	61.2	153.2	185.4	84.4		113.2	230.1	219.8	77.5		146.5	192.9	211.9	32.2
<i>Lomatium dissectum</i> ^d	388.1	460.3	444.4	NS		527.8	959.8	1166.7	282.4		360.0	767.6	710.5	153.1
<i>Lomatium grayi</i> ^d	231.9	404.4	377.3	107.4		596.7	933.4	1036.3	NS		460.5	715.6	675.6	NS
<i>Lomatium triternatum</i> ^d	238.7	603.0	733.2	323.9		153.7	734.4	1050.9	425.0		627.4	1235.7	1299.5	168.2
<i>Penstemon speciosus</i> ^a	103.8	141.1	99.1	NS		8.7	80.7	138.6	63.7		112.5	162.8	144.9	35.9

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

^b Values within the same row and year are significantly different $p=0.10$.

^c Planted March 2005, whole area replanted in October 2005.

^d Planted spring 2006, whole area replanted in November 2006.

^e Planted spring 2006, whole area replanted in November 2006.

Table 12. Regression analysis for native wildflower seed yield response to irrigation rate (inches/season) from 2006 to 2013 at OSU-MES, Ontario, OR. For the quadratic equations, amount of irrigation that resulted in maximum seed yield was calculated using the formula: $-b/2c$, where b is the linear parameter and c is the quadratic parameter.

<i>Eriogonum umbellatum</i>						Maximum yield (lb/acre)	Water applied for maximum yield (inches/season)
Year	intercept	linear	quadratic	R^2	P		
2006	137.9	27.8		0.68	0.01	360.3	8.0
2007	79.6	28.3	-1.8	0.69	0.05	194.0	8.1
2008	121.3	34.6	-2.4	0.73	0.01	246.0	7.2
2009	132.3	31.9	-2.3	0.60	0.05	242.9	6.9
2010	252.9	9.2	-1.8	0.08	NS ^a		
2011	232.7	-16.0		0.58	0.01	232.7	0.0
2012	71.2	15.5		0.61	0.01	195.2	8.0
2013	101.1	33.4	-3.0	0.40	0.10	194.1	5.6
Average	151.0	8.2		0.67	0.01	216.6	8.0
<i>Lomatium dissectum</i>							
2009	86.4	34.6		0.31	0.10	363.2	8.0
2010	265.8	109.8	-10.1	0.68	0.01	564.2	5.4
2011	567.5	319.3	-31.4	0.86	0.001	1379.2	5.1
2012	402.7	7.0		0.04	NS ^a		
2013	565.3	79.9		0.65	0.01	1204.2	8.0
Average	360.0	160.0	-14.5	0.80	0.001	800.7	5.5
<i>Lomatium grayi</i>							
2007	37.5	12.0		0.26	0.10	133.5	8.0
2008	393.3	315.4	-23.0	0.93	0.001	1474.6	6.9
2009	378.7	40.8		0.38	0.05	705.1	8.0
2010	1035.7	95.3	-17.1	0.22	NS		
2011	608.2	-27.8		0.07	NS		
2012	231.9	68.1	-6.2	0.66	0.01	418.9	5.5
2013	635.6	55.0		0.25	0.10	1075.3	8.0
Average	460.5	100.6	-9.2	0.43	0.10	735.2	5.5
<i>Lomatium triternatum</i>							
2007	3.3	3.1		0.52	0.01	27.7	8.0
2008	195.3	283.9	-16.9	0.77	0.01	1387.6	8.4
2009	181.6	237.4	-22.0	0.83	0.001	822.0	5.4
2010	1637.2	401.5	-25.9	0.83	0.001	3193.2	7.8
2011	1982.9	315.1	-38.7	0.45	0.10	2624.3	4.1
2012	277.8	61.8		0.49	0.05	772.2	8.0
2013	211.5	101.8		0.57	0.01	1026.0	8.0
Average	627.4	221.6	-17.4	0.79	0.001	1333.7	6.4
<i>Penstemon speciosus</i>							
2006	163.5	85.1	-9.9	0.66	0.05	346.4	4.3
2007	2.5	3.2	-0.4	0.48	0.10	9.2	4.2
2008	94.1	113.7	-11.4	0.56	0.05	377.6	5.0
2009	6.8	4.4	-0.5	0.54	0.05	16.1	4.2
2010	147.2	29.8	-2.1	0.35	NS		
2011	360.6	-2.8		0.01	NS		
2012	103.8	19.3	-2.5	0.3	NS		
2013	11.0	16.2		0.77	0.001	141.0	8.0
Average	112.5	21.1	-2.1	0.45	0.10	164.8	4.9

^a Not significant; there was no statistically significant difference in yield between the non-irrigated plots and the plots receiving 4 or 8 inches (102 or 203 mm) of water.

Table 13. Amount of irrigation water for maximum native wildflower seed yield, years to seed set, and life span. A summary of multi-year research findings from OSU-MES, Oregon State University, Ontario, OR

Species	Optimum amount of irrigation	Years to first seed set	Life span
	inches/season	from fall planting	years
<i>Eriogonum umbellatum</i>	0 in wet years, 6 to 8 in dry years	1	7+
<i>Lomatium dissectum</i>	5 to 8	4	7+
<i>Lomatium grayi</i>	0 in wet years, 6 to 8 in dry years	2	7+
<i>Lomatium triternatum</i>	4 to 8 depending on precipitation	2	7+
<i>Penstemon acuminatus</i>	no response	1	3
<i>Penstemon speciosus</i>	0 in wet years, 4 to 8 in dry years	1	3
<i>Sphaeralcea coccinea</i>	no response	1	5
<i>Sphaeralcea grossulariifolia</i>	no response	1	5
<i>Sphaeralcea parvifolia</i>	no response	1	5

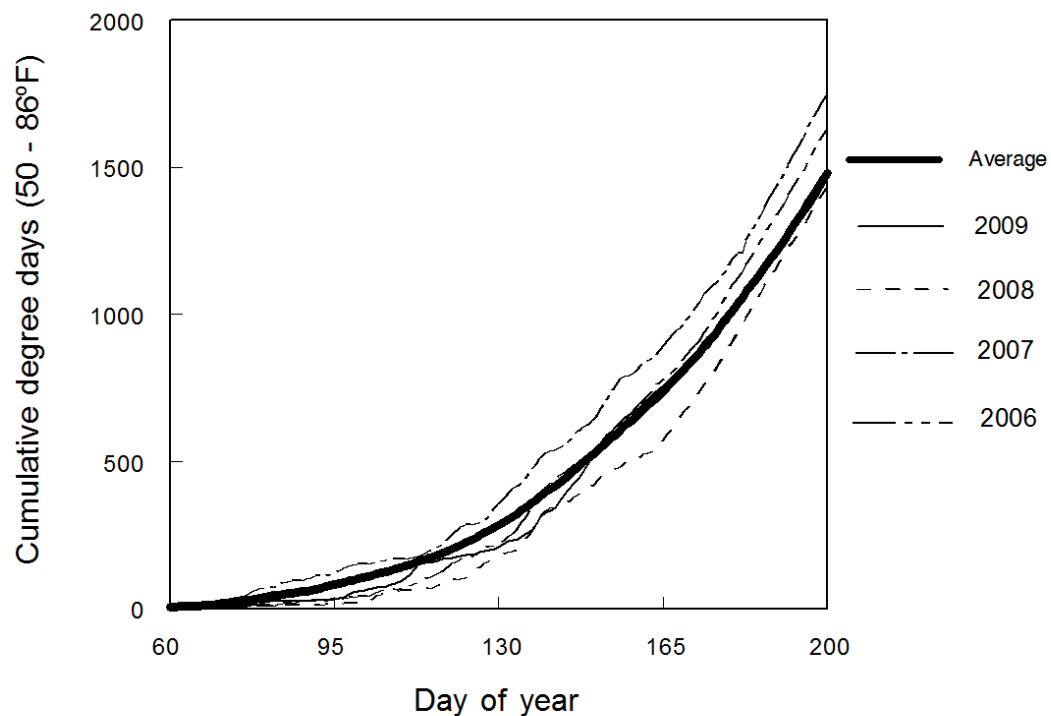


Figure 1. Cumulative annual growing degree-days for 2006-2009 compared with the 23-year average growing degree-days at OSU-MES, Ontario, OR.

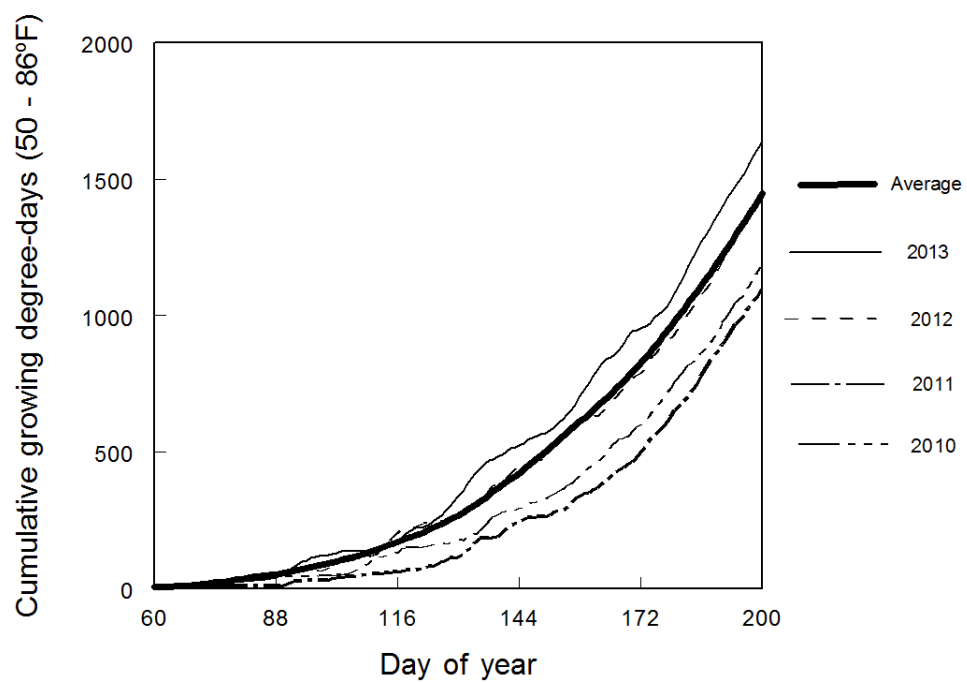


Figure 2. Cumulative annual growing degree-days for 2010-2013 compared with the 23-year average growing degree-days at OSU-MES, Ontario, OR.

C. Irrigation Requirements for Native Wildflower Seed Production for Perennial and Annual Species Planted in Fall of 2009

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Project Description

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 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 and are often not competitive with crop weeds in cultivated fields. Poor competitiveness with weeds could also limit wildflower seed production. Both sprinkler and furrow irrigation could provide supplemental water for seed production, but these irrigation systems risk further encouraging weeds. Also, sprinkler and furrow irrigation can lead to the loss of plant stand and seed production due to fungal pathogens. By burying drip tapes at 12-inch (30 cm) depths and avoiding wetting the soil surface, we hoped to assure flowering and seed set without undue encouragement of weeds or opportunistic diseases. Trials reported here tested the effects of three low rates of irrigation on the seed yield of 11 native wildflower species (Table 14) planted in 2009.

Methods

Plant Establishment

Each wildflower species was planted in four rows 30 inches (76 cm) apart (a 10-foot [3 m] wide strip) about 450 feet (137 m) long on Nyssa silt loam at OSU-MES, Ontario, Oregon. The soil had a pH of 8.3 and 1.1 percent organic matter. In October 2012, two drip tapes 5 feet (1.5 m) apart (T-Tape TSX 515-16-340) were buried at 12-inch (30 cm) depths 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 (41 cm) apart, resulting in a water application rate of 0.066 inch/hour.

On 25 November 2009, seed of nine perennial species (Table 14) was planted in 30-inch (76 cm) rows using a custom-made plot grain drill with disk openers. All seed was planted on the soil surface at 20 to 30 seeds/foot of row. After planting, sawdust was applied in a narrow band over the seed rows at 0.26 oz/ft of row (558 lb/acre). Following planting and sawdust application, 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 2 December 2009 due to very dry soil conditions.

Cultural Practices in 2010

After the newly planted wildflowers emerged in April, the row cover was removed. Irrigation treatments were not applied to these wildflowers in 2010. Stands of blue penstemon (*Penstemon cyaneus*), thistleleaf beardtongue (*P. pachyphyllus*), and parsnipflower buckwheat (*Eriogonum*

heracleoides) were not adequate for an irrigation trial. Gaps in the rows were replanted by hand on 5 November. The replanted seed was covered with a thin layer of a 50:50 mixture by volume of sawdust and hydro seeding mulch (Hydrostraw LLC, Manteno, IL). The mulch mixture was sprayed with water using a backpack sprayer.

On 18 November 2010, seed of Rocky Mountain beeplant (*Cleome serrulata*) was planted as described above.

Cultural Practices in 2011

Seed from the middle two rows in each plot of scabland penstemon (*P. deustus*) and parsnipflower buckwheat was harvested with a small plot combine. Seed from the middle two rows in each plot of the other species was harvested manually. On 11 November 2011, seed of Rocky Mountain beeplant was planted. On 5 December 2011, seed of yellow beeplant (*C. lutea*) was planted as described above. The beeplant species are annuals so they were replanted in new strips of land.

Cultural Practices in 2012

Many areas of the wildflower seed production were suffering from severe iron deficiency early in spring 2012. On 13 April 2012, 50 lb nitrogen (N)/acre, 10 lb phosphorus (P)/acre, and 5 lb iron (Fe)/acre was applied to all plots of barestem biscuitroot (*Lomatium nudicaule*), Hayden's cymopterus (*Cymopterus bipinnatus*), scabland penstemon (*P. deustus*), blue penstemon, and thickleaf beardtongue as liquid fertilizer injected through the drip tape. On 23 April 2012, 5 lb Fe/acre was applied to all plots of scabland penstemon, blue penstemon, thickleaf beardtongue, parsnipflower buckwheat, Searls' prairie clover (*Dalea searlsiae*), Blue Mountain prairie clover (*D. ornata*), and basalt milkvetch (*Astragalus filipes*) as liquid fertilizer injected through the drip tape.

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

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

On 1 November, seed of Rocky Mountain and yellow beeplant was planted on the soil surface at 20 to 30 seeds/foot of row. After planting, sawdust was applied in a narrow band over the seed row. Following planting and sawdust application, the beds were covered with row cover.

Cultural Practices in 2013

On 27 March, row cover was removed and bird netting placed over the Rocky Mountain and yellow beeplant plots to protect seedlings from bird feeding. The bird netting was placed over No. 9 galvanized wire hoops. Bird netting was also placed over Hayden's cymopterus on 29 March to protect new shoots.

Table 14. Wildflower species planted in fall 2009 at OSU-MES, Ontario, OR. All species are perennial except Rocky Mountain and yellow beeplant, which are annuals

Species	Common names	Growth habit
<i>Astragalus filipes</i>	basalt milkvetch	Perennial
<i>Cleome lutea</i>	yellow beeplant	Annual
<i>Cleome serrulata</i>	Rocky Mountain beeplant	Annual
<i>Cymopterus bipinnatus</i> ^a	Hayden's cymopterus	Perennial
<i>Dalea ornata</i>	western prairie clover, Blue Mountain prairie clover	Perennial
<i>Dalea searlsiae</i>	Searls' prairie clover	Perennial
<i>Eriogonum heracleoides</i>	parsnipflower buckwheat	Perennial
<i>Lomatium nudicaule</i>	barestem biscuitroot, barestem lomatium	Perennial
<i>Penstemon deustus</i>	scabland penstemon, hotrock penstemon	Perennial
<i>Penstemon cyaneus</i>	blue penstemon	Perennial
<i>Penstemon pachyphyllus</i>	thickleaf beardtongue	Perennial

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

Irrigation for Seed Production

In April 2011, each strip of each wildflower species was divided into twelve 30-foot (9 m) 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 (25 mm) of water applied per irrigation, and 2 inches (51 mm) of water applied per irrigation. Each treatment received four irrigations that were applied approximately every 2 weeks starting with flowering of the wildflowers. Amount of water applied to each treatment was calculated by the length of time necessary to deliver 1 or 2 inches through the drip system. Irrigations were regulated with a controller and solenoid valves. After each irrigation, the amount of water applied was read on a water meter and recorded to ensure correct water applications.

The drip-irrigation system was designed to allow separate irrigation of the species due to different timings of flowering and seed formation. The three penstemon species were irrigated together, and the two prairie clover species were irrigated together. Parsnipflower buckwheat and basalt milkvetch were irrigated individually. Flowering, irrigation, and harvest dates were recorded (Table 15). Barestem biscuitroot flowered in 2012; irrigation treatments were applied and seed was harvested. Hayden's cymopterus had not flowered as of 2012, and differential irrigation treatments were applied to Hayden's cymopterus starting in 2012.

Soil volumetric water content was measured by a neutron probe. The neutron probe was calibrated by taking soil samples and probe readings at 8-, 20-, and 32-inch (20, 51, and 81 cm) depths during installation of the access tubes. Soil water content was determined volumetrically from the soil samples and regressed against the neutron probe readings for each soil depth. Regression equations were then used to transform the neutron probe readings during the season into volumetric soil water content.

Table 15. Native wildflower flowering, irrigation, and seed harvest dates by species at OSU-MES, Ontario, OR

	Flowering				Irrigation		
Species	start	peak	end		start	end	Harvest
	2011						
<i>Astragalus filipes</i>	20-May	26-May	30-Jun		13-May	23-Jun	18-Jul
<i>Cleome serrulata</i>	25-Jun	30-Jul	15-Aug		21-Jun	2-Aug	26-Sep
<i>Cymopterus bipinnatus</i>		No flowering					
<i>Dalea ornata</i>	8-Jun	20-Jun	20-Jul		27-May	6-Jul	22-Jul
<i>Dalea searlsiae</i>	8-Jun	20-Jun	20-Jul		27-May	6-Jul	21-Jul
<i>Eriogonum heracleoides</i>	26-May	10-Jun	8-Jul		27-May	6-Jul	1-Aug
<i>Lomatium nudicaule</i>		No flowering					
<i>Penstemon cyaneus</i>	23-May	15-Jun	8-Jul		13-May	23-Jun	18-Jul
<i>Penstemon deustus</i>	23-May	20-Jun	14-Jul		13-May	23-Jun	16-Aug
<i>Penstemon pachyphyllus</i>	10-May	30-May	20-Jun		13-May	23-Jun	15-Jul
	2012						
<i>Astragalus filipes</i>	28-Apr	23-May	19-Jun		11-May	21-Jun	5-Jul
<i>Cleome lutea</i>	16-May	15-Jun	30-Jul		2-May	13-Jun	12-Jul to 30-Aug
<i>Cleome serrulata</i>	12-Jun	30-Jun	30-Jul		13-Jun	25-Jul	24-Jul to 30-Aug
<i>Cymopterus bipinnatus</i>		No flowering					
<i>Dalea ornata</i>	23-May	10-Jun	30-Jun		11-May	21-Jun	11-Jul
<i>Dalea searlsiae</i>	23-May	10-Jun	30-Jun		11-May	21-Jun	10-Jul
<i>Eriogonum heracleoides</i>	23-May	30-May	25-Jun		11-May	21-Jun	16-Jul
<i>Lomatium nudicaule</i>	12-Apr	1-May	30-May		18-Apr	30-May	22-Jun
<i>Penstemon cyaneus</i>	16-May	30-May	10-Jun		27-Apr	7-Jun	27-Jun
<i>Penstemon deustus</i>	16-May	30-May	4-Jul		27-Apr	7-Jun	7-Aug
<i>Penstemon pachyphyllus</i>	23-Apr	2-May	10-Jun	27-Apr	7-Jun	26-Jun	
	2013						
<i>Astragalus filipes</i>	3-May	10-May	25-May		8-May	19-Jun	28-Jun
<i>Cymopterus bipinnatus</i>	5-Apr		15-May		12-Apr	22-May	10-Jun
<i>Dalea ornata</i>	13-May	21-May	15-Jun		8-May	19-Jun	28-Jun
<i>Dalea searlsiae</i>	13-May		15-Jun		8-May	19-Jun	29-Jun
<i>Eriogonum heracleoides</i>	29-Apr	13-May	10-Jun		24-Apr	5-Jun	1-Jul
<i>Lomatium nudicaule</i>	11-Apr		20-May		12-Apr	22-May	10-Jun
<i>Penstemon cyaneus</i>	3-May	21-May	5-Jun		24-Apr	5-Jun	11-Jul
<i>Penstemon deustus</i>	3-May	18-May	15-Jun		24-Apr	5-Jun	
<i>Penstemon pachyphyllus</i>	26-Apr		21-May		24-Apr	5-Jun	8-Jul

Results and Discussion

Precipitation from January through July was higher than average in 2011, close to average in 2012, and lower than average in 2013 (Figure 3). The accumulation of growing degree-days (50-86 °F [10-30 °C]) was below average in 2011, close to average in 2012, and higher than average in 2013 (Figure 4).

Flea beetle feeding occurred earlier in 2013 than in 2012. Upon removal of the row cover in March, flea beetle damage to the seedlings of Rocky Mountain and yellow beeplant was extensive, resulting in full stand loss. Harvested seed pods of parsnipflower buckwheat and Searls' and Blue Mountain prairie clover had extensive damage from feeding by seed beetles in 2013, indicating that control measures during and following flowering will be necessary to maintain seed yields.

Blue Penstemon

Seed yields did not respond to irrigation in 2011 (Tables 16 and 17). In 2012, seed yields increased with increased irrigation up to the highest tested of 8 inches (203 mm). In 2013, seed yields showed a quadratic response to irrigation with a maximum seed yield at 4 inches (102 mm) of water applied.

Thickleaf Beardtongue

Seed yields did not respond to irrigation in 2011 and 2012. In 2013, seed yields increased with increasing irrigation up to the highest tested of 8 inches (203 mm).

Parsnipflower Buckwheat

Seed yields did not respond to irrigation in 2011 and 2012. In 2013, seed yields showed a quadratic response to irrigation with a maximum seed yield at 4.9 inches (125 mm) of water applied.

Searls' and Blue Mountain Prairie Clover

In 2011, Searls' prairie clover seed yields were highest with no irrigation. In 2012, seed yields showed a quadratic response to irrigation with a maximum seed yield at 6.6 inches (168 mm) of water applied. In 2013, Searls' prairie clover seed yields increased with increasing irrigation rate up to the highest tested of 8 inches (203 mm).

Blue Mountain prairie clover seed yields did not respond to irrigation in 2011. Seed yields showed a quadratic response to irrigation in 2012 and 2013, with a maximum seed yield at 7.7 and 8.1 inches (196 and 206 mm) of water applied, respectively. Averaged over the 3 years, Blue Mountain prairie clover seed yield increased with increasing irrigation rate up to the highest tested of 8 inches (203 mm).

Basalt Milkvech, Barestem Lomatium, and Hayden's Cymopterus

Basalt milkvech seed yields did not respond to irrigation in any year from 2011 through 2013. Barestem lomatium seed yields did not respond to irrigation in either 2012 or 2013. Hayden's cymopterus seed yields did not respond to irrigation in 2013.

Rocky Mountain and Yellow Beeplant

In 2011, Rocky Mountain beeplant seed yields increased with increased irrigation up to the highest tested of 8 inches (203 mm). Seed yields did not respond to irrigation in 2012. Averaged over 2 years, Rocky Mountain beeplant seed yield increased with increasing irrigation rate up to the highest tested. There was no plant stand in 2013.

Yellow beeplant seed yields did not respond to irrigation in 2012. There was no plant stand in 2013. Early attention to flea beetle control is essential for beeplant seed production.

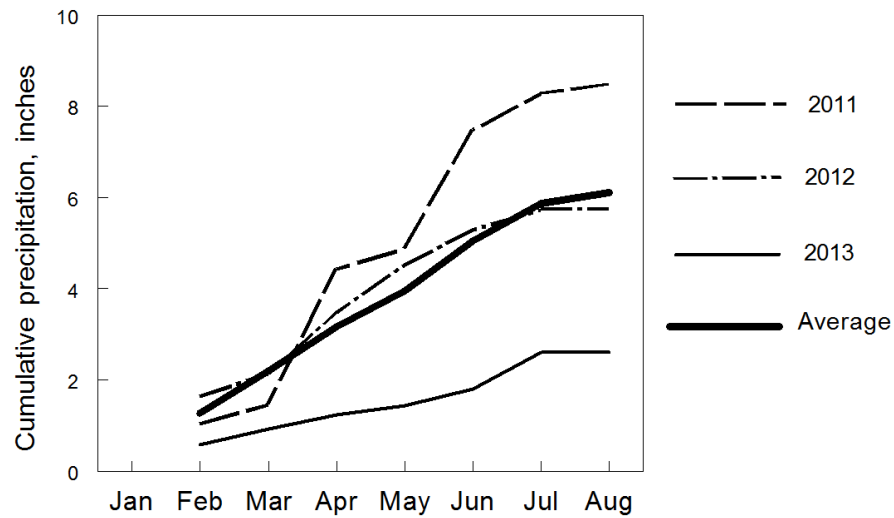


Figure 3. Cumulative annual and 66-year average precipitation from January through July at OSU-MES, Ontario, OR.

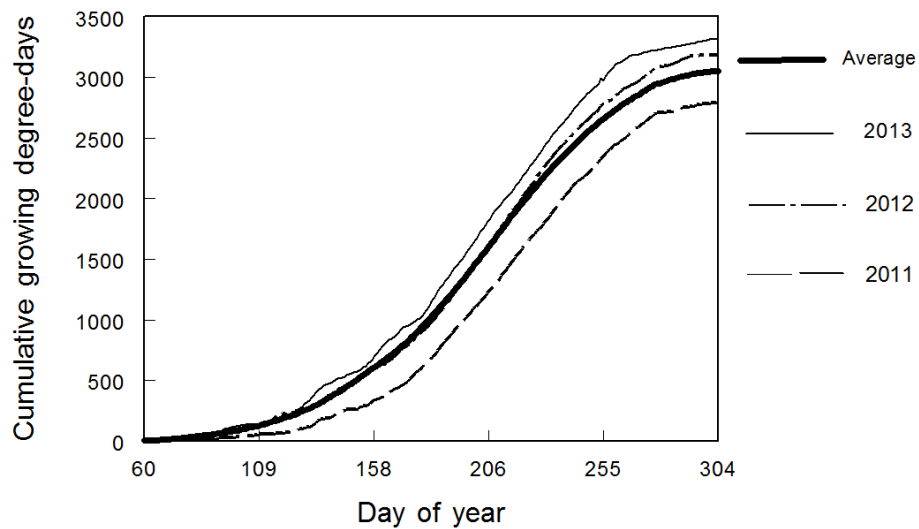


Figure 4. Cumulative growing degree-days (50-86 °F [10-30 °C]) for selected years and 23-year average at OSU-MES, Ontario, OR.

Table 16. Native wildflower seed yield response to irrigation rate (inches/season) at OSU-MES, Ontario, OR

Species	2011					2012			
	0 inches	4 inches	8 inches	LSD (0.05)		0 inches	4 inches	8 inches	LSD (0.05)
	----- lb/acre -----					----- lb/acre -----			
<i>Astragalus filipes</i>	87.0	98.4	74.0	NS		22.7	12.6	16.1	NS
<i>Cleome lutea</i>						111.7	83.7	111.4	NS
<i>Cleome serrulata</i>	446.5	499.3	593.6	100.9 ^b		184.3	162.9	194.7	NS
<i>Dalea ornata</i>	451.9	410.8	351.7	NS		145.1	365.1	431.4	189.3
<i>Dalea searlsiae</i>	262.7	231.2	196.3	50.1		175.5	288.8	303.0	93.6
<i>Eriogonum heracleoides</i>	55.2	71.6	49.0	NS		252.3	316.8	266.4	NS
<i>Lomatium nudicaule</i>						53.8	123.8	61.1	NS
<i>Penstemon cyaneus</i>	857.2	821.4	909.4	NS ^a		343.3	474.6	581.2	202.6 ^b
<i>Penstemon deustus</i>	637.6	477.8	452.6	NS		308.7	291.8	299.7	NS
<i>Penstemon pachyphyllus</i>	569.9	337.6	482.2	NS		280.5	215.0	253.7	NS
	2013					Average			
Species	0 inches	4 inches	8 inches	LSD (0.05)		0 inches	4 inches	8 inches	LSD (0.05)
	----- lb/acre -----					----- lb/acre -----			
<i>Astragalus filipes</i>	8.5	9.8	6.1	2.7		39.4	24.0	32.1	NS
<i>Cleome lutea</i>						111.7 ^d	83.7 ^d	111.4 ^d	NS
<i>Cleome serrulata</i>						315.4 ^c	331.1 ^c	349.2 ^c	NS
<i>Cymopterus bipinnatus</i>	194.2	274.5	350.6	NS		194.2 ^d	274.5 ^d	350.6 ^d	NS
<i>Dalea ornata</i>	28.6	104.6	130.4	38.8		208.5	293.5	304.5	64.2 ^b
<i>Dalea searlsiae</i>	14.8	31.7	44.4	6.1		151.0	183.9	181.2	NS
<i>Eriogonum heracleoides</i>	287.4	516.9	431.7	103.2		198.3	301.7	249.0	NS
<i>Penstemon cyaneus</i>	221.7	399.4	229.2	74.4		474.1	565.1	573.2	NS
<i>Penstemon deustus</i>						512.7 ^c	403.1 ^c	374.2 ^c	NS
<i>Penstemon pachyphyllus</i>	159.4	196.8	249.7	83.6		336.6	249.8	328.5	NS
<i>Lomatium nudicaule</i>	357.6	499.1	544.0	NS		205.7 ^c	311.5 ^c	302.6 ^c	NS

^a Not significant.

^b LSD (0.10).

^c Two-year average.

^d Only one year of data.

Table 17. Regression parameters for native wildflower seed yield in response to irrigation rate (inches/season) at OSU-MES, Ontario, OR; 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

Year	Intercept	Linear	Quadratic	R^2	P	Estimated maximum yield	Water applied for estimated maximum yield
<i>Astragalus filipes</i>							inches/season
2011	90.6	-1.6		0.01	NS ^a	90.6	0
2012	19.7	-0.8		0.04	NS	19.7	0
2013	9.3	-0.3		0.1	NS	9.3	0
Average	35.5	-0.9		0.02	NS	39.9	0
<i>Cymopterus bipinnatus</i>							
2013	194.9	19.6		0.07	NS	No resp. ^b	
<i>Cleome lutea</i>							
2012	102.4	-0.031		0.01	NS	102.4	0
<i>Cleome serrulata</i>							
2011	439.6	18.4		0.35	0.05	586.7	8
2012	175.4	1.3		0.01	NS	No resp. ^b	
Average	307.5	9.8		0.33	0.05	386.3	8
<i>Dalea ornata</i>							
2011	454.9	-12.5		0.11	NS	454.9	
2012	145.1	74.2	-4.8	0.65	0.01	431.8	7.7
2013	28.6	25.3	-1.6	0.88	0.001	130.4	8.1
Average	220.9	12.0		0.37	0.05	316.8	8.0
<i>Dalea searlsiae</i>							
2011	263.3	-8.3		0.49	0.05	263.3	0
2012	175.5	40.7	-3.1	0.62	0.05	309.3	6.6
2013	15.5	3.7		0.54	0.01	45.1	8.0
Average	156.9	3.8		0.22	NS		
<i>Eriogonum heracleoides</i>							
2011	61.7	-0.8		0.01	NS	61.7	0
2012	271.5	1.8		0.01	NS	No resp. ^b	
2013	287.4	96.7	-9.8	0.64	0.05	525.1	4.9
Average	166.6	0.5		0.01	NS		
<i>Lomatium nudicaule</i>							
2012	75.9	0.9		0.01	NS	No resp. ^b	
2013	373.7	23.3		0.1	NS	No resp. ^b	
Average	224.8	12.1		0.07	NS		
<i>Penstemon pachyphyllus</i>							
2011	507.1	-11.0		0.04	NS	507.1	0
2012	263.1	-3.3		0.01	NS	263.1	0
2013	156.8	11.3		0.33	0.10	247.2	8.0
Average	385.1	-7.2		0.03	NS		

^aNot significant; there was no statistically significant difference in yield between the non-irrigated plots and the plots receiving 4 or 8 inches (102 or 203 mm) of water.

^bNo response.

D: Irrigation Requirements of Annual Native Wildflower Species for Seed Production, Fall 2012 Planting

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Project Description

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 multiple years.

In natural rangelands, the natural variations in rainfall modify the emergence and establishment of annual wildflowers. Spring rainfall and soil moisture result in highly unpredictable water stress at flowering, seed set, and seed development, which are factors known to compromise seed yield and quality for other seed crops.

Native wildflower plants may not be well adapted to croplands and are often not competitive with crop weeds in cultivated fields. Poor competitiveness with weeds could limit wildflower seed production. Both sprinkler and furrow irrigation could provide supplemental water for seed production, but these irrigation systems risk further encouraging weeds. Also, sprinkler and furrow irrigation can lead to the loss of plant stand and seed production due to fungal pathogens. By burying drip tapes at 12-inch (30 cm) depths and avoiding wetting the soil surface, we hoped to assure flowering and seed set without undue encouragement of weeds or opportunistic diseases. The trials reported here tested the effects of three low rates of irrigation on the 2013 seed yield of 11 native wildflower species (Table 18) planted in fall 2012.

Methods

Plant Establishment

Each wildflower species was planted in four rows 30 inches (76 cm) apart (a 10-foot [3 m] wide strip) about 450 feet (137 m) long on Nyssa silt loam at OSU-MES, Ontario, Oregon. The soil had a pH of 8.3 and 1.1 percent organic matter. In October 2012, two drip tapes 5 feet (1.5 m) apart (T-Tape TSX 515-16-340) were buried at 12-inch (30 cm) depths to irrigate the four rows in each 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 (41 cm) apart, resulting in a water application rate of 0.066 inch/hour.

On 30 October 2012, seed of 11 species (Table 18) was planted in 30-inch (76 cm) rows using a custom-made plot grain drill with disk openers. All seed was planted on the soil surface at 20 to 30 seeds/foot of row. After planting, sawdust was applied in a narrow band over the seed row at 0.26 oz/ft of row (558 lb/acre). Following planting and sawdust application, the beds were covered with row cover. The row cover (N-sulate, DeWitt Co., Inc., Sikeston, MO) covered four rows (two beds) and was applied with a mechanical plastic mulch layer.

Cultural Practices in 2013

Starting on 29 March, the row cover was removed. Immediately following the removal of the row cover, bird netting was placed over the seedlings to prevent bird feeding on young seedlings and new shoots. The bird netting was placed over No. 9 galvanized wire hoops. During seedling

emergence, wild bird seed was placed several hundred feet from the trial to attract quail away from the trials. On 26 July, all plots of hoary tansyaster (*Machaeranthera canescens*) were sprayed with Capture at 19 oz/acre (0.3 lb ai/acre) for aphid control.

Table 18. Wildflower species planted in fall 2012 at OSU-MES, Ontario, OR

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

Irrigation for Seed Production

In March 2013, the strip of each wildflower species was divided into twelve 30-foot (9 m) long plots. Each plot contained four rows of each species. The experimental design for each species was a randomized complete block with four replicates. The three treatments were a non-irrigated check, 1 inch (25 mm) of water per irrigation, and 2 inches (51 mm) of water per irrigation. Each treatment received four irrigations that were applied approximately every 2 weeks starting with flowering of the wildflowers. The amount of water applied to each treatment was calculated by the length of time necessary to deliver 1 or 2 inches through the drip system. Irrigations were regulated with a controller and solenoid valves.

The drip-irrigation system was designed to allow separate irrigation of each species due to different timings of flowering and seed formation. All species were irrigated separately except for the two phacelia (*Phacelia* spp.) and the two licorice-root (*Ligusticum* spp.) Flowering, irrigation, and harvest dates were recorded (Table 19) with the exception of coyote tobacco (*Nicotiana attenuata*), which did not germinate and the licorice-root species, which did not flower.

Table 19. Native wildflower flowering, irrigation, and seed harvest dates in 2013 by species from experiments conducted at OSU-MES, Ontario, OR

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

^a Seeds from plants grown in the 0- and 8-inch pots did not ripen at the same time.

Results and Discussion

Precipitation from January through July in 2013 was 2.6 inches (66 mm), below the 66-year average of 6.1 inches (155 mm) (Figure 5). The accumulation of growing degree-days (50-86 °F [10-30 °C]) was higher than average in 2013 (Figure 6).

Stands of Douglas' dustymaiden (*Chaenactis douglasii*), coyote tobacco (*Nicotiana attenuata*), Porter's licorice-root (*L. porteri*), and Canby's licorice-root (*L. canbyi*) were poor and uneven, not permitting evaluation of irrigation responses. Manyflower thelypody (*Thelypodium milleflorum*) is a biennial and scarlet gilia (*Ipomopsis aggregata*) had very little flowering in 2013, perhaps also a biennial in this trial.

Seed yields of hoary tansyaster, silverleaf phacelia (*Phacelia hastata*), and threadleaf phacelia (*P. linearis*) showed a quadratic response to irrigation rate (Tables 20 and 21). Seed yields were estimated to be maximized by a seasonal total of 2.4, 5.4, and 6.2 inches (61, 137, and 158 mm) of applied water for hoary tansyaster, silverleaf phacelia, and threadleaf phacelia, respectively. Seed yield of nakedstem sunray (*Enceliopsis nudicaulis*) was very low and was not responsive to irrigation. Seed yield of showy goldeneye (*Heliomeris multiflora*) increased with increasing irrigation rate up to the highest tested of 8 inches (203 mm) (Tables 20 and 21).

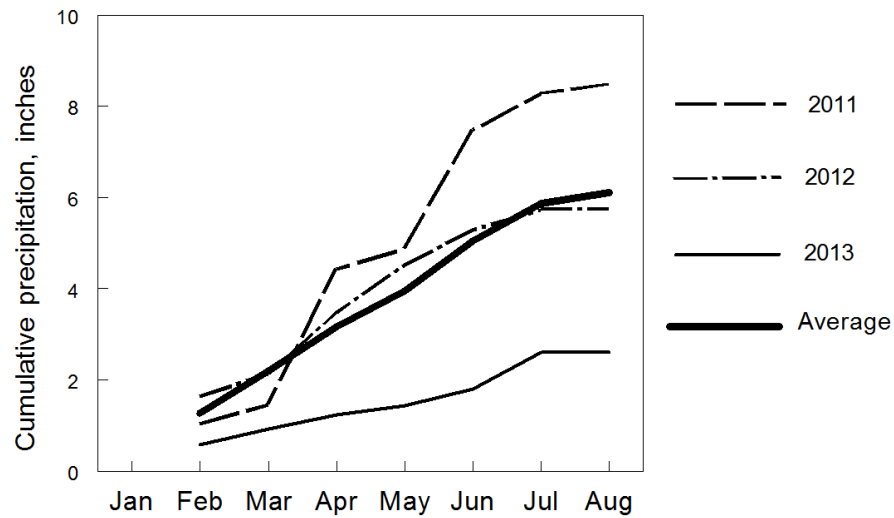


Figure 5. Cumulative annual and 66-year average precipitation from January through July at OSU-MES, Ontario, OR.

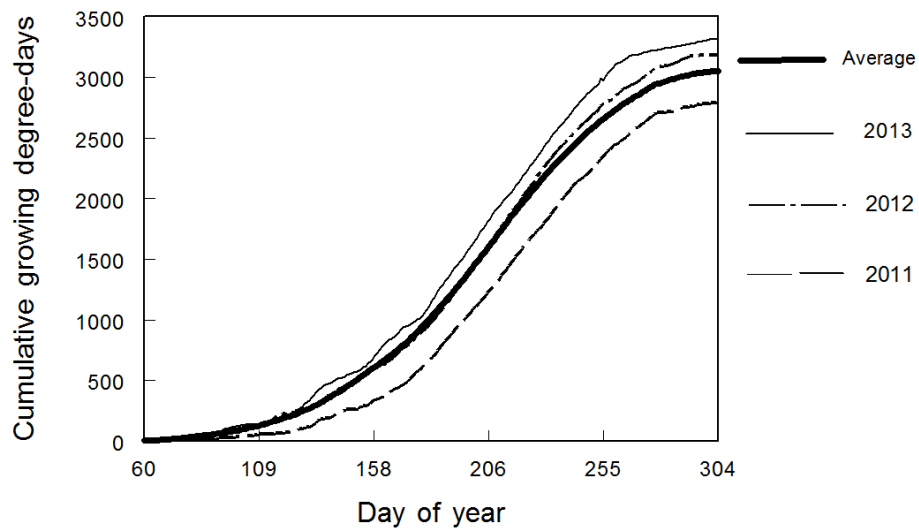


Figure 6. Cumulative growing degree-days (50-86 °F [10-30 °C]) for selected years and 23-year average at OSU-MES, Ontario, OR.

Table 20. Native wildflower seed yield response to season-long irrigation rates (inches) at OSU-MES, Ontario, OR

Species	----- Irrigation -----			LSD (0.05)
	0 in	4 in	8 in	
	----- lb/acre -----			
<i>Enceliopsis nudicaulis</i>	2.3	6.8	5.9	NS
<i>Heliomeris multiflora</i>	28.7	57.6	96.9	NS
<i>Machaeranthera canescens</i>	206.1	215.0	124.3	73.6
<i>Phacelia hastata</i>	35.3	102.7	91.2	35.7
<i>Phacelia linearis</i>	121.4	306.2	314.2	96.0

Table 21. Regression parameters for native wildflower seed yield response to irrigation rate (inches/season) at OSU-MES, Ontario, OR. 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.

Species	Intercept	Linear	Quadratic	R^2	P	Estimated maximum yield lb/acre	Water applied for estimated maximum yield inches/season
<i>Enceliopsis nudicaulis</i>	3.1	0.4		0.16	NS ^a		
<i>Heliomeris multiflora</i>	27.0	8.5		0.38	0.05	95.1	8.0
<i>Machaeranthera canescens</i>	206.1	14.7	-3.1	0.54	0.05	223.4	2.4
<i>Phacelia linearis</i>	121.4	68.3	-5.5	0.69	0.01	332.5	6.2
<i>Phacelia hastata</i>	35.3	26.7	-2.5	0.66	0.01	107.7	5.4

^aNot significant; there was no statistically significant difference in yield between the non-irrigated plots and the plots receiving 4 or 8 inches (102 or 203 mm) of water.

E: Tolerance of Native Wildflower Seedlings to Preemergence and Postemergence Herbicides

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Project Description

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 seed is weed competition. Weeds are adapted to growing in disturbed soil, and native wildflowers are not competitive with these weeds. The use of preemergence and postemergence herbicides for wildflower weed control is important, because wildflowers are fall planted. Fall planting results in nearly simultaneous wildflower and weed emergence early in the spring, complicating weed control. There is considerable knowledge about the relative efficacy of different herbicides to control target weeds, but few trials have tested the tolerance of native wildflowers to commercial herbicides. Two trials in 2013 tested the tolerance of 11 wildflower species to preemergence and postemergence herbicides.

This work sought to discover products that could eventually be registered for use for native wildflower seed production. The information in this report is for the purpose of informing cooperators and colleagues in other agencies, universities, and industries of the research results. Reference to products and companies in this publication is for their specific information only and does not endorse or recommend that product or company to the exclusion of others that may be suitable. Nor should any information and interpretation thereof be considered as recommendations for the application of any of these herbicides. Pesticide labels should always be consulted before any pesticide use. Considerable efforts may be required to register these herbicides for use in native wildflower seed production.

Methods

The trials were conducted on a field of Nyssa silt loam with a pH of 8.3 and 1.1 percent organic matter where wheat was the previous crop. After the wheat harvest in fall 2012, the stubble was flailed and the field was plowed, disked, and groundhogged.

Before planting, drip tape (T-Tape TSX 515-16-340) was buried at 12-inch (30 cm) depths midway between each pair of 30-inch (76 cm) rows. The flow rate for the drip tape was 0.34 gal/min/100 ft at 8 psi with emitters spaced 16 inches (41 cm) apart, resulting in a water application rate of 0.066 inch/hour.

Seed of 11 wildflower species (Table 22) was planted on the soil surface on 27 November at 30 seeds/foot of row. After planting, a thin layer of sawdust was applied over the seed row. The sawdust was applied at approximately 0.18 oz per foot of row (198 lb per acre). Row cover (N-sulate, DeWitt Co., Inc., Sikeston, MO 63801) that covered 4 rows was applied with a mechanical plastic mulch layer after planting. The field was divided in two. One half of the field was used for a preemergence herbicide trial and the other half was dedicated to a post emergence

trial. Each half of the field was divided into plots which consisted of 11 single rows 5 feet (1.5 m) long with one wildflower species planted per row.

Procedures for Preemergence Trial

The experimental design was a randomized complete block with 13 herbicide treatments (Table 22) replicated 4 times. For the treatments receiving charcoal, the charcoal was applied on 28 November in a narrow band over the seed row that had been covered with sawdust. Charcoal was applied using a CO₂ sprayer with a 5-foot (1.5 m) boom and 8008 nozzles spraying at 10 PSI. The sprayer boom was oriented parallel to the seed row. Charcoal was mixed at 23 grams of charcoal per gallon of water and applied at a rate of 189 pounds of charcoal per treated acre and 3,675 gallons of water per treated acre. The herbicides were broadcast following the charcoal application using the same CO₂ sprayer but spraying at 30 PSI, applying 20 gallons per acre. Row cover was applied after the herbicide application. On 24 April 2013, the row cover was removed and stand counts were made in each plot.

Procedures for Postemergence Trial

The experimental design was a randomized complete block with 9 herbicide treatments (Table 24) replicated 4 times. Each plot consisted of 11 single rows 5 feet (1.5 m) long with one wildflower species planted per row. On 24 April 2013, the row cover was removed and stand counts were made in each plot. On 26 April, the treatments were broadcast using the same CO₂ sprayer described above at 30 PSI applying 20 gallons per acre. On 14 May, stand counts and subjective plant damage ratings were made in each plot.

General Considerations

The focus of the evaluations was wildflower tolerance to the herbicides, not weed control, so weeds were removed as needed.

Treatment differences were compared using ANOVA and protected least significant differences at the 95 percent confidence level (LSD 0.05) using NCSS Number Cruncher software (NCSS, Kaysville, UT).

Results and Discussion

The weather during the winter and spring of 2012 was relatively dry, not favoring stand establishment. Even weed emergence was erratic.

All observations made on the herbicides tested are strictly preliminary observations. Herbicides that damaged wildflowers as reported here might be helpful if used at a lower rate or in a different environment. The herbicides were relatively safe in this trial but they might be harmful if used at higher rates or in a different environment. Nothing in this report should be construed as a recommendation.

Response to Preemergence Herbicides

Emergence was not uniform between replicates, complicating the interpretation of results. Weed pressure was too poor and not uniform enough to allow any estimates of the relative effectiveness of herbicide weed control. Emergence for threadleaf phacelia (*Phacelia linearis*), showy goldeneye (*Heliomeris multiflora*), coyote tobacco (*Nicotiana attenuata*), cleftleaf wildheliotrope (*P. crenulata*), and Porter's licorice-root (*Ligusticum porteri*) was extremely poor, and data is not presented. Emergence for manyflower thelypodium (*Thelypodium*

milleflorum) and Canby's licorice-root (*L. canbyi*) was too poor to result in statistically significant differences.

For Douglas' dustymaiden (*Chaenactis douglasii*), common woolly sunflower (*Eriophyllum lanatum*), manyflower thelypody and Canby's licorice-root none of the herbicides significantly reduced emergence compared to the check (Table 25). For Douglas' dustymaiden, plant stands following treatment with Eptam plus charcoal were statistically greater than the untreated check treatment. For hoary tansyaster, only Prowl without charcoal, Outlook without charcoal, and Treflan significantly reduced stands compared to check treatment. For silverleaf phacelia (*Phacelia hastata*), many products tested significantly reduced emergence compared to untreated check. For Douglas' dustymaiden, Eptam with charcoal resulted in higher emergence than Eptam without charcoal, but charcoal provided no benefits for the Prowl or Dual Magnum treatments. For hoary tansyaster, Prowl with charcoal resulted in higher emergence than Prowl without charcoal, but charcoal provided no benefits for the Eptam or Dual Magnum treatments. Charcoal application did not significantly improve emergence for any other species plus herbicide combinations tested.

Response to Postemergence Herbicides

Postemergence herbicides were evaluated on 26 April 26 (Table 26). Buctril resulted in significantly higher injury than the untreated check for all species tested, except the licorice-root (*Ligusticum* spp.) for which poor stand development did not allow for injury evaluation. Aim resulted in significantly higher injury than the check for all species tested, except for the licorice-root species for which poor stand did not allow for injury evaluation. Buctril resulted in significantly higher stand loss than the check for silverleaf phacelia, showy goldeneye, manyflower thelypody, Canby's licorice-root, and Porter's licorice-root. Aim resulted in significantly higher stand loss than the check for silverleaf phacelia, showy goldeneye, and manyflower thelypody. Raptor and Chateau resulted in significantly higher stand loss than the check for manyflower thelypody. Goal Tender, Select Max, Prowl H₂O, and Outlook did not result in higher injury or stand loss than the check for any species.

Conclusions

These results, while preliminary, suggest that some of the herbicides tested in these trials could be used for weed control in wildflower seed production. Charcoal was an effective safening agent for certain species-herbicide combinations. For additional information regarding the use of charcoal to reduce the toxicity of preemergent herbicides, please see

Felix, J.; Ishida, J. 2010. Use of activated charcoal to detoxify Dual Magnum and Outlook applied pre-emergence on direct-seeded onions. Malheur Experiment Station Annual Report 2009: 115-118.

Table 22. Wildflower species planted in fall 2012 in herbicide trials conducted at OSU-MES, Ontario, OR

Species	Common name
<i>Chaenactis douglasii</i>	Douglas' dustymaiden
<i>Eriophyllum lanatum</i>	common woolly sunflower, Oregon sunshine
<i>Heliomeris multiflora</i> var. <i>nevadensis</i>	showy goldeneye
<i>Ligusticum canbyi</i>	Canby's licorice-root
<i>Ligusticum porteri</i>	Porter's licorice-root
<i>Machaeranthera canescens</i>	hoary tansyaster
<i>Nicotiana attenuata</i>	coyote tobacco
<i>Phacelia crenulata</i> var. <i>congesta</i>	clefleaf wildheliotrope
<i>Phacelia hastata</i>	silverleaf phacelia
<i>Phacelia linearis</i>	threadleaf phacelia
<i>Thelypodium milleflorum</i>	manyflower thelypody

Table 23. Preemergence herbicide treatments applied in fall 2012 following fall planting of native wildflowers at OSU-MES, Ontario, OR

Treatment	Herbicide	Charcoal	Rate (lbs ai/acre)
1	Check	no	none
2	Prowl	no	0.95
3	Outlook	no	0.84
4	Eptam	no	2.60
5	Dual Magnum	no	0.95
6	Prowl	yes	0.95
7	Outlook	yes	0.85
8	Eptam	yes	2.60
9	Dual Magnum	yes	0.95
10	Treflan	no	0.38
11	Balan	no	1.20
12	Prefar	no	5.00

Table 24. Postemergence herbicide treatments applied in spring 2013 following fall planting of native wildflowers at OSU_MES, Ontario, OR

Treatment	Activity	Rate	
		oz/acre	lb ai/acre
Buctril	foliar	8.0	0.12
Goal Tender	soil/foliar	2.0	0.06
Select max	foliar	6.0	0.05
Prowl H ₂ O	soil	32.0	0.95
Outlook	soil	18.0	0.85
Aim	foliar	1.0	0.02
Chateau	soil/foliar	1.5	0.05
Raptor	soil/foliar	4.0	0.03

Table 25. Plant stand of native wildflowers on 24 April 2013 in response to preemergence herbicide treatments with and without charcoal applied in the fall of 2012 to fall planted seed at OSU_MES, Ontario, OR

Herbicide	Rate	Charcoal	<i>Chaenactis douglasii</i>	<i>Machaeranthera canescens</i>	<i>Phacelia hastata</i>	<i>Eriophyllum lanatum</i>	<i>Thelypodium milleflorum</i>	<i>Ligusticum canbyi</i>	Average
	(lbs ai/acre)		----- Stand, % emergence -----						
Check	none	no	27.5	46.3	30.0	24.5	21.0	8.8	26.3
Prowl	0.95	no	30.8	23.0	10.5	24.0	5.0	13.3	17.8
Outlook	0.84	no	6.8	8.5	5.8	5.8	5.5	3.3	5.9
Eptam	2.6	no	22.3	62.8	25.0	15.0	9.8	4.8	23.3
Dual Magnum	0.95	no	32.5	55.5	0.3	14.0	5.5	8.0	19.3
Prowl	0.95	yes	14.5	65.3	18.3	13.8	11.8	15.3	23.1
Outlook	0.85	yes	20.5	22.5	9.3	14.3	12.0	7.3	14.3
Eptam	2.60	yes	47.0	45.0	8.5	15.8	11.0	6.3	22.3
Dual Magnum	0.95	yes	31.0	49.3	15.3	28.8	16.3	3.8	24.0
Treflan	0.38	no	33.3	22.0	7.5	34.0	5.5	12.0	19.0
Balan	1.20	no	30.5	42.8	6.8	21.0	8.5	5.8	19.2
Prefar	5.00	no	29.0	43.5	14.5	15.5	8.5	13.0	20.7
		Average	27.1	40.5	12.6	18.9	10.0	8.4	19.6
LSD (0.05) Treatment									13.8
LSD (0.05) Species									5.9
LSD (0.05) Treatment × Species									20.4

Table 26. Native wildflower stand loss and subjective evaluation of injury (0 = no injury, 10 = highest injury) in response to postemergence herbicide treatments applied on 26 April to fall-planted seed at OSU-MESOntario, OR

	<i>Chaenactis douglasii</i>		<i>Machaeranthera canescens</i>		<i>Phacelia hastata</i>		<i>Eriophyllum lanatum</i>		Average	
Treatment	Injury	Stand loss	Injury	Stand loss	Injury	Stand loss	Injury	Stand loss	Injury	Stand loss
	0 - 10	%	0 - 10	%	0 - 10	%	0 - 10	%	0 - 10	%
Untreated	0.0	4.8	0.0	4.3	0.0	3.4	0.0	3.8	0.7	6.6
Buctril	2.0	7.8	2.3	0.0	3.7	43.3	4.0	22.3	3.9	31.7
Goal Tender	0.0	1.3	0.0	4.6	0.5	13.5	1.0	3.8	1.1	9.1
Select max	0.0	2.5	0.0	8.6	0.0	5.0	0.0	22.8	0.8	10.0
Prowl H ₂ O	0.0	9.0	0.0	10.7	0.0	21.5	0.0	0.0	0.4	10.8
Outlook	0.0	5.6	0.0	1.6	0.0	0.0	0.0	13.2	0.6	11.5
Aim	2.4	5.4	3.2	4.1	7.0	52.8	7.5	16.7	4.5	22.1
Chateau	0.0	2.3	0.0	2.7	1.7	4.2	1.3	14.0	1.2	14.7
Raptor	0.0	13.3	0.3	8.2	5.0	6.7	0.0	5.6	2.6	12.9
Average	0.5	5.8	0.6	5.0	2.0	16.2	1.5	11.4	1.8	14.4
	<i>Heliomeris multiflora</i>		<i>Thelypodium milleflorum</i>		<i>Ligusticum porteri</i>		<i>Ligusticum canbyi</i>		Average	
Untreated	0.0	4.0	2.5	12.2	1.0	12.5	4.0	8.5	0.7	6.6
Buctril	4.0	33.3	6.5	59.3	0.0	51.7	0.0	41.7	3.9	31.7
Goal Tender	0.0	0.0	3.7	27.7	1.0	19.6	5.0	0.0	1.1	9.1
Select max	0.0	7.1	2.8	26.0	2.0	0.0	4.0	6.3	0.8	10.0
Prowl H ₂ O	0.0	12.5	2.3	11.0	0.0	17.8	2.0	8.3	0.4	10.8
Outlook	0.0	12.5	3.0	27.9	1.0	16.7	1.5	15.5	0.6	11.5
Aim	4.5	40.5	4.2	39.6	0.0	8.3	0.0	21.4	4.5	22.1
Chateau	0.0	0.0	3.0	43.8	3.0	21.3	0.0	25.0	1.2	14.7
Raptor	0.0	0.0	7.7	37.5	5.0	22.2	5.0	5.1	2.6	12.9
Average	0.9	12.2	4.0	31.7	1.4	18.9	2.4	14.6	1.8	14.4
LSD (0.05) Treatment									NS	8.0
LSD (0.05) Species									0.5	7.6
LSD (0.05) Treatment × Species									1.4	22.9

Publications

Annual Reports

Shock, C. C.; Feibert, E. B. G.; Saunders, L.,D.; Johnson, D.; Bushman, S. 2013. Direct surface seeding strategies for the establishment of two native legumes of the Intermountain West. In: Shock, C. C., ed. Oregon State University Agricultural Experiment Station, Malheur Experiment Station Annual Report 2012, Department of Crop and Soil Science Ext/CrS 144. p. 132-137.

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Shock, C. C.; Feibert, E. B. G.; Saunders, L.,D.; Shaw, N.; Sampangi, R. S. 2013. Preliminary estimates of the irrigation requirements for novel native wildflower seed production. In: Shock, C. C., ed. Oregon State University Agricultural Experiment Station, Malheur Experiment Station Annual Report 2012, Department of Crop and Soil Science Ext/CrS 144. p. 160-172.

Shock, C. C.; Feibert, E. B. G.; Saunders, L.,D.; Shaw, N. 2013. Tolerance of sulphur-flower buckwheat (*Eriogonum umbellatum*) to rates and mixtures of postemergence herbicides. In: Shock, C. C., ed. Oregon State University Agricultural Experiment Station, Malheur Experiment Station Annual Report 2012, Department of Crop and Soil Science Ext/CrS 144. p 173-175.

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<http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/37461/em8782.pdf>

Shock, C. C.; Welch, T. 2013. El riego por goteo: una introducción. Tecnicas para la agricultura sostenible, Oregon State University Extension Service, Corvallis. EM 8782-S. 9 p. Available:
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Shock, C. C.; Feibert, E. B. G.; Saunders, L. D.; Shaw, N. 2013. Tolerance of three Great Basin wildflower species to rates and mixtures of postemergence herbicides. 2nd National Native Seed Conference; 2013 April 8-11; Santa Fe, NM.

Shock, C. C.; Feibert, E. B. G.; Saunders, L.,D.; Parris, C.A.; Shaw, N. L. 2013. Planting systems for improved stands of Great Basin native perennials. 2nd National Native Seed Conference; 2013 April 8-11; Santa Fe, NM.

Field days

Feibert, E. B. G.; Shock, C. C. 2013. Establishing wildflower plantings. Native Wildflower Seed Production Field Day; 2013 May 23; Oregon State University Malheur Experiment Station, Ontario, OR.

Feibert, E. B. G.; Felix, J.; Shock, C. C. 2013. Weed control for native wildflowers. Native Wildflower Seed Production Field Day; 2013 May 23; Oregon State University Malheur Experiment Station, Ontario, OR.

Shock, C. C.; Feibert, E. B. G. 2013. Low irrigation water needs of native wildflowers. Native Wildflower Seed Production Field Day; 2013 May 23; Oregon State University Malheur Experiment Station, Ontario, OR.

Shock, C. C.; Larsen, L.; Klauzer, J. 2013. Irrigation efficiency and water quality. Summer Farm Festival and Field Day; 2013 July 10; Oregon State University Malheur Experiment Station, Ontario, OR.

Shock, C. C.; Feibert, E. B. G. 2013. Wildflower and native plant seed production. Summer Farm Festival and Field Day; 2013 July 10; Oregon State University Malheur Experiment Station. Ontario, OR.

Management Applications and/or Seed Production Guidelines

This section can be found at the beginning of this report.

Additional Products

- Seed produced from these plantings was used to establish commercial seed production fields.
- A field tour for growers was conducted in May 2013; a tour of the seed production trials was incorporated into the annual Malheur Experiment Station Field Day activities in July 2013.
- Continued improvement of native plant database on the internet:
<http://www.malag.aes.oregonstate.edu/wildflowers/>

Project Title Stock Seed Production and Inventory for Native Plants in the Great Basin

Project Agreement No. 09-JV-11221632-268

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Project Description

This project was initially titled “Establishment and Maintenance of the Buy-Back Program for Certified Seed”. It was funded through a Memorandum of Understanding between the United States Forest Service, Rocky Mountain Research Station (USFS-RMRS) in Boise and the Utah Crop Improvement Association (UCIA), initiated in fall 2003 and renewed with additional funds in fall 2004 and fall 2007. A new joint venture agreement titled “Stock Seed Production of Native Plants for the Great Basin” was completed on August 17, 2009. Seed has been distributed during this time period through a Buy-Back Program, a mechanism for returning a portion of the seed increased by private growers back to the UCIA for redistribution to the original and new seed growers to further seed increase.

Germplasm identity and purity of both original plant materials (as collected) and field increase has been facilitated by the Pre-Variety Germplasm program of the Association of Official Seed Certifying Agencies (AOSCA), of which the UCIA is a vested member. Following the protocols of this program is mandatory to make sure that what is on the tag, is in the bag and all the work of original germplasm collectors is maintained during field production, marketing, and planting.

A synopsis of the Stock Seed Buy-Back Program for the 1 January to 30 September 2013 period is available (see Table 1).

Objectives

The objectives of the UCIA Buy-Back Program were to:

- Increase stock seed of specific germplasm accessions, pooled accessions, and/or formal germplasm releases developed through the Great Basin Native Plant Project (GBNPP)
- Quickly identify and recruit interested seed growers, who would potentially benefit economically, to facilitate this seed increase
- Accelerate stock seed supplies and ultimately increase the availability and decrease the cost of commercial seed of specific species on the open market for reclamation projects and fire rehabilitation in the Great Basin

Methods

A detailed procedure for the Buy-Back Program has been outlined in previous GBNPP reports. In summary, small amounts of seed of selected species that were wildland collected or increased by public agency cooperators are allocated and distributed to private growers with special interests and/or experience in native plant seed production. A portion of the initial seed production is purchased by the UCIA through a Buy-Back agreement with specified quantities and costs. The Buy-Back seed is held in inventory and allocated, distributed, and sold to original or new growers with an interest in producing and marketing commercial quantities of select Great Basin species.

In addition, germplasm accessions of some species were distributed by public agencies to growers without specific agreements for stock seed Buy-Back or seed being held in UCIA inventory. In these cases, UCIA printed Source Identified certification tags from information provided by the germplasm developer on the UCIA Stock Materials Tagging Information Form (see Appendix 2). This identification legitimizes seed transfer, and the grower can enter the production field information for certification with the applicable state agency, whether the production is meant to have a Buy-Back contract or not.

Results and Discussion

For many of the species being studied by GBNPP cooperators, wildland seed collection is insufficient to provide for reclamation planting needs. Thus, accessions consisting of limited quantities of seed, obtained from distinct wildland stands or pooled from defined geographic areas, must be increased in commercial fields or nurseries in order to be available in the marketplace in quantities sufficient for revegetation projects needed in the Great Basin.

The UCIA Buy-Back Program has been nominally successful in providing a bridge between a) small-quantity initial accessions and b) commercial marketplace production. The UCIA has worked with specialized growers who have been willing to provide land, time, and expertise to produce increased amounts of stock seed from the small quantity of initial accessions. With UCIA facilitation, these have become available for commercial marketplace production.

This process has been more successful for some species than others, but in general, progress was made in defining seed accession groupings, compiling knowledge of agronomic seed production techniques, establishing the importance of maintaining genetic identity and purity through seed certification, and understanding the reality of the commercial seed marketplace.

The pounds of seed of grasses and forbs that have been entered into inventory and distributed to growers under the auspices of the UCIA project from 2002 to 2012 are now updated for 2013 and are summarized in Table 1. Grasses are easier to produce and are generally used in greater quantities than forbs in reclamation plantings. Stock seed quantities in Table 1 reflect this reality.

Management Applications

The overall application and impact of this project has been minimal as related to the stated objective, which was to “accelerate stock seed supplies and ultimately increase availability and decrease cost of commercial seed of specific species on the open market for reclamation projects and fire rehabilitation in the Great Basin”.

The few successes in the commercial market include plant materials that were previously identified and developed by USFS-RMRS scientists and were adopted by the GBNPP originally. These include Eagle Germplasm yarrow, Mountain Home Germplasm Sandberg bluegrass, and Anatone Germplasm bluebunch wheatgrass. A notable exception is the Utah Department of Wildlife Resources (UDWR) Tetra Germplasm basin wildrye developed by a GBNPP cooperator at the UDWR Great Basin Experiment Station utilizing

pooled tetraploid accessions from the Great Basin. It is now a factor in the commercial market since it is being purchased in sufficient quantities by both the UDWR and Bureau of Land Management consolidated seed buys and allowing growers to make money producing and marketing it.

Some of the forbs listed in Table 1 were increased successfully and made available in the commercial market but only Eagle Germplasm yarrow was purchased in any significant amount for revegetation projects by the BLM. Growers have thus abandoned some production because of unsold inventory. These include most of the buckwheat (*Eriogonum* spp.), penstemon (*Penstemon* spp.), globemallow (*Sphaeralcea* spp.), and lomatium (*Lomatium*) species. Most of these forbs are difficult and expensive to grow and economy of scale may never be applicable for the limited quantity of these niche species needed for revegetation projects. However, these niche species could be used in “island” plantings for the improvement of habitat for sage-grouse and other wildlife.

Publications

Young, S. A.; Vernon, J.; Shaw, N. 2013. Basin wildrye (*Leymus cinereus*) pooled tetraploid accessions for U. S. Intermountain West rangeland reclamation. In: Proceedings of the 22nd International Grasslands Congress; 2013 September 15-19; Sydney, New South Wales, Australia; p. 381-382.

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Young, S. A. 2013. Native plants seed certification for genetic identity and purity (varieties and pre-variety germplasm). National Native Seed Conference; 2013 April 8-11; Santa Fe, NM.

Young, S. A.; Andersen, W. 2013. Seed certification for wildland collected seed. National Native Seed Conference; 2013 April 8-11; Santa Fe, NM.

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Table 1. Great Basin Native Plant Project 2013 stock seed inventory/distributed report

Species/Crop	Variety/Germplasm ID	Class/ Generation	Lot #	2004-2012	2013	2013	2013
				Distributed from inventory	Added to Inventory	Distributed from inventory	Inventory
				Bulk lbs.	Bulk lbs.	Bulk lbs.	Bulk lbs.
<i>Achillea millefolium</i>	Eagle Germplasm?	S G3	ACMI2-RMRS-63-G3-ERSTROM-10				3.3
<i>Achillea millefolium</i>	Eagle Germplasm	S G3	RMRS-ACMI2-11	0.5			0.0
<i>Achillea millefolium</i>	Eagle Germplasm	S G2	NWS-1-YAR-FDN	12.0			
<i>Achillea millefolium</i>	Eagle Germplasm	S G1	NSW4-1-EMY1-1	6.5			0.0
<i>Achnatherum thurberianum</i>	Orchard Idaho Site	SI G1	2005.0394-1	13.0			0.0
<i>Achnatherum thurberianum</i>	Orchard Idaho Site	SI G1	2005.0394-2				1.0
<i>Achnatherum thurberianum</i>	Orchard Idaho Site	SI G1	2005.0394-C				6.0
<i>Achnatherum thurberianum</i>	Orchard Idaho Site	SI G1	2007.0498	1.0			0.0
<i>Balsamorhiza hookeri</i>	BAHO B1	SI G0	BAHO B1-02	0.6			
<i>Balsamorhiza hookeri</i>	BAHO B1	SI G??	2009.0426				15.9
<i>Chaenactis douglasii</i>	NBR	??	??		4.0		4.0
<i>Chaenactis douglasii</i>	NBR	??	??		12.0		12.0
<i>Crepis intermedia</i>	CRIN U36-2004	SI G1	RP 2013-U36		0.2		0.2
<i>Elymus elymoides</i>	Little Sahara	SI/ G0	Lot # CU-907	91.0			32.0
<i>Elymus elymoides</i>	Toe Jam Creek Germplasm	S G4	Lot # LHS1B2G-335	40.2			
<i>Elymus elymoides</i>	Fish Creek Germplasm	S G3	Lot # LHS1B2H-335	47.1			
<i>Elymus elymoides</i>	Toe Jam Creek Germplasm	S G4	Lot # LHS1B2J-337	127.5			
<i>Elymus elymoides</i>	Fish Creek Germplasm	S G3	Lot # LHS1B2K-337	113.5			
<i>Eriogonum heracleoides</i>	NBR/SRP	SI G1	BFI-10-10139687				220.0
<i>Eriogonum umbellatum</i>	NBR	??	??		20.0		20.0
<i>Leymus cinereus</i>	UDWR Tetra Germplasm	S/G1	ELCI-GBG-SFS-08	42.0			
<i>Leymus cinereus</i>	UDWR Tetra Germplasm	S/G2	BF-10-101596762	405.0			
<i>Leymus cinereus</i>	UDWR Tetra Germplasm	S/G2	BFI-11-1159676	1850.0		229.0	121.0

Species/Crop	Variety/Germplasm ID	Class/ Generation	Lot #	Distributed from inventory from 2004- 2012 (bulk lbs.)	Added to Inventory in 2013 (bulk lbs.)	Distributed from inventory in 2013 (bulk lbs.)	Inventory in 2013 (bulk lbs.)
<i>Leymus cinereus</i>	UDWR Tetra Germplasm	S/G1	SFS Tetra-11			70.0	59.0
<i>Lomatium dissectum</i>	NBR	SI/G1	LODI TD-10	1.2			0.0
<i>Lomatium dissectum</i>	NBR	SI/G1	LODI TD-12		10.0		10.0
<i>Machaeranthera canescens</i>	NBR	??	??		20.0		20.0
<i>Penstemon cyaneus</i>	PECY B6-02	SI G1	2009-0570	6.1			0.0
<i>Penstemon cyaneus</i>	PECY B6-02	SI G1	2004.0448	16.0			0.0
<i>Penstemon cyaneus</i>	PECY B6-02	SI G2	2006.0413	5.0			0.0
<i>Penstemon cyaneus</i>	PECY B6-02	SI G2	PPI-04-1	3.0			0.0
<i>Penstemon deustus</i>	PEDE B11	SI G2	??				20.0
<i>Penstemon pachyphyllus</i>	Pine Hollow Canyon	SI G1	A5-4-P1	11.9			38.1
<i>Penstemon palmerii</i>	Cedar Variety	Foundation	CPP KL-05-3, GBRI 36			10.0	10.0
<i>Penstemon palmerii</i>	Cedar Variety	Foundation	CPP KL-05-2, GBRI 26			4.0	0.0
<i>Penstemon palmerii</i>	Cedar Variety	Foundation	CPP KL-05-1, GBRI 16	96.5		36.5	0.0
<i>Penstemon speciosus</i>	Great Basin	SI	BFI-12-10178761				20.0
<i>Penstemon speciosus</i>	NBR	??	??		20.0		20.0
<i>Poa secunda</i>	Mountain Home Germplasm	S/G1	NBS-RR8-MTH-1	829.0		171.0	0.0
<i>Poa secunda</i>	Mountain Home Germplasm	S/G1	NBS-RR9-MTH-1				534.0
<i>Poa secunda</i>	Mountain Home Germplasm	SI G2	557-215-31A	304.0			0.0
<i>Poa secunda</i>	Mountain Home Germplasm	SI G2	016-215-611A	112.0			0.0
<i>Pseudoroegneria spicata</i>	Anatone Germplasm	SI G1	JA-03, UCIA 44	300.0			0.0
<i>Sphaeralcea coccinea</i>	SPCO-U55,U6	SI G1	WB 2013-U55,U6		1.0		1.0
<i>Sphaeralcea grossulariifolia</i>	SPGR-U63-2007	SI G1	SPGR2-U63-2007- 2012	3.0			3.0
<i>Sphaeralcea grossulariifolia</i>	CBR	SI G1	GBGM-12				40.0

Species/Crop	Variety/Germplasm ID	Class/ Generation	Lot #	Distributed from inventory from 2004- 2012 (bulk lbs.)	Added to Inventory in 2013 (bulk lbs.)	Distributed from inventory in 2013 (bulk lbs.)	Inventory in 2013 (bulk lbs.)
<i>Sphaeralcea grossulariifolia</i>	SPGR 2 U-63-09	SI G1	GLM-1		20.0		20.0
<i>Sphaeralcea grossulariifolia</i>	SPGR 2 U-63-08	SI G1	WB 2013-U63		2.0		2.0
<i>Sphaeralcea munroana</i>	NBR	SI G1	MGM-12-B				24.0
<i>Sphaeralcea munroana</i>	Succor Creek	SI G1	MUN-2		20.0		20.0
<i>Sphaeralcea parvifolia</i>	SPGR U14	SI G1	S04-2-4	5.0			0.0

Project Title Coordination of Great Basin Native Plant Project Seed Increase and Eastern Oregon/Northern Nevada Seed Collections

Project Agreement No. 12-JV-11221632-044

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Project Description

Objectives

- Develop distribution and seed zone maps for sulphur-flower buckwheat (*Eriogonum umbellatum*), fernleaf biscuitroot (*Lomatium dissectum*), nineleaf biscuitroot (*Lomatium triternatum*), and other priority seed collections in eastern Oregon.
- Establish a Great Basin Native Plant Project (GBNPP) Native Seed Growers Information Network and collect seed for GBNPP growers.
- Assist with bluebunch wheatgrass (*Pseudoroegneria spicata*) seed collections for research to determine efficacy of using species-specific seed zones for re-establishment of native bunchgrass populations after fire.

Introduction

Some background is needed to understand the procedures necessary to develop a method for collecting genetically diverse, regionally-adapted native plant material for restoration in the Great Basin.

- Seed zones are used to select restoration plant materials that are best adapted to current and projected future climatic conditions.
- Provisional seed zones are used when common garden studies have not been used to develop species-specific seed zones. Common garden studies are rare for non-tree species in the United States.
- Great Basin provisional seed zone maps (Figure 1) are based on total annual precipitation and an aridity index.
- By mapping the distribution of known collection sites on provisional seed zone maps, we can identify future seed collection needs for genecology (common garden) studies, germplasm conservation, and wildland seed collection of agricultural seed field increase for restoration.

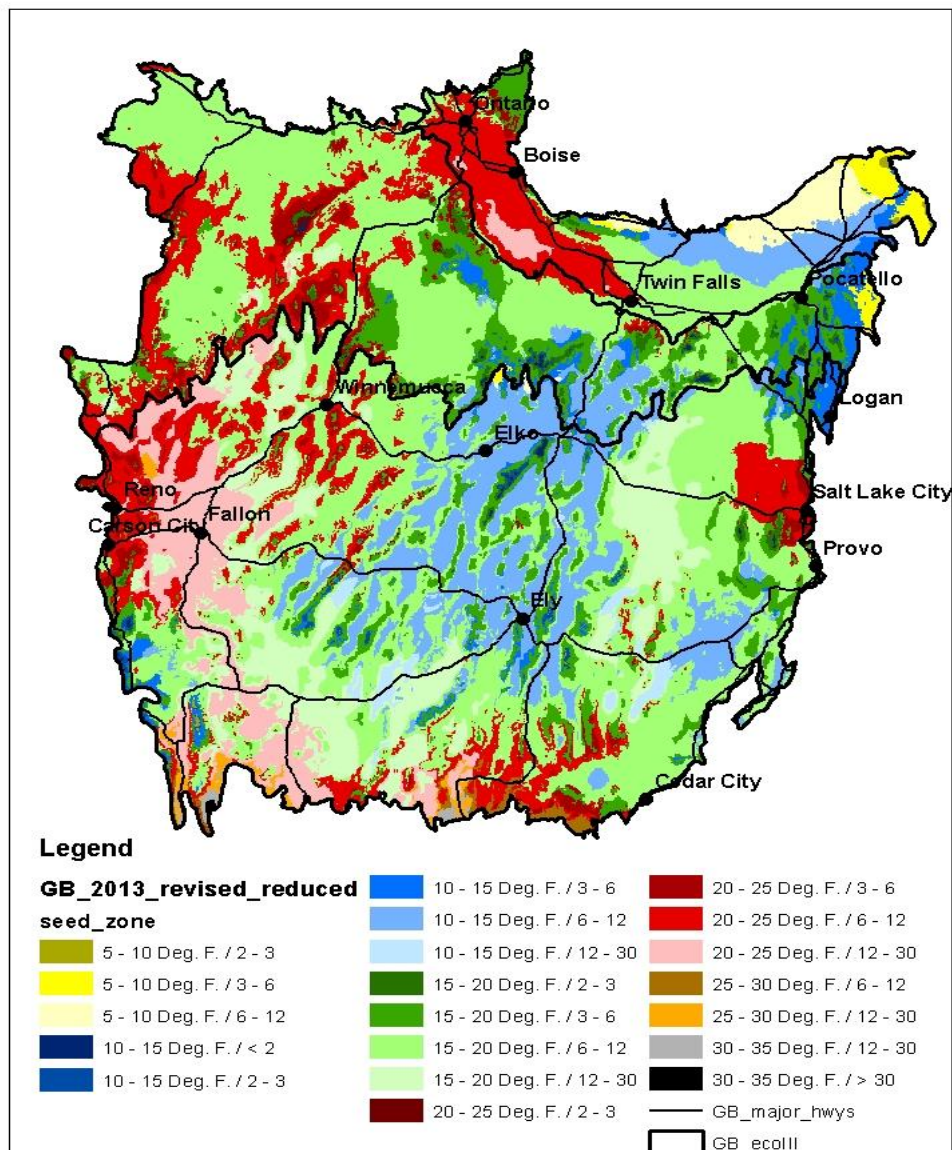


Figure 1. Great Basin provisional seed zone map (Bower et al. 2014).

For each commonly used restoration species, our goal is to provide adapted and genetically diverse germplasm for each provisional seed zone within the species distribution where there is a restoration need.

Methods

Germplasm for a specific seed zone is developed by pooling multiple seed collections from the seed zone to provide genetically diverse, regionally adapted material. This material can then be planted immediately, increased in agricultural seed fields, or propagated in a nursery to provide seed or plants for restoration use.

We mapped known collection sites for three important Great Basin restoration species: sulphur-flower buckwheat (Figure 2), nineleaf biscuitroot (Figure 3), and fernleaf biscuitroot (Figure 4) to identify collection sites within the range of each species.

Maps were examined to develop field season collection plans that focused on identified collection site gaps.

Results and Discussion

Development of Distribution and Seed Zone Maps for Important Great Basin Restoration Species

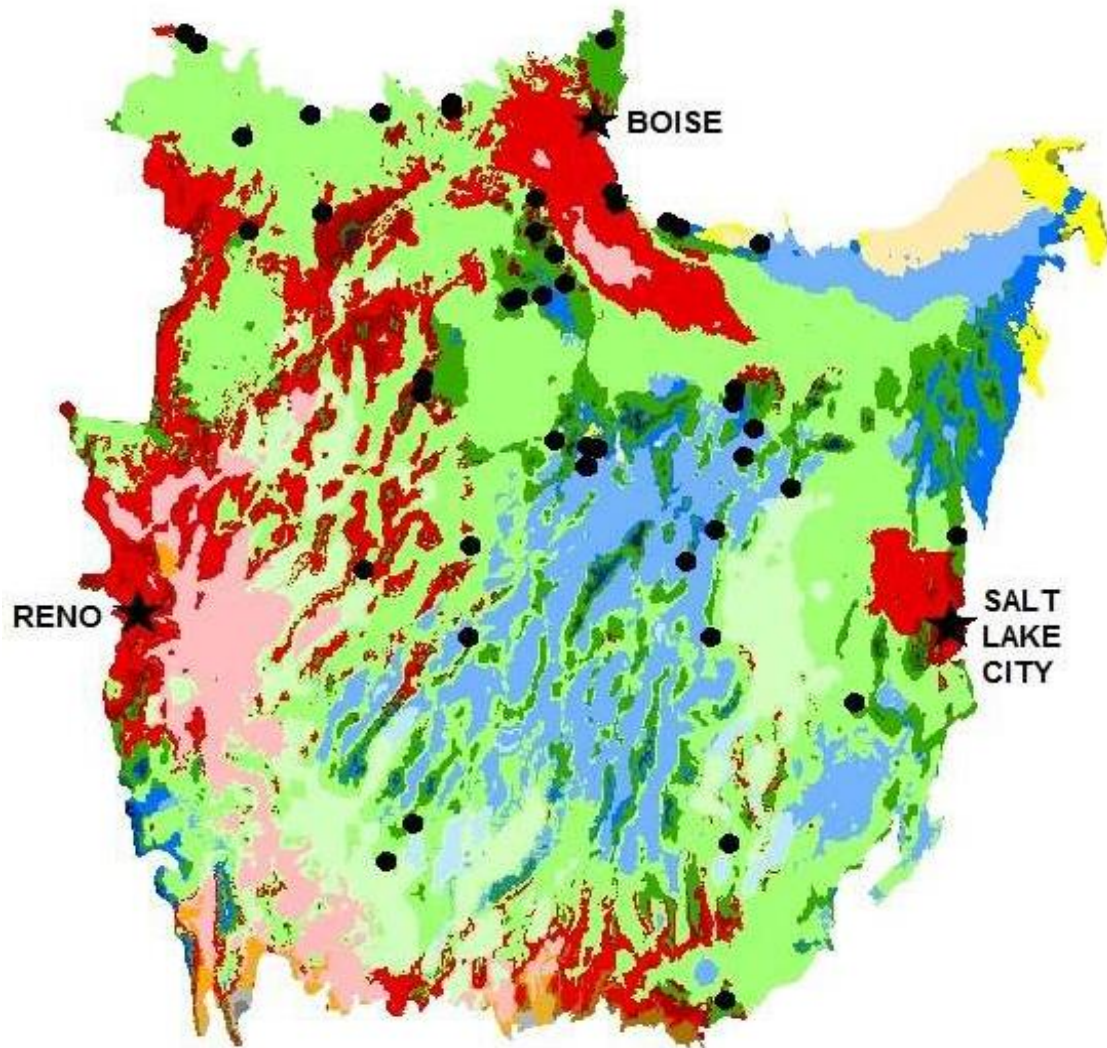


Figure 2. Map of sulphur-flower buckwheat collection sites.

Sulphur-flower buckwheat is an important, widespread, and often dominant Great Basin species. Seed will be collected from at least five of the seed zones where sulphur-flower buckwheat is most common (Northern region: bright green, dark green, and red; Central region: blue; Southern region: light green). Collections will be from the most common subspecies within each zone and populations from each seed zone will be pooled.

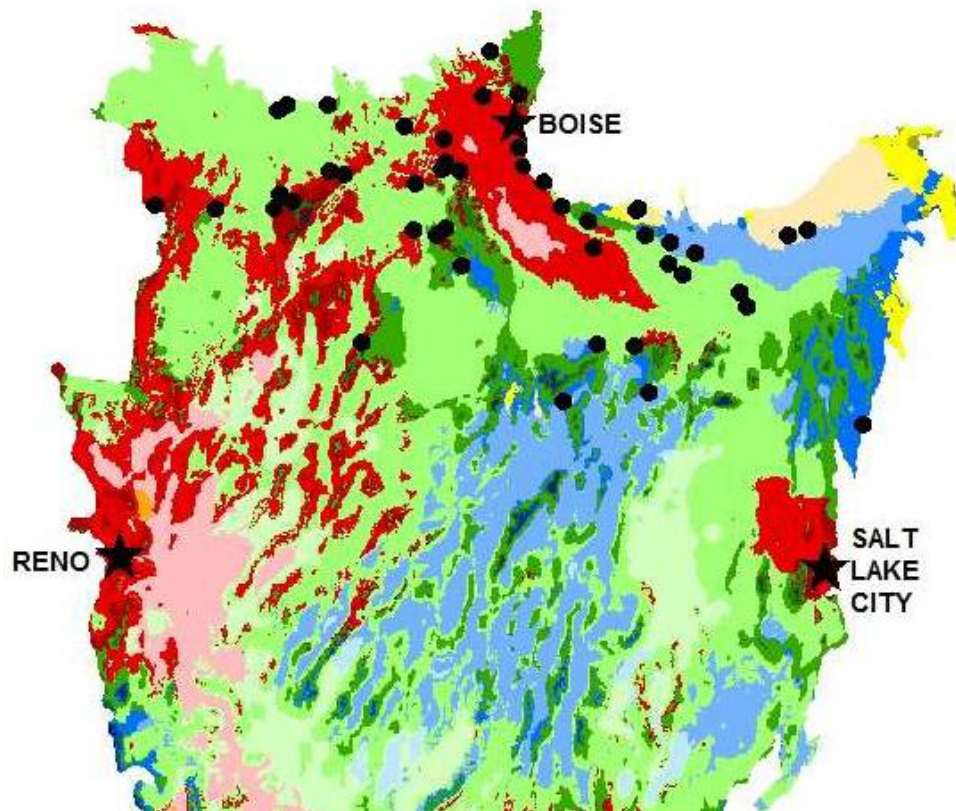


Figure 3. Map of nineleaf biscuitroot collection sites.

Nineleaf biscuitroot is important only in the northern part of the Great Basin, and the target variety is *Lomatium triternatum* var. *triternatum*. Additional seed collections are needed in southeastern Oregon, northern Nevada, northeastern Utah, and eastern Idaho. Pooled sources are needed for the bright green, dark green, and tan zones on the map.

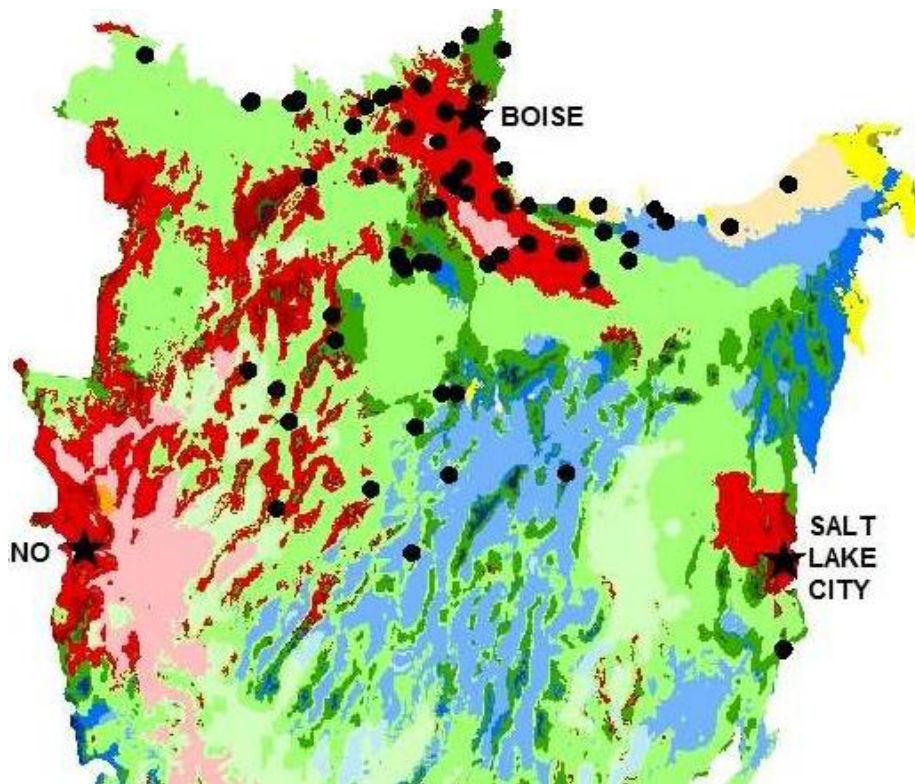


Figure 4. Fernleaf biscuitroot collection sites map.

The most common fernleaf biscuitroot variety in the Great Basin is *Lomatium dissectum* var. *multifidum*. Current collections are concentrated in the Snake River Plain (red regions on the map). Future seed collecting work will focus in the red and tan zones of the map to develop two pooled sources in the north. Further collecting and herbarium research is needed to identify needs for the central region.

Conclusion

The Great Basin provisional seed zone map provides a valuable tool that can be used to strategically plan future collections. Additional tools that are valuable for seed collecting include soil surveys, ecological site descriptions, and local knowledge and experience. Provisional seed zone maps and some species-specific seed zones maps based on common garden or genecological studies of widespread species are available on the USFS Western Wildlands Environmental Threat Assessment Center (WWETAC) website:

http://www.fs.fed.us/wwetac/threat_mapIntro.html

Results and Discussion

Establishment of a GBNPP Native Seed Growers Information Network and Seed Collection for GBNPP Growers

Two native seed farms in the Columbia Basin of Washington were visited in 2013. In May and June, forb fields of hoary aster (*Machaeranthera canescens*), showy penstemon (*Penstemon speciosus*), sharpleaf penstemon (*Penstemon acuminatus*), basalt milkvetch (*Astragalus filipes*), Wyeth's buckwheat (*Eriogonum heracleoides*), sulphur-flower buckwheat, dusty maiden (*Chaenactis douglasii*), and western prairie clover (*Dalea ornata*) were inspected. In 2013, there was an early warm period in May and unseasonable June rains, some seed yields were low. However, a few fields planted in 2011 or 2012 were growing well. Growers were encouraged with their latest BLM seed buys.

Eastern Oregon Stewardship Services (EOSS) collected 23 seed lots from 11 species for GBNPP growers and cooperators (Tables 1 and 2). Collections were made for Richard Johnson at the USDA Agricultural Research Service, Western Regional Plant Introduction Station; Clint Shock at the Oregon State University Malheur Experiment Station, and Robert Karrfalt at the USFS Forest Service National Seed Laboratory. Sulphur-flower buckwheat flowering specimens were collected for Matt Fisk, graduate student researcher at the University of Idaho.

Table 1. Forb species collected in 2013 for the GBNPP

Scientific name	Common name
<i>Chaenactis douglasii</i>	Douglas' dusty maiden
<i>Dalea ornata</i>	Blue Mountain prairie clover
<i>Eriogonum heracleoides</i>	Wyeth's buckwheat
<i>Eriogonum umbellatum</i>	sulphur-flowerbuckwheat
<i>Ipomopsis aggregata</i>	scarlet gilia
<i>Lomatium triternatum</i>	nineleaf biscuitroot
<i>Machaeranthera canescens</i>	hoary tansyaster
<i>Penstemon acuminatus</i>	sharpleaf penstemon
<i>Penstemon deustus</i>	scabland penstemon
<i>Penstemon speciosus</i>	royal penstemon
<i>Sphaeralcea munroana</i>	Munro's globemallow

Table 2. Seed lots collected during the 2013 field season by Eastern Oregon Stewardship Services for the GBNPP

Site number	Site details	Collection date	No. of plants
CHDO1BY13S	Lookout Mt., OR	7/24/13	50
CHDO2BY13S	Pine Creek, ID	7/31/13	50
DAOR1BY08S	North of Harper, OR	6/8/13	120
DAOR1BY13S	Sag RD (Halfway), OR	6/25/13	72
ERHE1BY13S	Lookout Mt., OR	7/24/13	50
ERHE2BY13S	Pine Creek, ID	7/28/13	50
ERUM2BY13S	Drinking Water Pass, OR	8/9/13	30
ERUM3BY13S	Hwy 20 MP 196, OR	8/9/13	30
ERUM4BY13S	Lookout Mt., OR	8/15/13	30
ERUM5BY13S	Rye Valley, OR	8/15/13	30
ERUM6BY13S	Boise Ridge, ID	8/17/13	30
ERUM7BY13S	Upper Pine Creek, ID	8/17/13	30
ERUM8BY13S	Lower Pine Creek, ID	8/17/13	30
ERUM9BY13S	Pine Creek Ranch, ID	8/18/13	30
IPAG1BY13S	Lookout Mt., OR	7/24/13	50
IPAG2BY13S	Pine Creek, ID	7/31/13	50
LOTR1BY13S	Bonita RD, OR	6/17/13	122
MACA1BY 13S	Pine Creek, ID	8/18/13	50
MACA2BY13S	Walgreens, Ontario, OR	10/15/13	50
PEAC11BY13S	Keeney Pass, OR	6/17/13	91
PEDE1BY13S	Sag RD (Halfway), OR	6/28/13	72
PESP1BY13S	Halliday RD., OR	7/3/13	151
SPMUBY10S	Overstreet RD, OR	6/17/13	86

Results and Discussion

Bluebunch wheatgrass Collections Using Species-specific Seed Zones

Bluebunch wheatgrass seed was collected in all major seed zones within the Columbia Plateau/Blue Mountains and Northern Great Basin/Snake River Plain Ecoregions for a new research project to establish common gardens and evaluate the efficacy of using species-specific seed zones for establishment of bluebunch wheatgrass on burned sites. The EOSS made 33 seed collections from zones 3a, 4,7a, and 7b.

Management Applications and/or Seed Production Guidelines

Increased communication and collaboration has led to better seed distribution to growers and development of new forb species that may be used in BLM seed buys and restoration projects in the future. The USFS preliminary seed zone maps for the Great Basin are used for developing seed accessions for on-the-ground restoration.

Presentations

Youtie, Berta. Using preliminary USFS seed zones for developing seed collections for GBNPP native seed growers. 2nd Annual National Native Seed Conference; 2013 April 9-11; Santa Fe, NM.

Youtie, Berta; Shaw, Nancy. The Great Basin provisional seed zone map: a tool for developing genetically diverse native plant materials for ecological restoration. 5th World Conference on Ecological Restoration; 2013 October 6-11; Madison, WI.

References

Johnson, R.; Stitch, L.; Olwell, P.; Lambert, S.; Horning, M.; Cronn, R. 2010. What are the best seed sources for ecosystem restoration on BLM and USFS lands? *Native Plants Journal*. 11: 117-130.

Bower, A. D.; St.Clair, B.; Erickson, V. [In press]. Generalized provisional seed zones for native plants. Available: <http://dx.doi.org/10.1890/13-0285.1>

Project Title Demonstration, Propagation, and Outreach Education Related to Great Basin Native Plant Project Plant Materials

Project Agreement No 11-CR-11221632-008

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Project Description

Introduction

The greatest challenges to increasing the use of native plants in northwestern Nevada urban landscapes are the lack of local availability and prevailing myths about native plant characteristics. Our main objective is to encourage greater adoption of native plants by the local retail nursery industry and the general public in urban areas of northwestern Nevada. This year, our focus was on the *Penstemon* genus because of their showy floral display and attractiveness to pollinators.

Objectives

- Develop regional demonstration/trial gardens with interpretive signage for Great Basin Native Plant Project plant materials deemed appropriate for horticultural use.
- Investigate practical propagation methods for difficult native Great Basin plant species and communicate those methods through written publications and web-based educational resources.
- Integrate information on the ornamental, habitat, and water conservation benefits of native plants into appropriate courses and master gardener programs.

Methods

In May 2013, University of Nevada Cooperative Extension (UNCE) Master Gardeners planned and installed a penstemon demonstration garden on the grounds of the Washoe County Extension building. Ninety seedlings, representing nine regionally appropriate penstemon species were planted on the west side of the building. Species planted were Palmer's penstemon (*Penstemon palmeri*), desert penstemon (*P. pseudospectabilis*), 'Red Rocks' penstemon (*P. x mexicali*), firecracker penstemon (*P. eatonii*), Rocky Mountain penstemon (*P. strictus*), Sunset Crater beardtongue (*P. clutei*), Front Range beardtongue (*P. virens*), 'Elfin Pink' beardlip penstemon (*P. barbatus*), and 'Tall Orange Mix' pineneedle beardtongue (*P. pinifolius*). Soil was prepared by ripping to eliminate the roots of shrubs that previously occupied the space. The site was amended with well-aged compost. A temporary drip system was installed for first-year establishment. Irrigation occurred three times per week for 30 minutes the first month and once per week thereafter.

Results and Discussion

We installed nine species of penstemon in a common garden under similar conditions of soil fertility and irrigation to compare their performance in a typical western Nevada garden setting. We are hoping to introduce the most successful and easiest care species to our retail nurseries that are largely unfamiliar with native plant

species. In a preliminary evaluation, we judged desert penstemon, ‘Red Rocks’ penstemon, Rocky Mountain penstemon, firecracker penstemon, and ‘Elfin Pink’ beardlip penstemon as excellent performers under typical garden conditions of regular irrigation and compost-amended soil. Palmer’s penstemon and Sunset Crater beardtongue exhibited a 40 percent mortality rate over the summer, likely due to over-watering. Front Range beardtongue exhibited burning of foliage with western sun exposure and may be more successful if planted in eastern exposure. ‘Tall Orange Mix’ pineneedle beardtongue survived the season but was slow to establish; performance may be improved in its second season.

We have used various methods to evaluate and educate members of the public about the potential use of native plant materials. A public survey was developed to gather marketing information about public perception, plant preferences, and plant purchasing habits related to penstemon and other flowering perennials. The survey is being conducted from June 2013 through June 2014. Information gathered will be disseminated to nursery owners, landscapers, and the public through a Native Plant Summit to be held in June 2014. A UNCE fact sheet titled *Penstemons are for Great Basin Gardens* was developed for distribution at educational events. Preliminary results from our survey showed that two out of three respondents had no idea that penstemons were native to Nevada, and 100 percent would purchase them if made available locally. Commonly cited factors in plant purchase decisions were: ‘native’, ‘color’, ‘attractive to pollinators’, ‘ease of care’, and ‘hardy to our climate’.

We also developed an online training module to educate Nevada Master Gardeners and the general public about regionally appropriate native plants for urban garden use. The module will be included as one component of a new online Master Gardener training program for the UNCE and is expected to go live in 2015. We developed two accompanying UNCE publications *Flowers at the Border: Plant Native Flowers around your Yard to Attract Native Pollinators and other Beneficial Insects* and *Gardening Guide for High-Desert Urban Landscapes of Great Basin Regions in Nevada and Utah*. These publications will be used to support the Master Gardener and other UNCE training programs, including Grow Your Own, Nevada, which trains the public on growing edible and ornamental plants in northern Nevada. *Flowers at the Border* includes an extensive list of herbaceous annual and perennial plants native to northern Nevada or surrounding states with similar climates. It highlights plant characteristics, cultural requirements, and attractiveness to pollinators and other beneficial insects. The *Gardening Guide for High Desert* targets northern Nevada newcomers and focuses on plant selection and care.

Management Applications and/or Seed Production Guidelines

Our work demonstrates that common gardens can be useful in determining species that will survive conditions common to a typical homeowner or landscaper. Demonstration gardens can also create awareness, interest, and excitement about plant species. Preliminary results of our survey confirm that if we are to be successful in increasing adoption of native species by the public on a large scale, we need to focus on those that exhibit elements marketable to consumers. Conventional retail nurseries will not take on the economic risk for plants that cannot sell. Consumer education about the ecology and landscape care of native species is also important; early success with native species may encourage repeat purchases and active searches for similar species in future plantings.

Presentations

Kratsch, H. 2013. Native plants in Nevada. 5th Annual meeting of the Multistate Research and Extension Project, WERA 1013: Intermountain Regional Evaluation and Introduction of Native Plants. 2013 October 11; Reno, NV.

Publications

Bennett, P. J.; Bauske, E. M.; O'Connor, A. S.; Reeder, J.; Busch, C.; Kratsch, H. A.; Leger, E.; O'Callaghan, A.; Nitzche, P. J.; Downer, J. 2013. Farmer's market, demonstration gardens, and research projects expand outreach of extension Master Gardeners. *HortTechnology*. 23(4): 411-415.

Sriladda, C.; Kjelgren, R.; Kratsch, H. A.; Monaco, T.; Larson, S. R.; Shen, F. A. [In Press]. Ecological adaptation of the endemic *Shepherdia rotundifolia* to conditions in its Colorado Plateau range. *Western North American Naturalist*.

Additional Products

A list of intermountain regional native plant growers has been revised and sent to the Native Plants for the Intermountain West website: <http://www.wyoextension.org/westernnativeplants>.

Extension Fact Sheets/Special Publications/Newspaper Articles

Kratsch, H. [In Press]. Penstemons are for Great Basin gardens. University of Nevada Cooperative Extension (UNCE) Fact Sheet FS-13-35. Available: <http://www.unce.unr.edu/publications/files/ho/2013/fs1335.pdf>

Kratsch, H. [In press]. Flowers at the border: plant native flowers around your yard to attract pollinators and other beneficial insects. University of Nevada Cooperative Extension Spec. Pub. SP-13-XX.

Kratsch, H.; Heflebower, R. [In press]. Gardening guide for high-desert urban landscapes of Great Basin regions in Nevada and Utah. University of Nevada Cooperative Extension Special Publication SP-13-09. Available: <http://www.unce.unr.edu/publications/files/ho/2013/sp1309.pdf>

Kratsch, H. 2013. June is for penstemons. *Reno Gazette Journal*. 2013 June 22.

Web-Based Training Module

Kratsch, H. 2013. Native plants for garden pollinators. Training module for master gardeners and the general public. Available at <http://www.growyourownnevada.com/grow-your-own-nevada-summer-2013-native-plants-for-garden-pollinators/>.

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

Project No. 11-IA-11221632-011

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Project Description

Background/Objectives/Hypotheses

Use of native annual and early-seral species in Great Basin rangeland reseeding efforts may increase invasion resistance, facilitate succession to desired vegetation and improve restoration/rehabilitation success. Early-seral species may be similar to exotic annual grasses in growth and resource acquisition strategies. Because they occupy a similar ecological niche and have similar functional traits (e.g., growth rates and resource acquisition strategies), theory predicts that early-seral species would compete more strongly against invasives like

cheatgrass (*Bromus tectorum*) and medusahead (*Taeniatherum caput-medusae*). As invasion and success of exotic grasses appears to be associated with soil type, competitive interactions may also depend on soil type.

In this study, we used a common garden approach to evaluate the performance of two exotic annual grasses: cheatgrass and medusahead and mixtures of native species in two soil types: clay loam and sandy loam. We assessed emergence, early seedling survival, biomass, and reproductive output during the first growing season since early life stages are critical to restoration success. Our first objective was to assess the relative performance of two native seed mixes, a seed mix of early-seral species and a traditional seed mix of late-seral species, when seeded with an exotic annual grass. We hypothesized that the early-seral seed mix would be more successful than the late-seral seed mix. Our second objective was to test the potential suppressive effect of the early- and late-seral seed mixes on the early life stages of the exotic annual grasses. Here we hypothesized that the early-seral seed mix would have a greater suppressive effect on the exotic annual grasses than the late-seral seed mix and that the suppressive effect would be strongest in the soil type where the exotic is presumed to be least well adapted. Our third objective was to examine the performance of exotics and natives in two different soil types: clay loam and sandy loam. We hypothesized that the exotics would be more successful when growing in soils where they are presumed to be best adapted. Specifically, we predicted that medusahead would be most successful in clay loam, while cheatgrass would be most successful in sandy loam. For the native species, we hypothesized that performance would differ by soil type based on the soil preference of the exotics.

Methods

We used a common garden approach to assess exotic and native plant performance in two soil types under the same climatic conditions. Three experiments were performed, using completely randomized designs. We designed two, parallel 2×3-factorial experiments, one with cheatgrass another with medusahead, to assess the performance of the early-seral native seed mix and the late-seral seed mix and the relative performance of cheatgrass and medusahead growing with and without native species. In these experiments, clay loam and sandy loam soil types were planted with three types of seed mixes (early-seral species, late-seral species, and no native species). In an additional experiment we evaluated the performance of native species growing without exotics. In the ‘No Exotic’ experiment, soil type was crossed with early- and late-seral seed mixes.

Each seed mix consisted of two forbs, two perennial grasses, and one shrub. The early-seral mix included: bristly fiddleneck (*Amsinckia tessellata*), Veatch’s blazingstar (*Mentzelia veatchiana*), squirreltail (*Elymus elymoides*), Sandberg bluegrass (*Poa secunda*), and rubber rabbitbrush (*Ericameria nauseosa*). Early-seral species seed was collected from multiple wild populations. The late-seral mix was representative of species used in restoration and included: Palmer’s penstemon (*Penstemon palmeri*), goosberryleaf globemallow (*Sphaeralcea grossulariifolia*), Snake River wheatgrass (*Elymus wawawaiensis*), Indian ricegrass (*Achnatherum hymenoides*), and Wyoming big sagebrush (*Artemisia tridentata* spp. *wyomingensis*). Late-seral species seeds were purchased from Comstock Seeds (Gardnerville, Nevada). Representative clay loam soils (clayey, smectitic, mesic, Lithic Argixeroll) and sandy loam soils (fine-loamy, mixed, superactive, mesic Durinodic Xeric Haplargid) were collected from multiple field locations, homogenized by soil type, and used to fill 16-inch (41 cm) deep treepots. Pots were sunk into the ground at a site on the University of Nevada Agricultural Experiment Station grounds in Reno, Nevada. Pots were seeded in October 2010. In each pot, seeds were sown by hand into randomized locations within each pot using a 20-location fixed grid (pot surface area was 6 × 6 in² [15 × 15 cm²]). In the ‘No Exotic’ experiment, we used two species combinations: 1) early-seral native species only (10 total seeds, two of each species), and 2) late-seral native species only (10 total seeds, two of each species). In the two parallel experiments with exotic grasses, we used three species combinations: 1) exotic

species only (10 seeds of either cheatgrass or medusahead), 2) exotic and early-seral native species together (10 exotic and 10 native seeds), and 3) exotic and late-seral native species together (10 exotic and 10 native seeds).

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



Figure 1. One of the replicates in the medusahead experiment where several exotic and native individuals have emerged. Photo taken during emergence monitoring about three weeks after seeding.

Results

Emergence and Survival

We found that early-seral species generally outperformed late-seral species growing with exotic annual grasses, for emergence probabilities ($p < 0.0001$), survival probabilities ($p < 0.05$, with medusahead), and earlier emergence timing ($p < 0.0001$), though results differed among functional groups and soil types. When growing with cheatgrass, early- and late-seral native species survivorship was variable in sandy loam soil but not in clay loam soil ($p < 0.01$). Within each seed mix, native grasses exhibited the highest emergence probabilities of the functional groups ($p < 0.0001$). In both the cheatgrass and medusahead experiments, we found that the presence of native species did not have a suppressive effect on the exotics. Cheatgrass had a high probability of survival when growing with either of the native seed mixes. A suppressive effect of the natives on the exotics may be more likely in later life stages. In terms of soil preference, we found that cheatgrass performed better in sandy loam, as predicted, for emergence and survival ($p < 0.0001$). Contrary to our prediction, medusahead did not show a preference for clay loam; medusahead demonstrated superior performance in both soil types. Emergence of all native functional groups was generally higher on sandy loam when growing with exotics ($p < 0.01$). We also found that native grasses had higher survival in sandy loam, while forbs and shrubs had higher survival in clay loam when growing with exotics ($p < 0.0001$).

Establishment, Biomass, and Reproductive Output in the Medusahead Experiment

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



Figure 2. Bristly fiddleneck suppressing the medusahead. Photo taken 3 June 2011.

Conclusions

Given their generally better performance, early-seral native species may have a greater chance of persisting in the presence of cheatgrass or medusahead than late-seral native species. Success of seeded natives at the seedling stage is likely critical in determining the eventual success of native reseeding efforts. Our findings suggest that use of native annuals and other early-seral species in reseeding may result in greater density of native species in communities with exotics; though additional studies or longer term monitoring are needed to assess future persistence and successional change. Based on the few species that we tested, differences in native species emergence and survival with exotics on the two soil types suggest that use of early-seral species in restoration may result in greater success on sites with coarse-textured soils, particularly when native grasses comprise a large proportion of the native seed mix. However, when biomass and reproductive output were measured, the early-seral forb, bristly fiddleneck, had a suppressive effect on medusahead on both soil types and performance of medusahead was comparable in the two soil types. To date, medusahead invasions have been most closely associated with fine-textured soils, but it has been observed on sites with coarse-textured soils (Dahl and Tisdale 1975). Our results support these observations and suggest that medusahead is capable of expanding its current range in the Intermountain West.

Management Applications and/or Seed Production Guidelines

This research lends support to the use of early-seral native species to improve success of rangeland restoration and rehabilitation in the Great Basin. Given their greater early life stage performance than late-seral native species growing with exotics, early-seral species may have a greater chance of persistence in communities with exotic annual grasses. If they persist, and possibly suppress exotics once they mature, their establishment may facilitate succession to a more native later seral community, provided a seed bank of late-seral species is present.

Our research findings on emergence and survival among the different native functional groups suggest that it may be advisable to rely more heavily on native grasses in restoration seedings. Although forbs in this study did not establish as well as the native grasses, certain species such as bristly fiddleneck show promise for use in rangeland reseeding. Further research is needed to say whether an increased seeding rate for bristly fiddleneck and a more diverse seeding mix improves suppression of exotics. Additional research is also needed to assess the impact of native perennial grasses on exotic annual grasses in later stages of community development. Our findings suggest that finding species for seed mixtures might focus on early-seral species similar to bristly fiddleneck.

Presentations

Uselman, S. M.; Snyder, K. A.; Leger, E. A.; Duke, S. E. Using annual forbs and early seral species in seeding mixtures for improved success in Great Basin restoration. 2nd National Native Seed Conference; 2013 April 8-11; Santa Fe, NM.

Publications

Uselman, S. M.; Snyder, K. A.; Leger, E. A.; Duke, S. E. 2014. First-year establishment, biomass and seed production of early vs. late seral natives in two medusahead (*Taeniatherum caput-medusae*) invaded soils. Invasive Plant Science and Management. [In Press].

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

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

Additional Products

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

References

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

Project Title Science Delivery for the Great Basin Native Plant Project

Project Agreement No. 14-JV-11221632-018

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Project Description

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

Objectives

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

Results and Discussion

At this early date of the project's life, considerable progress has been made in the attempt to disseminate the scientific developments made by the GBNPP project. Since January 2013, I have:

- Became acquainted with Great Basin Native Plant Project (GBNPP) cooperators, maintained contact and correspondence throughout the year about upcoming events and project due dates.
- Developed posters and brochures for Great Basin events and meetings.
- Updated the GBNPP website with meeting announcements, new publications, and updated cooperator information.
- Worked through all aspects of planning, logistics, scheduling, and running the GBNPP annual meeting with about 100 participants.
- Compiled and edited the GBNPP annual progress report of more than 200 pages.

Presentations

Kilkenny, F.; Gucker, C. L. 2013. The Great Basin Native Plant Project. Poster presented at the Great Basin Consortium Conference; 2013 December 9-10; Reno NV.

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

Project No. 10-CR-11221632-117

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Project Description

Objectives

Objectives of this research include:

- Determine the effect of crested wheatgrass (*Aropyron desertorum*) control methods on wheatgrass density and cover.
- Determine the effect of crested wheatgrass control methods and revegetation on establishment of seeded species.

Methods

Study Site

The study site, approximately 15 miles (24 km) southeast of Elko, Nevada, is located within the 8- to 10-inch (203-254 mm) precipitation zone on sandy loam soils (Orovada Puett association) in vegetation that was formerly dominated by Wyoming big sagebrush (*Artemisia tridentata* subsp. *wyomingensis*). The area was seeded with crested wheatgrass in the 1970s. Located within the boundaries of South Fork State Park, the site has had the necessary cultural resources clearance from the Nevada State Historic Protection Office and is fenced to eliminate livestock grazing.

Crested Wheatgrass Control and Revegetation Treatments

The following strategies are being tested in a randomized block, split-split plot design: 1) untreated crested wheatgrass, 2) partially controlled crested wheatgrass, and 3) completely controlled crested wheatgrass. The study site is comprised of five 5-acre (2 ha) blocks.

Within 1-acre (0.4 ha) plots in each block, the following methods are being compared: mechanical and chemical control, revegetation, and no revegetation. Specific strategies tested are:

- Untreated crested wheatgrass plots receiving no chemical or mechanical control treatment, but divided into unseeded and seeded subplots.
- Partially controlled crested wheatgrass plots split into three-way disked or herbicide-treated plots and divided into unseeded and seeded subplots.
- Completely controlled crested wheatgrass plots split into combined three-way disked and herbicide-treated plots or combined spring and fall herbicide-treated plots and divided into unseeded and seeded subplots.

Treatment Implementation and Sampling

The disked-only plots were three-way disked in November 2007. The spring-applied herbicide plots and combined disk + herbicide plots were sprayed with 66 oz. glyphosate (Roundup ®)/acre in May 2008. Combined spring + fall-applied herbicide plots were sprayed with 66 oz. glyphosate/acre in early October 2008. Subplots targeted for seeding were seeded at Natural Resources Conservation Service (NRCS)-recommended rates in late October 2008 by personnel from the NRCS Aberdeen Plant Materials Center with a Truax Rough Rider rangeland drill. For small-seed species, seed tubes were pulled so that seed fell on the soil surface; drill disks were raised, no furrows made, and a billion-type cultipacker was attached to the rear of the drill to press broadcast seeds into the soil surface. The seed mixture used is identified in Table 1.

In May 2010, another treatment trial was implemented within the same general study area using the same randomized block, split-split plot design. Crested wheatgrass control treatments consisted of 1) imazapic (Panoramic 2SL®), 2) chlorsulfuron + sulfometuron methyl (Landmark XP ®), 3) glyphosate (Roundup ®) full rate and glyphosate half-rate, and 4) untreated. The study site was comprised of five 5-acre (2 ha) blocks, with each 1-acre (0.4 ha) treatment plot divided into 0.5-acre (0.2 ha) seeded and unseeded subplots. All treatments were seeded in late October 2010 using the same seed mixture (Table 1), rates, and methodology described above.

During the summers of 2009 through 2013, we measured cover and density of crested wheatgrass, as well as nested frequency of crested wheatgrass seedlings. We also measured density of seeded species. All parameters were measured for each subplot with ten randomly placed 0.5-m² quadrats on each of 5 transects and perpendicular to each transect.

Results

2009

Complete control or 100% mortality of crested wheatgrass was not obtained with any of the control treatments. However, spring-applied glyphosate, combined spring + fall-applied glyphosate, and combined disk + glyphosate treatments all significantly reduced crested wheatgrass cover ($p < 0.05$) as compared to untreated plots, with no significant differences among these treatments ($p > 0.05$). Similarly, these same three treatments all significantly reduced crested wheatgrass density ($p < 0.05$), again with no significant differences among these treatments. Crested wheatgrass density was significantly greater on disked plots ($p < 0.05$) than on the untreated plots and plots receiving the other treatments, but crested wheatgrass cover was not significantly different ($p > 0.05$) between disked and untreated plots.

Preliminary observations showed the following: 1) four of the six seeded native grass species established, including basin wildrye (*Leymus cinereus*), bluebunch wheatgrass (*Psuedoroegneria spicata*), bottlebrush squirreltail (*Elymus elymoides*), and Indian ricegrass (*Achnatherum hymenoides*), 2) all of the seeded forb species: western yarrow (*Achillea millefolium*), Lewis flax (*Linum lewisii*), and Munro globemallow

(*Sphaeralcea munroana*) established, and 3) of the two seeded shrub species, establishment of Wyoming big sagebrush (*Artemisia tridentata* subsp. *wyomingensis*) was spotty and spiny hopsage (*Grayia spinosa*) failed to establish. Seeded native grasses germinated on plots with and without crested wheatgrass control, but were much taller and more robust in plots where crested wheatgrass was controlled to some extent. Spring growing conditions were nearly ideal, with an extremely wet June. Some grass and forb plants produced seed in the first growing season.

Table 1. Final seeding mix for South Fork study plots, Elko County, Nevada, in sandy loam soils (Orovada Puett association) at about the 8-inch (203 mm) precipitation zone

Species	Kind/Variety	Seeding Rate (PLS lb/acre)	Total no. lb (for 12.5 acres)
Indian ricegrass ¹ (<i>Achnatherum hymenoides</i>)	‘Nezpar’	2.0	25.0
Bottlebrush squirreltail ¹ (<i>Elymus elymoides</i>)	Toe Jam Creek	2.0	25.0
Needle-and-thread grass ² (<i>Stipa comata</i>)		2.0	25.0
Basin wildrye ³ (<i>Leymus cinereus</i>)	‘Magnar’	2.0	25.0
Bluebunch wheatgrass ³ (<i>Psuedoroegneria spicata</i>)	‘Secar’	1.0	12.5
Sandberg bluegrass ⁴ (<i>Poa secunda</i>)		0.75	9.4
Munro globemallow ⁴ (<i>Sphaeralcea munroana</i>)		0.50	6.25
Lewis flax ³ (<i>Linum lewisii</i>)	‘Appar’	0.75	9.4
Western yarrow ⁴ (<i>Achillea millefolium</i>)		0.20	2.5
Wyoming big sagebrush ³ (<i>Artemisia tridentata wyomingensis</i>)		0.20	2.5
Spiny hopsage ⁵ (<i>Grayia spinosa</i>)		0.50	6.25
Totals		11.9	148.8

¹Granite Seed Co.; ²BFI Native Seeds; ³Comstock Seed Co.; ⁴FS Collection; ⁵Native Seed Co.

2010

In 2010, density of crested wheatgrass seedlings continued to be significantly higher ($p<0.05$) in the untreated plots and disked plots. Density of seeded native grasses was highest in plots that received the combination of disking + spring glyphosate treatment, significantly greater than that of disk-treated plots ($p<0.05$), but not significantly different than either the spring-treated glyphosate plots or the spring + fall-applied glyphosate plots.

Forb densities were highest in the spring + fall-applied glyphosate plots and the disk + glyphosate plots, but because of large standard errors, only the latter treatment was significantly greater ($p<0.05$) than the untreated

plots and the disked only plots. For all seeded species combined, the spring + fall-applied glyphosate treatment and disk + glyphosate treatment produced significantly higher densities of seeded species than the disked only treatment ($p < 0.05$).

2011 through 2013

In 2013, we collected vegetation data, as described above, for both treatment trials (fifth-year data for the first trial, third-year data for second trial). Data analysis is currently being completed for data collected in 2011, 2012, and 2013. We noted an obvious increase in exotic annual forbs in the 2011 growing season, especially tansy mustard (*Sisymbrium altissimum*). In 2012 and 2013, the tansy mustard infestation was considerably less than in 2011. Preliminary indications are that glyphosate was more effective at reducing crested wheatgrass than imazapic or chlorsulfuron + sulfometuron. Establishment of seeded species from the 2010 planting was negligible.

In 2014, data will be analyzed using mixed model analysis, with blocks and years considered random and other treatments considered fixed.

Management Applications and/or Seed Production Guidelines

The relative success and/or failure of revegetation strategies and methodologies used in this research will be communicated in appropriate venues for the benefit of both public and private land managers and resource users. This research will add to the body of knowledge regarding the rehabilitation, functionality, and restoration of Great Basin rangelands.

Presentations

McAdoo, K.; Swanson, J.; Shaw, N. Native seed planting to diversify crested wheatgrass monocultures in Nevada. 2nd National Native Seed Conference; 2013 April 8-11; Santa Fe, NM.

Project Title The Ecology of Great Basin Native Forb Establishment

Project Agreement No. 13-JV-11221632-102

Principal Investigators and Contact Information

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Project Description

Objectives

Forbs are a key functional group in sage steppe systems, yet forb seed is expensive and many forb seedlings fail, greatly limiting the ability of practitioners to increase native forb density in degraded systems (Hardegree et al. 2011). Forb recruitment is likely limited by a complex set of interacting biotic and abiotic factors. The broad objective of this research is to examine the degree to which desert wheatgrass (*Agropyron desertorum*) competition, soil texture, and annual precipitation influence recruitment of three key native forb species. Restoration research has traditionally focused on ecological processes such as competition (Funk et al. 2008). However, there is little emphasis placed on understanding the relative importance of ecosystem processes in determining plant community structure, which is ultimately the information most useful to practitioners. Understanding the relative importance of various ecological processes in influencing forb establishment will provide the foundation for improving the ability of land managers to capitalize on the array of forb plant material available through the Great Basin Native Plant Project and ultimately understanding how to integrate available forb plant materials with other restoration practices.

Methods

This project consists of two phases. The first phase assessed general patterns of survival of native grass and forb seed. The interim and final results of this phase were published in a report focused on the methods and results of the first phase, which identified and quantified the ecological processes and conditions limiting native forb establishment (James et al. 2011).

In the second study phase, we seeded three native forb species across nine sites in the Great Basin that differed in soil texture, annual precipitation, and a number of other characteristics that influence seed bed abiotic conditions (Figure 1). Sites were seeded in fall 2012 and fall 2013. This report highlights results from the first seeding year. In spring 2014, we will have results from the second seeding year. Ultimately we will combine results across all seeding years so we can quantify forb establishment

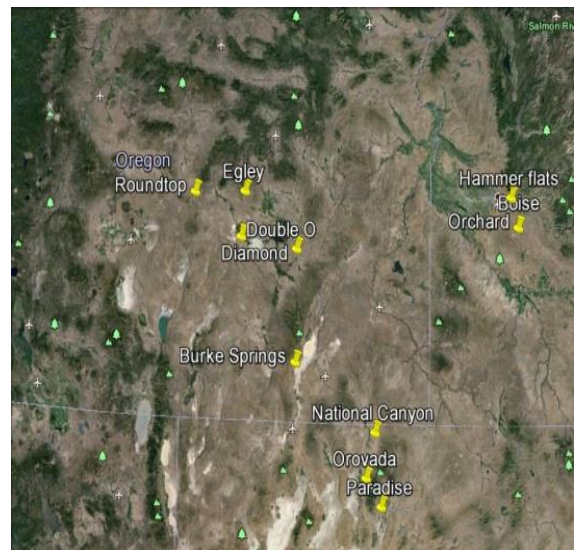


Figure 1. Location of the nine study sites for phase 2.

as a function of abiotic and biotic conditions rather than categorical responses.

The forbs seeded in this study were western yarrow (*Achillea millefolium* var. *occidentalis*), fernleaf biscuitroot (*Lomatium dissectum*), and scarlet globemallow (*Sphaeralcea coccinea*). Forbs were seeded at recommended seeding depths and rates (600 pure live seed [PLS]/m²). Ten (3 × 3-foot [1 × 1 m]) plots were seeded for each species at each site, and half of the plots also were seeded with desert wheatgrass at 600 PLS/m². Desert wheatgrass is often used in restoration as a bet-hedging strategy for managers. Depending on the drill and seed mixture used, desert wheatgrass seed may or may not be planted in the same rows as forb seed. Our desert wheatgrass seeding treatment allows us to quantify the degree to which these seeding practices may influence native forb establishment. Scarlet globemallow seeds were acid scarified prior to sowing.

Forb and desert wheatgrass seeds (50 seeds/bag) were also sown in germination bags in the fall of each planting year to quantify germination rates and express seedling emergence rates as a function of seeds germinating in the field (James et al. 2011). Demographic transitions key to recruitment including seedling emergence and survival were monitored at the plots each month in the spring and each month throughout the second growing season. Forb and desert wheatgrass survival will be measured in spring 2012 and spring 2013. Final data will be summarized and published in the last year of the study.

Results and Discussion

Germination for the three native forb species differed by site ($p < 0.01$) and broadly corresponded to mean annual precipitation with wet sites showing higher germination (Figure 2). Desert wheatgrass showed higher and less variable germination than the native forbs and high germination ($> 85\%$) across all sites. Seeding desert wheatgrass with forbs had no effect on native forb germination rates. Emergence was categorically low for all forbs across the five sites (Figure 3) and represented a major bottleneck in the recruitment process. Even when germination was high (80% germination of fernleaf biscuitroot on a wet, silt loam site) less than 2% of the germinated seeds emerged and survived the spring. This recruitment bottleneck was also apparent for desert wheatgrass, which had less than 2% emergence and survival. Given the relatively low desert wheatgrass densities, seeding desert wheatgrass with forbs had little effect on forb recruitment ($p > 0.5$). Precipitation for the 2012 and 2013 growing seasons was about 30% of normal with an exceptionally dry winter. Combining the second seeding year with these first year responses will improve our ability to link precipitation to germination, emergence, and survival. Results to date suggest a minimal role for biotic interactions in influencing forb establishment and that for many sites precipitation may be adequate to stimulate germination but mortality rates are massive following germination.

Future Plans

We will sample our first- and second-year forb plots in spring 2014. This will give us two seeding years across nine sites to try and link precipitation patterns, soil texture, and desert wheatgrass seedling density to native forb establishment rates. We plan to use multivariate linear regression on the full data set to assess the relationships between environmental variables and recruitment.

Management Applications and/or Seed Production Guidelines

Under the conditions of this first seeding year, seeding desert wheatgrass with forbs had no short-term negative effect on forb recruitment. As a result, managers may be able to simultaneously seed these two contrasting functional groups without major risks to native forb establishment. There is substantial mortality of germinated forb seeds (98% or greater). Decreasing the time between sowing and when seedlings emerge in spring may mitigate this mortality to some degree. For plant material selection and development, these results indicate that

it is hugely important to understand and quantify population variation in traits related to emergence and that selecting for these traits may be one way to accelerate our ability to increase native forb establishment in restoration.

Presentations

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

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

Publications

James, Jeremy J.; Sheley, Roger L.; Erickson, Todd; Rollins, Kimberly S.; Taylor, Michael H.; Dixon, Kingsley W. 2013. A systems approach to restoring degraded drylands. *Journal of Applied Ecology*. 50:730-739.

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Hardegree, Stuart P.; Jones, Tom A.; Roundy, Bruce A.; Shaw, Nancy L.; Monaco, Tom A. 2011. Assessment of range planting as a conservation practice. In: Briske, David D., ed. *Conservation benefits of rangeland practices: assessment, recommendations, and knowledge gaps*. Lawrence, KS: Allen Press: 171-212.

James, Jeremy J.; Svejcar, Tony J.; Rinella, Mathew J. 2011. Demographic processes limiting seedling recruitment in arid grassland restoration. *Journal of Applied Ecology*. 48: 961-969.

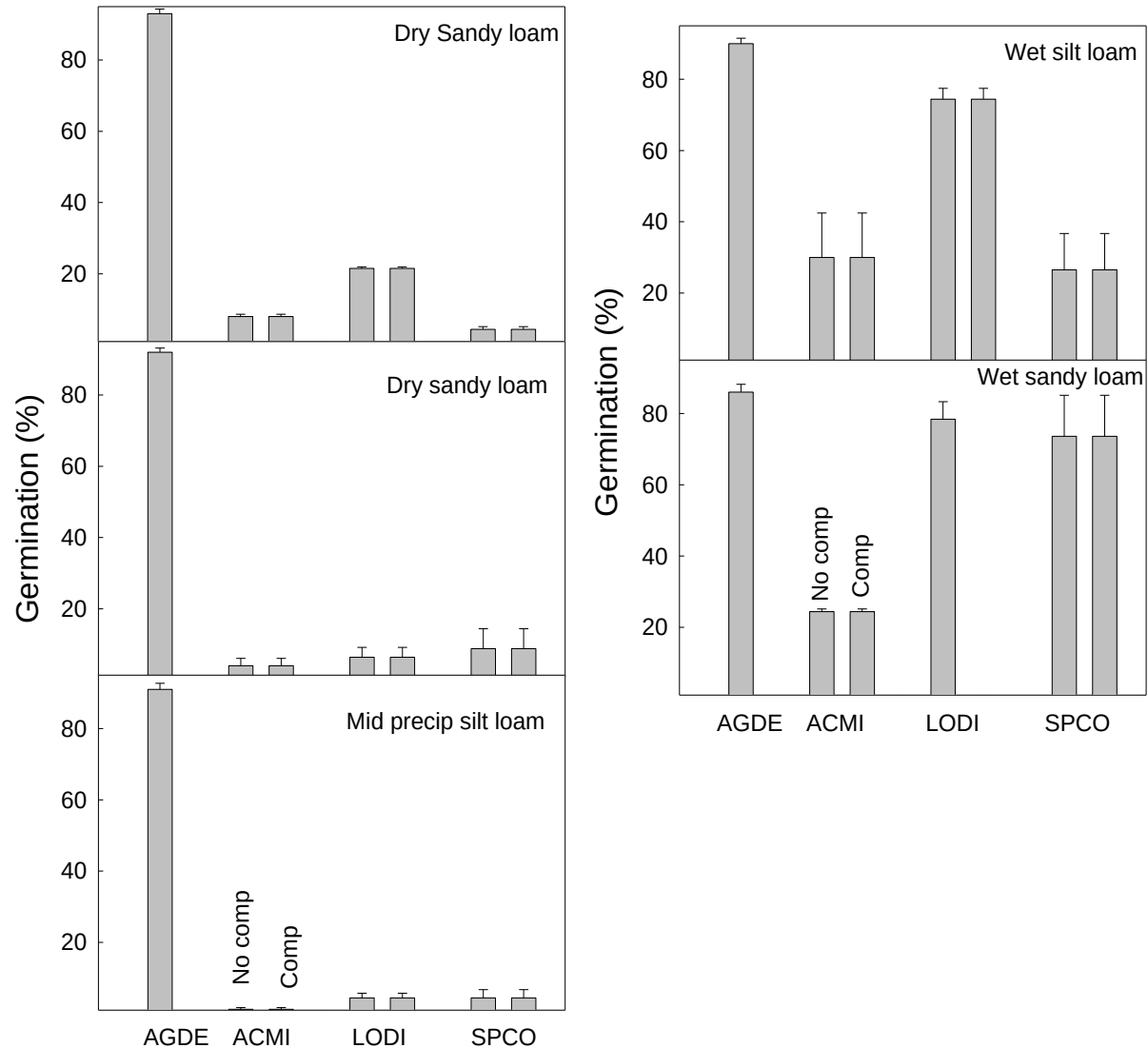


Figure 2. Field germination of the four study species seeded at five study sites with two competition treatments (seeded without desert wheatgrass = No comp and seeded with desert wheatgrass= Comp). Sites were sown fall 2012 and sites are characterized by mean annual precipitation and soil texture from published ecological site descriptions. Species codes: AGDE = *Agropyron desertorum*, ACMI = *Achillea millefolium* var. *occidentalis*, LODI = *Lomatium dissectum*, and SPCO = *Sphaeralcea coccinea*. Germination was quantified from germination bags with 50 PLS/bag.

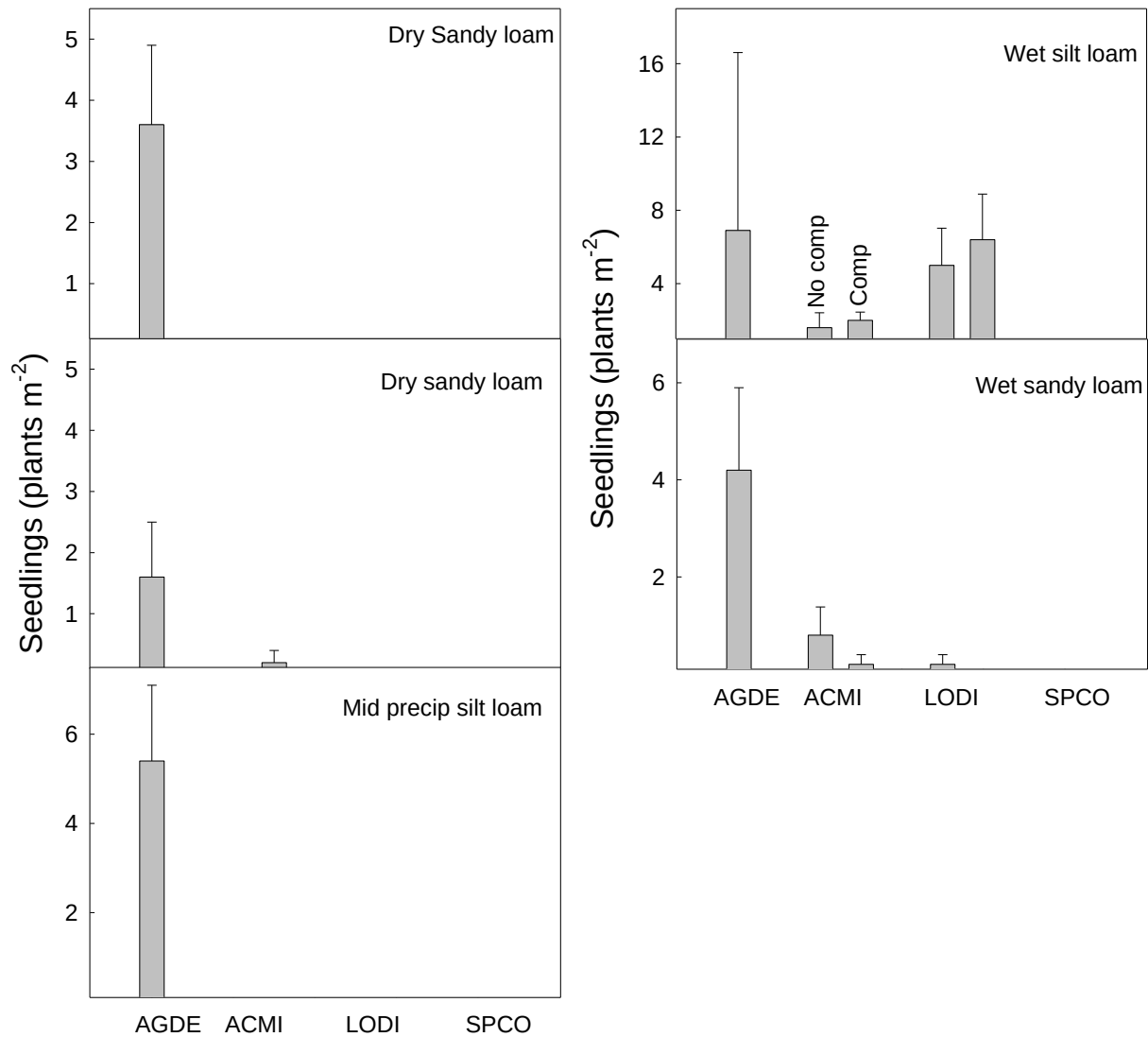


Figure 3. Seedling establishment of the four study species seeded at five study sites with two competition treatments (seeded without desert wheatgrass = No comp and seeded with desert wheatgrass= Comp). Species codes: AGDE = *Agropyron desertorum*, ACMI = *Achillea millefolium* var. *occidentalis*, LODI = *Lomatium dissectum*, and SPCO = *Sphaeralcea coccinea*. Sites were sown fall 2012 and sites are characterized by mean annual precipitation and soil texture from published ecological site descriptions.

Project Title Recruitment of Native Vegetation into Crested Wheatgrass Seedings and the Influence of Crested Wheatgrass on Native Vegetation

Project Agreement No. 11-IA-11221632-003

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Project Description

Objectives

The objectives of our study were to 1) determine what factors (management, site/environmental characteristics, etc.) are associated with native plant recruitment in crested wheatgrass (*Agropyron cristatum*) plant communities, and 2) determine vegetation successional trajectories of native perennial bunchgrasses that were co-planted with crested wheatgrass and their persistence in the community.

Methods

We sampled 20 crested wheatgrass plant communities in southeastern Oregon between June and September 2013 to try to determine which factors promote native plant recruitment in crested wheatgrass plant communities. This data supplements data collected in 2012. The same sampling protocol was followed in both years.

Sites were selected with input from BLM Rangeland Management Specialists to represent a wide range of management practices such as timing (spring or fall) and intensity (distance to water/fence lines) of grazing, a range of time since seeding, and a variety of environmental conditions (elevation, aspect, slope, and proximity to untreated areas). At each plot, slope, aspect, elevation, and UTM coordinates were recorded.

To sample vegetation, 197 × 164-foot (60 × 50 m) plots were used to sample each site. In each plot, four 164-foot (50 m) transects were deployed at 66-foot (20 m) intervals along the 197-foot (60 m) transect. Along each transect, herbaceous vegetation, basal cover and density were visually estimated by species inside 16 × 20-inch (40 × 50 cm) frames located at 10-foot (3 m) intervals on each transect line (starting at the 10 foot mark and ending at 148 feet [45 m]), resulting in 15 frames per transect and 75 frames per plot. Percentage ground cover (bare ground, rock, litter and crypto-biotic crust) were measured in the 16 × 20-inch frames. Shrub canopy

cover by species was measured by line intercept. Canopy gaps less than 6 inches (15 cm) were included in the canopy cover measurements. Shrub density was determined by counting all rooted individuals in five, 7 × 164-foot (2 × 50 m) belt transects at each plot.

Soil samples were collected at three locations in each plot from a 24-inch (61 cm) deep hole located at the center of the plot and at 49 feet (15 m) NW and SE of the center of the plot. From each of these holes soil samples were taken from 0 to 6 inches (15 cm), 0 to 8 inches (20 cm), and 8 to 24 inches (15-60 cm). Depth to hardpan was recorded if it was observed within the 24 inch hole. The values for each of the samples per plot were averaged into a single plot value. Soil texture for the 0- to 8-inch and 8- to 24-inch samples was measured using the hydrometer method. The 0- to 6-inch samples were used to obtain soil pH, nitrogen, carbon, and total organic matter for each site.

We accessed BLM records at local offices to determine past management. We collected actual use data and disturbance and seeding history for each site when available.

Future plans are to perform statistical analysis on data and submit two peer-reviewed manuscripts.

Management Applications and/or Seed Production Guidelines

Results are still preliminary and should not yet be incorporated into management applications.

Presentations

Nafus, Aleta M; Davies, Kirk W.; Svejcar, T. J. 2013. Recruitment of native vegetation into crested wheatgrass seedings and the influence of crested wheatgrass on native vegetation. Society for Range Management Annual Meeting; 2013 February 2-6; Oklahoma City, OK.

Project Title Revegetation Equipment Catalog Website Maintenance

Project Agreement No. 12-IA-11221632-149

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Project Description

Objectives

The Revegetation Equipment Catalog is an online repository of descriptions, photos, and company information for equipment used for revegetation efforts throughout the United States. With pages on topics ranging from “All-terrain Vehicles” through “Fertilizing and Mulching,” to “Transport Trailers,” the catalog is an important reference for information about revegetation equipment.

Methods

In 2013, the online catalog was updated. All links were checked and corrected, and the website was fully redesigned. The website is now entirely hosted by Texas Tech University.

Future Plans

We plan to begin tracking visits to the website, as well as expanding it to include a wider variety of topics.

Project Title Evaluation of Imazapic Rates and Forb Planting Times on Native Forb Establishment

Project No. 09-JV-11221632-100

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Project Description

Successful establishment of native forb species is critical to re-establish structure and function to disturbed range sites. A large portion of degraded rangeland in the Intermountain West is invaded by cheatgrass (*Bromus tectorum*). The most common herbicide currently available for cheatgrass control is imazapic (Plateau). Since restoration sites will likely be treated with imazapic for cheatgrass control prior to successful establishment of desirable species, a greater understanding of the tolerance of different native forb species to imazapic is needed. This project aims to describe native forb and grass species' tolerance to imazapic and other herbicides often used to suppress cheatgrass. This project will also examine the effect of herbicide application timing and planting dates on successful species germination and growth.

Methods

Field Plantings

Maintenance treatments were applied to 0.125-acre (0.5 ha) plots of both basalt milkvetch (*Astragalus filipes*) and Blue Mountain prairie clover (*Dalea ornata*). Roundup plus Prowl H₂O was applied to the basalt milkvetch while only Prowl H₂O was applied to the Blue Mountain prairie clover because new buds were present at the time of application. Treatments were applied with a 4-wheeler mounted sprayer. Plots were hand-weeded several times during the summer at which time it was determined that variation among plants across the plot area would be too great to allow additional herbicide tolerance testing. The plot areas were maintained weed free throughout the season. Basalt milkvetch was in full flower by mid-May and Blue Mountain prairie clover by early to mid-June. Basalt milkvetch seed was harvested on 1 July using a small-plot forage harvester to collect all biomass into large bags. Bags were allowed to dry, and harvested material was run through a stationary combine and then a seed thresher to try to extract seeds from their pods. Further hand cleaning was done to collect as much seed as possible, but a substantial amount of seed was lost. Blue Mountain prairie clover seed was harvested on 15 July using a gas-powered leaf blower as a vacuum. Seed tufts had begun to shatter from the plants, and tufts were vacuumed from both the soil and the plants. Seed was further processed by running it through a set of sieves to remove chaff and fluff. Seeds were also dropped in front of a fan to remove additional seed contaminants.

Fresh seed of basalt milkvetch and Blue Mountain prairie clover were used in additional tests, which are described below.

Scarification to Increase Germination

Inadequate germination of basalt milkvetch and Blue Mountain prairie clover in the 2012 petri dish trials made it difficult to determine herbicide tolerance. A second test had to be developed. We germinated these species on agar media containing the herbicides of interest following a screening model used by the agrichemical industry. Preliminary trials were conducted to determine if both species were conducive to culture on agar growth media. Freshly harvested seeds were scarified for different durations using concentrated sulfuric acid. Scarification times for Blue Mountain prairie clover were 0, 5, 15, 20, and 30 minutes. Scarification times for basalt milkvetch were 0, 5, 15, 30, 45, 60, 75, and 90 minutes. After scarification, seeds were placed on agar media in petri dishes with 35 seeds per dish, and treatments were replicated four times. Petri dishes were placed in a growth chamber at 77 °F (25 °C). The number of seeds germinating and the percent of each petri dish contaminated by fungal growth were recorded at 7 and 14 days after treatment.

Stratification to Increase Germination

Low germination in basalt milkvetch seed, even following long scarification times required that a second germination trial be established. In this trial, all basalt milkvetch seeds were scarified for 30 minutes in sulfuric acid, placed on the agar media in petri dishes, and then placed in a refrigerator (39-43 °F [4-6 °C]) for durations of 0, 3, 7, 11, 17, and 21 days. The number of germinated seeds was counted 7 days after the dishes were removed from the refrigerator.

Petri dish Agar-Herbicide Tolerance Trial

Because Blue Mountain prairie clover exhibited high germination percentages when seeds were incubated on agar, an additional trial was conducted to evaluate Blue Mountain prairie clover germination in response to various rates of Plateau and Matrix herbicides added to the agar media. Blue Mountain prairie clover seeds were placed in concentrated sulfuric acid for 2.5 minutes, not to increase germination, but to disinfest the seeds from the fungal contamination that was observed in the previous trials. Treatments included Plateau at 0, 0.19, 0.375, 0.75, 1.5, 3.0, 6.0, and 12.0 oz ai/acre and Matrix at 0, 0.06, 0.125, 0.25, 0.5, 1.0, 2.0, and 4.0 oz ai/acre. Herbicides were placed on the surface of agar media just prior to the agar solidifying in the petri dishes when temperatures were low enough not to affect the herbicide molecule. Seeds were then placed in each dish, and the dishes were sealed and placed in the growth chamber as described for the previous experiments. Petri dishes were kept in the dark to reduce any potential photolysis of the herbicides. At 7 and 14 days after treatment, germination percentages and the number of plants with root and shoot development were recorded. Shoot length, root length, number of plants with secondary leaves, average secondary root length, visual estimates of shoot vigor, and plant biomass were measured at 14 days after treatment.

Greenhouse Field Soil Herbicide Tolerance Trial

A greenhouse trial was established to evaluate basalt milkvetch and Blue Mountain prairie clover response to herbicides in pots filled with Millville silt loam soil. Basalt milkvetch seeds from a 2013 harvest were scarified for 30 minutes, sown in 4-inch (10 cm) pots (12 seeds/pot), and sprayed with the appropriate herbicide treatment. Pots were then placed in a 39 °F (4 °C) refrigerator for 11 days before being placed in the greenhouse. Blue Mountain prairie clover seeds were scarified for 1 minute, planted in pots, and sprayed with herbicide treatments. Treatments were replicated 8 times. Blue Mountain prairie clover planted pots were placed directly in the greenhouse. Once moved to the greenhouse, pots were placed under a shade cloth where temperatures were maintained at 77 °F (25 °C) during the day and 73 °F (23 °C) at night. Treatments included Plateau, Matrix, Prowl H2O, and Outlook at various rates (Table 1).

Results and Discussion

Data from all trials were analyzed using ANOVA. Treatment means were separated using Fishers Protected LSD ($P < 0.05$).

Field Plantings

There was no evidence of herbicide injury from early spring applications of Roundup plus Prowl H₂O to basalt milkvetch or Prowl H₂O to Blue Mountain prairie clover. In total, approximately 1,100 grams of *Astragalus* and 1,800 grams of Blue Mountain prairie clover seed were recovered from harvesting 0.125-acre (0.05 ha) plots that were maintained weed free. Fresh seed of basalt milkvetch and Blue Mountain prairie clover were used in additional tests described below.

Scarification to Increase Germination

In the scarification trials (Figure 1), basalt milkvetch germination increased slightly as duration of exposure to sulfuric acid increased, but at exposure of 45 minutes or more injury to emerging shoots was observed. It was also observed that scarification for 45 minutes or more significantly reduced fungal contamination found in the agar-filled petri dishes. In contrast, scarification of Blue Mountain prairie clover for longer than 5 minutes caused significant reductions in germination. Any exposure of Blue Mountain prairie clover to sulfuric acid reduced fungal contamination in the agar plates. Blue Mountain prairie clover was scarified in concentrated sulfuric acid for 2.5 minutes before plating seed in the agar-herbicide trial described below.

Stratification to Increase Germination

As expected, when basalt milkvetch seed was scarified for 30 minutes and then subjected to cold stratification, seed germination increased dramatically (Figure 2). Seed germination was greater than 80% for stratification periods longer than 11 days. Scarification followed by stratification could potentially allow summer plantings of basalt milkvetch to establish successfully where previous attempts at summer field plantings of have failed. This would need to be tested through field trials.

Petri dish Agar-Herbicide Tolerance Trial

Similar to 2012 trials conducted on filter paper, Blue Mountain prairie clover germination, root and shoot number, root and shoot length, secondary root and shoot length, and total biomass were not significantly affected by any of the rates of either Plateau or Matrix added to an agar substrate (data not shown). This demonstrates that testing forb tolerance to herbicides using an agar-based system is not a viable testing technique using the methods employed in this trial. It may be that the herbicides are not available to the plant in the agar or that the plants need to be rooted in the agar to take up the herbicides.

Greenhouse Field Soil Herbicide Tolerance Trial

The impact of herbicides on germination in the greenhouse was highly variable. While some treatments were significantly different from each other, there was no logical trend and some higher herbicide rates had higher germination than lower rates (Table 1). However, for basalt milkvetch, the number of leaves per pot displayed an expected trend, with leaf numbers generally following a dose response pattern. Interestingly, Plateau at 0.188 oz ai/acre or higher, Matrix at 0.063 oz ai/acre and higher, and Outlook at all rates significantly reduced the formation of new leaves compared to the untreated controls. None of the Prowl H₂O treatments reduced leaf numbers compared to untreated controls. The lack of response to Prowl H₂O supports field observations that suggest that basalt milkvetch is quite tolerant of Prowl H₂O. Our data does suggest, however, that basalt milkvetch seedling development will be reduced by high rates of Plateau and Matrix. The reduction in basalt milkvetch plant establishment after treatment with Plateau was observed in a field trial conducted in 2010

(Figure 3) and suggests that delayed planting of basalt milkvetch following Plateau or Matrix applications may be required to allow the herbicides to break down in the soil to low levels. Challenges in growing basalt milkvetch plants uniformly has greatly limited the knowledge of its tolerance to herbicides

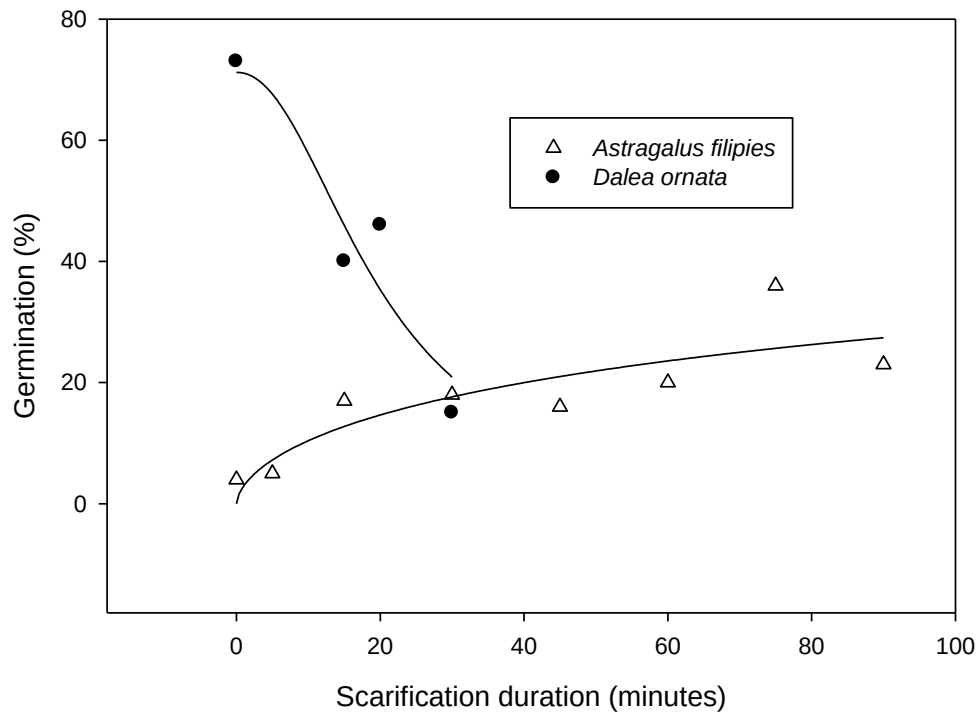


Figure 1. Effect of concentrated sulfuric acid scarification on basalt milkvetch (*Astragalus filipies*) and Blue Mountain prairie clover (*Dalea ornata*) seed germination in petri dishes. While basalt milkvetch germination generally increased with longer durations of scarification up to 90 minutes, durations above 45 minutes appeared to cause injury to cotyledons.

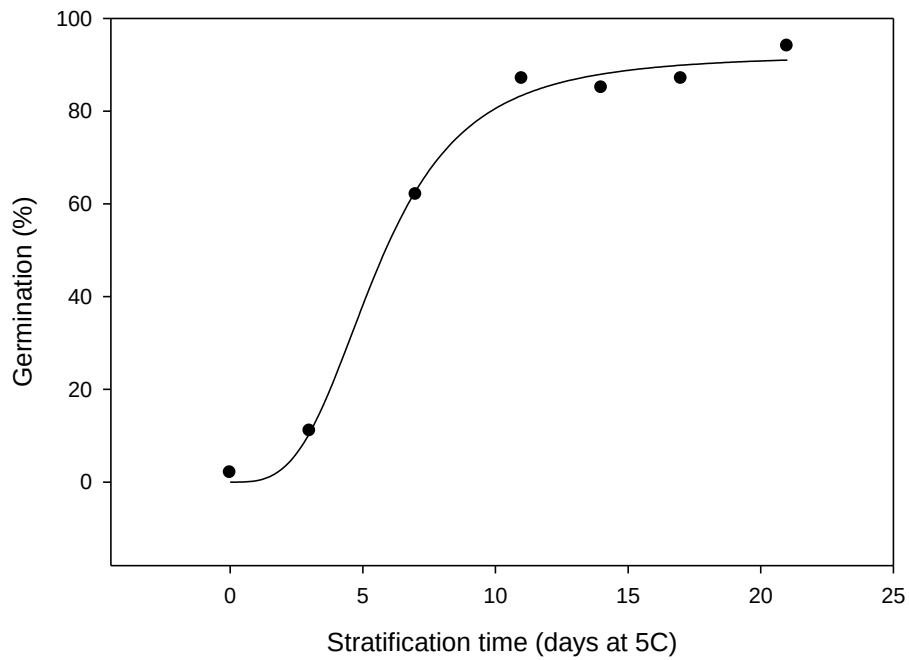


Figure 2. Effect of cold stratification at 39 to 43 °F (4-6 °C) on scarified basalt milkvetch seeds. All seeds were scarified for 30 minutes in concentrated sulfuric acid prior to stratification.

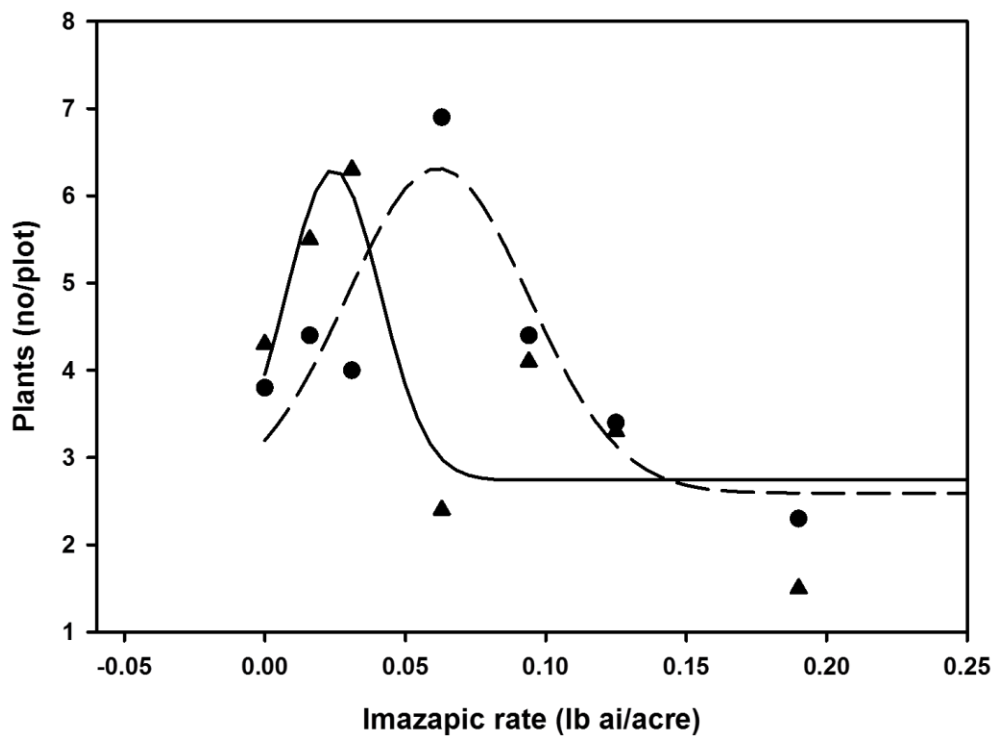


Figure 3. Response of basalt milkvetch plant density to various rates of imazapic applied in either the spring (circles) or the fall (triangles).

Table 1. Germination of Blue Mountain prairie clover and germination and number of cotyledons of basalt milkvetch in response to herbicide treatments in the greenhouse

Treatment	Rate	Blue Mountain prairie clover	basalt milkvetch	basalt milkvetch
	oz ai/acre	emergence (% of untreated)		leaves/pot
Untreated		100 abcd	100 abc	1.25 abc
Plateau	0.0235	80 cde	125 a	1.50 ab
Plateau	0.047	88 cde	96 abc	0.75 bcdef
Plateau	0.094	60 def	118 ab	0.50 cdef
Plateau	0.188	80 cde	89 abc	0.375 def
Plateau	0.375	100 abcd	111 abc	0.125 ef
Plateau	0.75	72 de	68 bc	0.125 ef
Plateau	1.5	96 bcd	132 a	0.125 ef
Plateau	3.0	76 cde	100 abc	0.125 ef
Matrix	0.0158	72 de	61 c	0.50 cdef
Matrix	0.0314	72 de	93 abc	0.75 bcdef
Matrix	0.063	56 def	82 abc	0.125 ef
Matrix	0.126	88 cde	68 bc	0.00 f
Matrix	0.25	80 cde	61 c	0.125 ef
Matrix	0.5	16 f	64 c	0.00 f
Matrix	1.0	128 abc	68 bc	0.00 f
Prowl H ₂ O	1.5	144 ab	96 abc	0.875 abcdef
Prowl H ₂ O	3.0	148 a	121 a	1.125 abcd
Prowl H ₂ O	6.0	84 cde	93 abc	1.00 abcde
Prowl H ₂ O	12.0	100 abcd	96 abc	1.125 abcd
Prowl H ₂ O	24.0	92 bcde	118 ab	1.25 abc
Outlook	1.5	56 def	61 c	0.25 def
Outlook	3.0	40 ef	104 abc	0.25 def
Outlook	6.0	60 def	100 abc	0.25 def
Outlook	12.0	92 bcde	68 bc	0.00 f

Means within a column followed by the same letter do not differ significantly according to the LSD test at $p=0.05$.

Project Title Development of Seeding Equipment for Establishing Diverse Native Communities

Project Agreement No. 09-JV-11221632-068

Principal Investigators and Contact Information

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Project Description

Background

The historical rangeland drill that was designed, developed, and first manufactured in the late 1940's and early 1950's has been the backbone of restoration and reclamation research for over 60 years. This untiring tool has re-seeded millions of acres in many areas, but as researchers learned more about soils, plant diversity, and habitat restoration there has been increased interest in updating and improving this tool.

Design of a New Rangeland Drill

The Truax Company from New Hope, Minnesota took up the challenge to design a better rangeland drill 14 years ago and has worked with the U.S. Department of Agriculture Forest Service, USDI Bureau of Land Management, U.S. Department of Defense, and other non-governmental organizations to improve the restoration success rate achieved by researchers to:

- Improve the habitat diversity
- Improve seeding economics
- Control erosion on disturbed lands

Improving habitat diversity requires the introduction of multiple species of native grasses and forbs into existing stands. This has been challenging when using historic, as well as current "Rangeland" drills because of the closeness of planter assemblies and therefore their inability to plant in trashy sites. Rangeland drill planters are on 12-inch (30.5 cm) row spacing; however, the discs and mounting hardware take up all but 2 inches (5 cm) of the space between individual planting units. As a result, the drill becomes a giant rake when used for interseeding on sites with existing vegetation. Truax overcame this problem by adding a second rock shaft that increases the individual spacing between rakes to 48 inches (122 cm) and side-to-side spacing between planters to 24 inches (61 cm). This increased spacing between planters allows the Truax Roughrider to plant through sites with heavy litter without plugging or raking litter. Unfortunately, little attention has been paid to the need to introduce multiple native species to existing range sites and over the last 10 to 15 years only a few trials were directed to this important issue.

The engineering that resulted in the two-rock shaft design complicated the Truax Roughrider Rangeland Minimum Till Drill in several ways. For example:

- The two rock shafts were made of solid steel bars (2.5× 2.5 inches [6.4 × 6.4 cm]) and added a lot of weight. Re-engineering the stroke control knuckles in 2011 allowed us to change to structural tubing and reduced the weight of the Roughrider by nearly 1,000 lbs (450 kg).
- The long distance to the individual planters required three telescoping seed delivery tubes in early production drills; however, re-engineering in 2005 and 2006 allowed us to move the seed boxes forward and reduce the number of tubes to two. This modification was followed by a second re-engineering in 2011 to modify the seed tube mounts under the seed boxes.
- Fabricated boots or shoes on early production drills had open tops that allowed dirt, mud, and snow to enter and thereby plug the seed delivery unit. Re-engineering in 2007 and 2008 and changing to ductile iron boots solved the dirt-plugging problems; yet, this resulted in an internal plugging problem. Re-engineering in 2011 identified a 37% restriction of the seed passage way in the ductile casting which was then subsequently changed to allow free flow of the seed to the ground.
- Weight transfer from machine mass to individual planting units is achieved through flexible-stroke control knuckles. Early production drills experienced a lot of frame breakage and damage because the control knuckles moved only in one direction. Re-engineering in 2011 changed the stroke control knuckle to allow free movement in the both directions when placed under load and reduced frame breakage and damage to zero.
- Metal seed tube lengths varied between rows and between drills because of the inherent, manufactured twist in the hot rolled material used in the rock shafts, which affected the clamp point of the tube attachment. A change to structural tubes for the rock shafts in 2011 resolved this problem.

Several other changes and improvements have been made to the Truax Roughrider Minimum-till Drill to increase its performance, including:

- The gage wheels were changed in 2012 from a semi-pneumatic style to a solid rubber, 90 durometer tire that is vulcanized to a steel backing plate that is then bolted to the disc blade.
- The drive-wheel linkage was changed in 2012 to an adjustable/clevis style, which allowed the operator to compensate for misalignment of the linkage.
- Molded rubber elbows were added in the 2008 re-engineering and replaced the open neck boots, which were subject to plugging.

Decreasing Seed Waste in Restoration

Restoration economics can be improved through small reductions in the seeding rate per acre, which is particularly important for landscape-scale projects. Current and historical rangeland drills are calibrated from the perspective that "if a little seed is good, then a lot of seed is better" with little consideration given to minimizing the quantity of seed needed by maximizing controlled seed placement.

Rangeland drills typically plant by allowing a concave disc to open a furrow 1 to 4 inches (2.5-10 cm) deep and then broadcasting seeds into the furrow before dragging a chain across the surface to randomly cover the seed. This is called "drill seeding." To broadcast seed using conventional rangeland drills you follow the same protocol but without the drag chain. Unlike these drill seeding methods, the Truax Roughrider Minimum Till Drill utilizes a flat planting disc with an attached rubber 3 × 18-inch (8 × 46 cm) depth gage tire to assure that the furrow is no deeper than 0.75 inch (2 cm), so that seed is planted at a depth of 0.5 to 0.75 inch (1-2 cm) with a following, independent rubber press wheel to firm the soil over the planted seed.

During the course of research and development, several changes and improvements have been made in addition to those mentioned in the previous section to improve seed placement and potentially reduce the quantity of seed needed.

- An internal seed deflector was added to the Roughrider boot to help move the seed to the bottom of the furrow. Failure led us to remove the internal deflector after several attempts proved ineffective.
- Wind deflectors were added to the top of the seed delivery tubes and later improvements included a closed seed tube or hose from the seed cup down to the metal seed tube.
- Aluminum seed transitions had their incline angle changed to help prevent plugging of the front rank of planters.
- Planter mud scrapers were moved to a higher location to help deflect mud.
- Mud scraper material was changed to heat-treated spring steel for greater durability.

These changes, as well as improvements currently being made, help users to better control placement of seed and reduce waste of valuable seed supplies.

Minimizing Erosion

Erosion control, whether by wind or water, can be a major limiting factor to success when restoring rangelands. The historical rangeland drills did little to control erosion from wind or water, and in fact, contributed to increased erosion. The deep furrowing action of the concave discs loosened soils, which were later blown away. Loose soil would hold some rainfall if drilling was done on the contour; however, furrows would contribute to riling actions if the drilling was not done on the contour.

Seeding Wyoming Big Sagebrush

Unlike conventional rangeland-drills the Truax Roughrider Minimum-till Drill can micro-plant multiple species. The single disc openers of the Roughrider open a controlled depth seed slot for the metered seed to be deposited. Soil crusts are not destroyed and important soil cryptograms are left intact. More importantly, existing species, which have survived the disturbance caused by fire or construction, are able to reestablish themselves because they are not plowed under by the conventional rangeland drill's concave discs. Most importantly the Truax Roughrider Minimum-till Drill has addressed the historical challenge of establishing Wyoming big sagebrush (*Artemisia tridentata* subsp. *wyomingensis*) after disturbances.

Proper seed placement and getting soil to seed contact for Wyoming big sagebrush has challenged researchers for years, and it was only after a U.S. Forest Service scientist's observation and suggestion that the first Roughrider Imprinter was installed and tested. The first plantings done with the imprinter were spotty and had a lot of skips. It became apparent that the lack of mud scrapers allowed dirt and seed to stick to the rolling imprinter and then drop off several feet down the row, much like snow does when rolling a large snow ball. The addition of effective mud scrapers solved this problem. A second problem involved the blowing of seed as it dropped in front of the rolling imprinter wheel. A 6-inch (15 cm) rubber hose was added below the metal tube to carry the seed close to the ground so it could be immediately pressed into the soil surface. It is estimated that up to 40% of the seed was blown away before the imprinter could press it into the soil surface.

Conclusion

A lot has been learned about ways to improve the equipment to restore and repair disturbed rangelands; however, there can always be more improvements.

Project Title Seeding Native Species following Wildfire in Wyoming Big Sagebrush (*Artemisia tridentata* ssp. *wyomingensis*)

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Project Description

The cycle of annual weed invasion and wildfire has altered western shrublands, disrupted ecosystem functioning, and increased wildfire size, intensity, and frequency. These impacts are costly in terms of losses to native species and ecosystems. Postfire seeding provides an opportunity to stabilize and revegetate at-risk shrublands. United States Department of Interior, Bureau of Land Management policies and regulations encourage the use of native species, but improved seeding equipment and strategies are required to increase the success of multi-species native seedings. We examined the effectiveness of two drills, a conventional rangeland drill and a minimum-till drill, techniques for seeding small-seeded species, and sagebrush seeding rates as approaches for re-establishing native species in Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) shrublands following wildfire.

Objectives

We sought to evaluate the general effectiveness of different drill types and seeding techniques for establishing native plants and suppressing exotic annual weeds in burned Wyoming big sagebrush communities. Our experiment compares conventional vs. minimum-till drills, drill-broadcasting vs. aerial broadcasting in fall and winter, and different seeding rates for Wyoming big sagebrush. We monitored density and cover of individual species for two years following treatment applications at four sites where the experiment was replicated.

Methods

Study Sites and Experimental Treatments

Postfire seeding treatments were established at four locations in the northern Great Basin following wildfires in 2007 to 2010 (Figure 1; Table 1). A total of 13 treatments differing by drill type (conventional rangeland drill or minimum-till drill), seeding method, and sagebrush seeding rate (Table 2) were applied to 99 × 230-foot (30 m × 70 m) plots in fall or winter following each fire. A randomized complete block design with five blocks was replicated at each site. A drill seed mix (large seeds) was seeded in alternate rows (Table 3). The seed passed from the large seed box through the drill assembly of each drill. The broadcast mix (small seeds) (Table 3) was allowed to fall to the soil surface of the intervening rows from the broadcast seed box and was covered by chains (conventional drill) or imprinter units (minimum-till drill). Aerial seeding was simulated by hand-seeding the broadcast mix in fall or winter on plots that had been drill-seeded in alternate rows with the broadcast seed boxes empty. All plots were fenced to exclude livestock.



Figure 1. Northern Great Basin postfire seeding locations.

Data Collection

Vegetation data were collected at each site during the first two growing seasons following protocols modified from Herrick et al. (2005) and Wirth and Pyke (2007). Five 66-foot (20 m) transects were established 33 feet (10 m) apart, perpendicular to the long axis of each plot. Density of seeded species and cheatgrass (*Bromus tectorum*) was recorded for each of four quadrats along each transect. Canopy cover by species was recorded by line point intercept at 20 points along each transect.

Data Analysis

Data were parsed into sets containing relevant treatments for each species (Table 2). All thirteen treatments were included for Wyoming big sagebrush, but the 1X and 10X sagebrush seeding rate treatments were excluded for other broadcast species. Analyses of drilled species and cheatgrass focused on five treatments: three unseeded and two 5X seeded treatments (Table 2). Each seeded species was analyzed only for the sites where it was seeded (Table 3). We ultimately merged all drilled species into a single category. The broadcast species rubber rabbitbrush (*Ericameria nauseosa*) and penstemon (*Penstemon* spp.) are excluded from this report.

For each species with relevant treatments, density and cover were analyzed in SAS 9.3 (SAS Institute Inc. 2011) as general linear mixed effects models with the Poisson or negative binomial distribution. Treatment and year were modeled as fixed effects; site and block were nested random effects. We built models testing treatment, year, and treatment-year interactions. We used Tukey's HSD for mean comparisons.

Table 1. Northern Great Basin study locations, fire and seeding dates, and site attributes

Location	Mountain Home	Glass Butte	Scooby	Saylor Creek
	42°58'42" N, 115°37'57" W	43°31'44" N, 119°54'4" W	41°51'16" N, 113°2'46" W	42°39'43" N, 115°28'18" W
County, State	Elmore, ID	Lake, OR	Box Elder, UT	Elmore, ID
Wildfire date	6 Jul 2007	5 Jul 2007	22 Sep 2008	29 Jun 2010
Fall seeding date	29-30 Oct 2007	31 Oct-1 Nov 2007	18-19 Nov 2008	27-28 Oct 2010
Winter broadcast date	18 Jan 2008	16 Jan 2008	29 Jan 2009	15 Feb 2011
Elevation (m)	911	1,430	1,422-1,475	1,204
Annual precip. (mm) ¹	178-305	203-305	203-356	203-330
Frost-free days ¹	100-170	50-90	100-150	90-170
Soils ¹	Coarse-silty, mixed, superactive mesic Xereptic and Xeric Haplocalcids	Ashy, glassy, frigid Vitriorrandic Haploxerolls	Loamy- skeletal, mixed, mesic Xeric Haplocalcids; Sandy-skeletal, mixed, mesic Xeric Torriorthents	Fine-silty, mixed, superactive, mesic Haploxeralfic Argidurids, Durinodic Xeric Haplargids, and Xeric Natridurids

¹Soil Survey Staff (2011).

Table 2. Postfire drilling and seeding treatments applied in the northern Great Basin

Drill	Drill mix ¹	Broadcast mix ²	Wyoming big sagebrush seeding rate ²	Relevant Treatments		
				Wyoming big sagebrush	Other broadcast species ³	Drilled species, cheatgrass
No drill	No seed	No Seed	No Seed	x	x	x
Conventional drill	No seed	No Seed	No Seed	x	x	x
	Drilled in alternate rows in fall	Broadcast through drill in alternate rows in fall	1X	x		
			5X	x	x	x
			10X	x		
		Hand broadcast in fall	5X	x	x	
		Hand broadcast in winter	5X	x	x	
Minimum-till drill	No seed	No Seed	No Seed	x	x	x
	Drilled in alternate rows in fall	Broadcast through drill in alternate rows in fall	1X	x		
			5X	x	x	x
			10X	x		
		Hand broadcast in fall	5X	x	x	
		Hand broadcast in winter	5X	x	x	

¹One drill mix was used for all seeding treatments.

²The broadcast mix varies among treatments only by the Wyoming big sagebrush seeding rate.

³Broadcast species other than Wyoming big sagebrush, e.g. Sandberg bluegrass, western yarrow.

Results and Discussion

Wyoming big sagebrush

First-year seedling density of Wyoming big sagebrush was near zero in the three non-seeded control treatments and was not significantly higher than controls in the winter hand-broadcast and 1X conventional drill-broadcast treatments (Figure 2). Sagebrush density in all other drill-broadcast treatments was higher than controls, increased with each increased seeding rate, and was higher for minimum-till than conventional drill treatments at each seeding rate (Figure 2). Sagebrush density was similar in the conventional drill + fall hand-broadcast treatment and the minimum-till drill-broadcast treatment at the equivalent rate (5X), and both treatments exceeded the sagebrush density resulting from the conventional drill-broadcast (5X) or the minimum-till + fall hand-broadcast treatments. Sagebrush density declined in all treatments by the second year but treatment differences remained (Figure 2). Sagebrush cover was low across all treatments in both years and could not be adequately modeled in SAS.

Table 3. Seed mixes for postfire seedings in the Northern Great Basin

MT.	Broadcast mix		Seed origin	PLS (%)	PLS*/m ²		
					1X**	5X	10X
HOME		<i>Artemisia tridentata</i> spp. <i>wyomingensis</i>	Lincoln/Blaine/Jerome Co., ID (1230 m)	20.9	52	262	525
		<i>Ericameria nauseosa</i>	Uinta Co., WY (2060m)	27.0	86	86	86
		<i>Poa secunda</i>	Mountain Home Germplasm	83.9	91	91	91
		<i>Penstemon deustus</i>	Northern Great Basin - pooled	56.2	76	76	76
Total Broadcast					305	515	778
	Drill mix						
		<i>Pseudoroegneria spicata</i>	Anatone Germplasm	86.3	67	67	67
		<i>Achnatherum hymenoides</i>	'Rimrock'	85.7	51	51	51
		<i>Elymus elymoides</i>	Toe Jam Creek Germplasm	91.6	47	47	47
		<i>Sphaeralcea munroana</i>	Utah Co., UT (1470 m)	53.2	93	93	93
		<i>Eriogonum umbellatum</i>	Northern Great Basin - pooled	61.0	8	8	8
Total Drill					266	266	266
Total Drill + Broadcast					571	781	1044
GLASS	Broadcast mix						
BUTTE		<i>A. tridentata</i> ssp. <i>wyomingensis</i>	Elko/Humboldt Co., NV (1220-1830 m)	29.3	52	234	495
		<i>Ericameria nauseosa</i>	Uinta Co., WY (2060 m)	27.0	86	86	86
		<i>Poa secunda</i>	Mountain Home Germplasm	83.9	91	91	91
		<i>Penstemon deustus</i>	Northern Great Basin - pooled	56.2	76	76	76
Total Broadcast					305	487	748
	Drill mix						
		<i>Pseudoroegneria spicata</i>	Anatone Germplasm	86.3	67	67	67
		<i>Achnatherum hymenoides</i>	'Rimrock'	85.7	51	51	51
		<i>Elymus elymoides</i>	Toe Jam Creek Germplasm	91.6	47	47	47
		<i>Sphaeralcea munroana</i>	Utah Co., UT (1470 m)	53.2	93	93	93
		<i>Eriogonum umbellatum</i>	Northern Great Basin - pooled	61.0	11	11	11
Total Drill					269	269	269
Total Drill + Broadcast					574	756	1017

				Broadcast mix	Seed origin	PLS (%)	PLS* /m ²
					X**	5X	10X
SCOOBY	Broadcast mix						
		<i>A. tridentata</i> spp. <i>wyomingensis</i>	Sanpete Co., UT (1460 m)	17.5	52	234	495
		<i>Ericameria nauseosa</i>	Sanpete Co., UT (1460 m)	14.8	86	86	86
		<i>Poa secunda</i>	Mountain Home Germplasm	81.6	91	91	91
		<i>Achillea millefolium</i>	Eagle Germplasm	88.2	100	100	100
		<i>Penstemon cyaneus</i>	Lincoln Co., ID (1370 m)	69.2	76	76	76
				Total Broadcast	405	587	848
	Drill mix						
		<i>Pseudoroegneria spicata</i>	Anatone Germplasm	88.9	67	67	67
		<i>Achnatherum hymenoides</i>	'Rimrock'	98.0	51	51	51
		<i>Elymus elymoides</i>	Toe Jam Creek Germplasm	94.3	47	47	47
		<i>Sphaeralcea munroana</i>	Uintah Co., UT (1550 m)	65.8	93	93	93
		<i>Eriogonum umbellatum</i>	Northern Great Basin - pooled	50.4	11	11	11
				Total Drill	269	269	269
				Total Drill + Broadcast	674	856	1117
SAYLOR	Broadcast mix						
CREEK		<i>A. tridentata</i> spp. <i>wyomingensis</i>	Power Co., ID (1390 m)	28.4	50	250	500
		<i>Ericameria nauseosa</i>	Utah Co., UT (1650 m)	40.5	85	85	85
		<i>Poa secunda</i>	Mountain Home Germplasm	82.0	100	100	100
		<i>Achillea millefolium</i>	Eagle Germplasm	94.3	100	100	100
		<i>Penstemon speciosus</i>	Northern Great Basin - pooled	57.8	15	15	15
				Total Broadcast	350	550	800
	Drill mix						
		<i>Pseudoroegneria spicata</i>	Anatone Germplasm	80.0	60	60	60
		<i>Achnatherum hymenoides</i>	'Rimrock'	96.6	50	50	50
		<i>Elymus elymoides</i>	Emigrant Germplasm	97.0	35	35	35
		<i>Achnatherum thuberianum</i>	Snake River Plain - pooled	55.4	30	30	30
		<i>Hesperostipa comata</i>	Millard Co., UT	77.6	20	20	20
		<i>Sphaeralcea munroana</i>	Uintah Co., UT (1550 m)	61.0	40	40	40
		<i>Astragalus filipes</i>	Deschutes Co., OR (1330 m)	90.0	14	14	14
				Total Drill	249	249	249
				Total Drill + Broadcast	599	799	1049
*Pure live seed; **Drill seed mix does not vary among treatments. Broadcast mix varies only by big sagebrush seeding rate, see Table 2.							

Sandberg bluegrass

Sandberg bluegrass (*Poa secunda*) was unique in having a substantial number of residual plants that survived fire. Consequently, the non-drilled, non-seeded control treatment had Sandberg bluegrass densities similar to any of the other treatments except the minimum-till drill-broadcast, which had significantly greater density (Figure 3). The non-seeded conventional drill treatment had lower Sandberg bluegrass density than the non-seeded minimum-till (Figure 3), suggesting conventional drill-induced mortality of residual plants. In the conventional drill-broadcast and conventional + fall hand-broadcast treatments, any such mortality was mitigated by new seedlings, but the conventional + winter hand-broadcast treatment was not significantly different from the conventional non-seeded control (Figure 3). Among minimum-till treatments, Sandberg bluegrass density did not differ between the non-seeded treatment and the hand-broadcast treatments but was significantly higher for drill-broadcast compared to non-seeded and fall hand-broadcast treatments (Figure 3). These treatment differences are applicable to both years because there was no treatment by year interaction, although Sandberg bluegrass densities for year 2 were lower than year 1 (Figure 3). Sandberg bluegrass cover, in contrast to density, increased from year 1 to year 2 (data not shown).

Western Yarrow

Western yarrow (*Achillea millefolium*) density and cover were significantly higher in seeded than non-seeded treatments regardless of broadcasting method, time of seeding, or drill type (Figure 4). Western yarrow density did not differ between seeded treatments, but cover was significantly greater in the minimum-till drill-broadcast than other seeded treatments (Figure 4). Year was non-significant for western yarrow density, implying no density difference between years within treatments, but western yarrow cover increased from year 1 to year 2 (Figure 4).

Drilled Species

Individual drilled species responded similarly to drilling and seeding treatments and could therefore be modeled collectively as a group (Figure 5). Density and cover of drilled species were higher in seeded than non-seeded treatments but did not differ by drill type within years in seeded treatments (Figure 5). Density decreased but cover increased between the first and second years in seeded treatments (Figure 5).

Cheatgrass

First-year cheatgrass density was lower in the conventional drill treatments, seeded and non-seeded, than in the non-drilled non-seeded control (Figure 6). First-year cheatgrass cover was lower in the conventional drill-seeded treatment than in the non-drilled non-seeded control and the minimum-till treatments (Figure 6). By the second year, cheatgrass cover had more than doubled in all treatments, and conventional drill treatments no longer differed from the non-drilled non-seeded control (Figure 6). On the other hand, second year cheatgrass cover was lower in seeded treatments for both drill types than in the non-seeded minimum-till treatment (Figure 6). These results suggest that conventional drill tillage reduced cheatgrass abundance via seed burial during the first year, but competition from seeded plants became a more important factor by the second year. Conventional drill furrows lacking perennial plants appeared to be favorable microsites for cheatgrass seed accumulation and germination.

Future Plans

Fifth-year monitoring has been or will be carried out at our study sites to evaluate longer-term treatment effects. We plan to examine more closely the influence of weather patterns on plant establishment and success across these and other experimental study sites. Vegetation recovery following a new fire (2012) at the Saylor Creek site is also under investigation.

Management Applications and/or Seed Production Guidelines

Large-seeded native species such as bluebunch wheatgrass (*Pseudoroegneria spicata*), bottlebrush squirreltail (*Elymus elymoides*), and Indian ricegrass (*Achnatherum hymenoides*) were readily established with either the conventional rangeland drill or the minimum-till drill. Small-seeded species such as Wyoming big sagebrush, Sandberg bluegrass, and western yarrow established equally well or better when broadcast seeded through drills than when aerially broadcast seeded (simulated by hand-broadcasting) in fall or winter. The minimum-till drill plus imprinter unit combination worked particularly well for establishing small-seeded species including Wyoming big sagebrush, which reached its greatest density at drill-seeding rates of about 500 PLS/m². A one-pass seeding of large- and small-seeded species through the minimum-till drill could be just as effective as and more economical than drilling large-seeded species followed by aerial seeding. Use of the minimum-till drill may also result in less loss of residual Sandberg bluegrass than the conventional drill. Conventional drilling has the benefit of reducing cheatgrass density during the first year following treatment, but in the absence of perennial plant establishment this effect is likely short-lived.

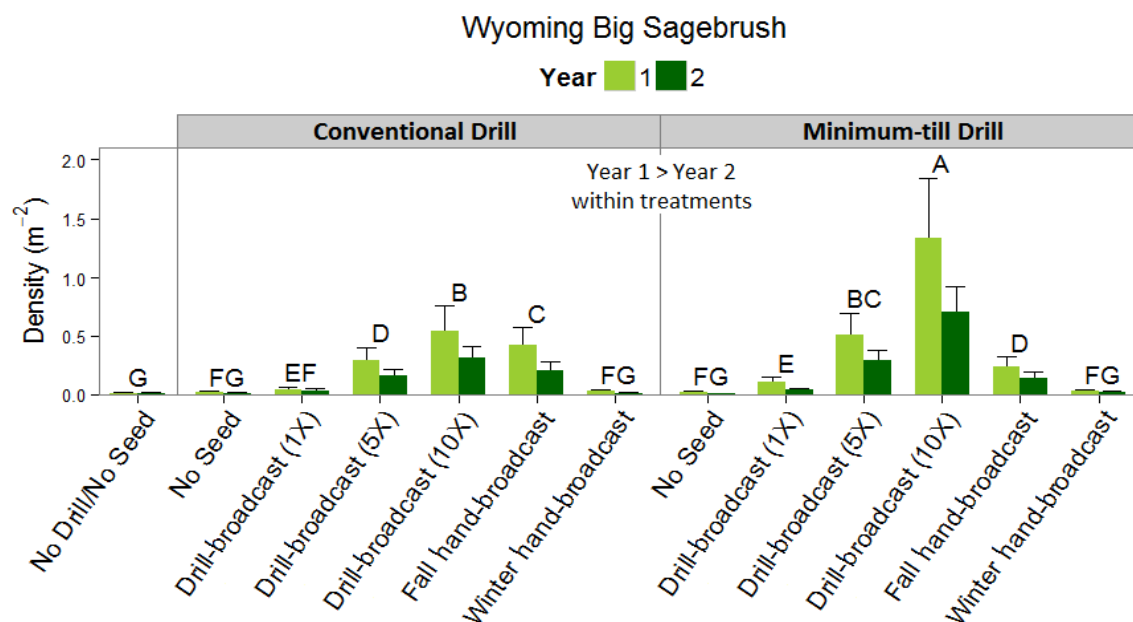


Figure 2. Wyoming big sagebrush density by seeding treatment and year following wildfires on four sites in the northern Great Basin, showing means (bars) and standard errors (error bars). Means with the same letter are not significantly different ($p < 0.05$). The treatment by year interaction term is not significant, but means differ by year within treatments ($p < 0.05$).

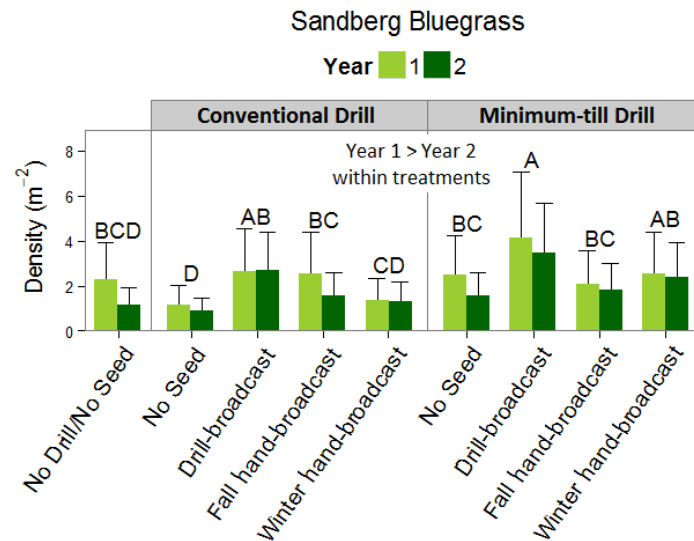


Figure 3. Sandberg bluegrass density by seeding treatment and year following wildfires on four sites in the northern Great Basin, showing means (bars) and standard errors (error bars). Means with the same letter are not significantly different ($p < 0.05$). The treatment by year interaction term is not significant, but means differ by year within treatments ($p < 0.05$).

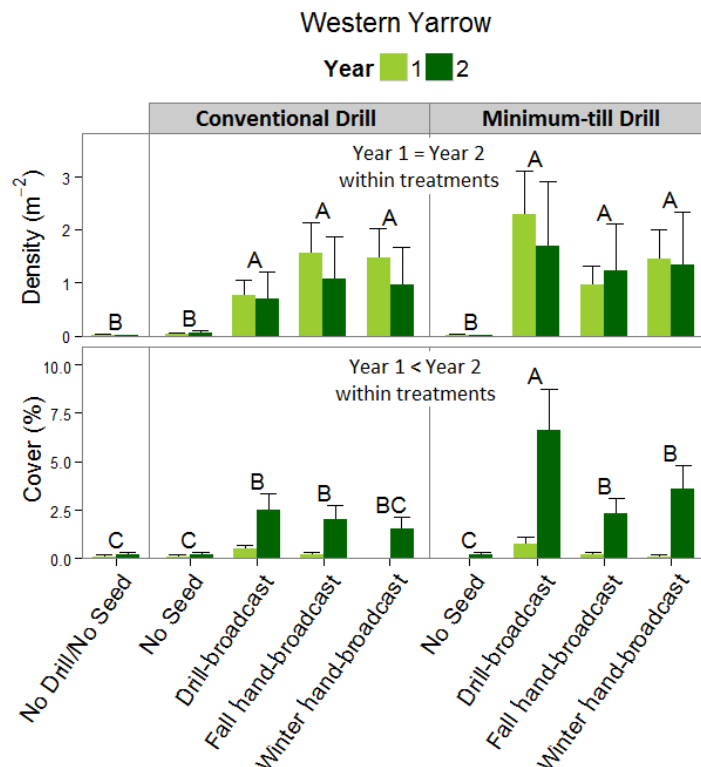


Figure 4. Western yarrow density and cover by seeding treatment and year following wildfires on two sites in the northern Great Basin, showing means (bars) and standard errors (error bars). Means with the same letter are not significantly different ($p < 0.05$). Means differed by year within treatments for cover but not density ($p < 0.05$). The treatment by year interaction term was omitted from these models.

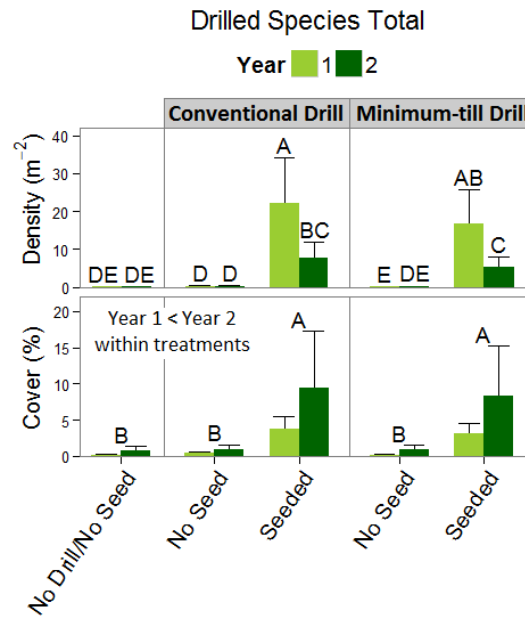


Figure 5. Density and cover of drilled species by seeding treatment and year following wildfires on four sites in the northern Great Basin, showing means (bars) and standard errors (error bars). Means with the same letter are not significantly different ($p < 0.05$). For cover, the treatment by year interaction term is not significant, but means differ by year within treatments ($p < 0.05$).

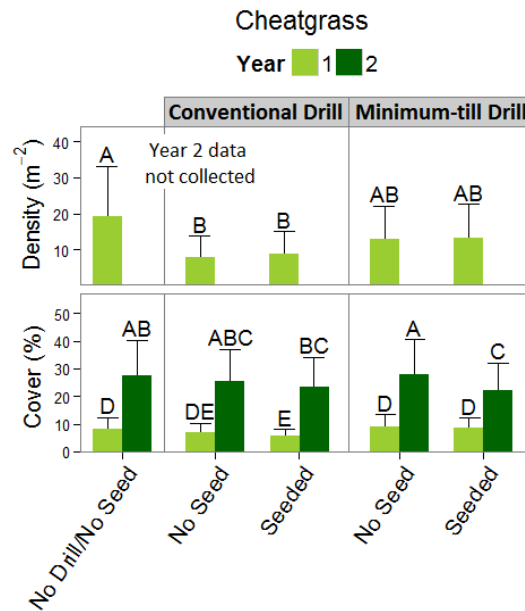


Figure 6. Cheatgrass density and cover by seeding treatment and year following wildfires on four sites in the northern Great Basin, showing means (bars) and standard errors (error bars). Means with the same letter are not significantly different ($p < 0.05$).

Presentations

Fisk, Matt R.; Shaw, Nancy L.; Cox, Robert D.; Ott, Jeffrey E. 2013. Post-fire native seeding strategies: results from a Wyoming big sagebrush site in northern Nevada. 2nd National Native Seed Conference; 2013 April 8-11; Santa Fe, NM. Abstract.

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Additional Products

Planning committee member, National Native Seed Conference, 2013 April 9-12, Santa Fe, NM. (N. Shaw)

Co-chair, planning committee, 2014 Joint Annual Meeting of the SER Northwest and Great Basin Chapters, including incorporation of sessions on native plant materials and sagebrush restoration. (Work begun summer 2013, N. Shaw)

USFS national excellence in native plant materials development and Asa Gray career achievement awards (N. Shaw)

Fisk, Matt. 2013. Moderator, Plant Materials Session. National Native Seed Conference, 2013 April 9-12, Santa Fe, NM.

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Project Title Reducing Cheatgrass: Research on *Bromus tectorum*-*Sordaria fimicola* Symbiosis and the *Fusarium-Ventenata* System

Project Agreement No. 10-CR-11221632-182

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Project Description

Objectives

A series of experiments were conducted to assess the complete life cycle of sordaria (*Sordaria fimicola*), isolate CID 323. Sordaria is being studied in order to determine whether it has a negative impact on growth of cheatgrass (*Bromus tectorum*). Additional experiments were conducted to assess the effects of sordaria on native perennial grasses and competition between native grasses and cheatgrass.

Experiments were conducted to assess the effects of endophytic fusarium (*Fusarium* spp.) isolated from ventenata (*Ventenata dubia*) on emergence and growth of ventenata, bluebunch wheatgrass (*Pseudoroegneria spicata*), and cheatgrass. Investigating the mechanisms behind the invasion of ventenata is likely to shed light on the nature of changing grassland communities throughout the region (including incursion of ventenata into cheatgrass monocultures).

Methods

Greenhouse plantings and field sites of cheatgrass were inoculated with sordaria in completely randomized (greenhouse) or randomized block (field) designs. Sordaria was grown to maturity *in vitro* in laboratory conditions, at which point inoculum was produced from spore suspensions. Inoculum was applied to cheatgrass and bluebunch wheatgrass seedlings using bottle sprayers in the greenhouse and backpack sprayers in the field. Seedlings in the greenhouse were randomized to bench position after inoculation, while treatment was randomized to position for field experiments. Observations on growth were made daily, and aboveground biomass was collected for drying and weighing.

Sordaria life cycle experiments involved the inoculation of seedlings in the greenhouse as described above. Leaf material from infected cheatgrass plants were collected two weeks post inoculation, surface sterilized, plated on potato dextrose agar to determine infection status, and incubated on sterile, washed sand. Fungal growth was observed and recorded daily.

Twenty fusarium species isolated from ventenata were grown *in agaro* and used to produce spore suspensions for treatment of seedlings. Inoculum was placed directly on seeds of ventenata, bluebunch wheatgrass, and cheatgrass, which were then covered with soilless media. Treated seedlings in 200-cell trays (one for each treatment and one seed per cell) were grown in the greenhouse and observed daily to document emergence. In some experiments, aboveground biomass of seedlings was collected 14 days after emergence for a treatment had ceased. Biomass was dried in ovens and weighed. Emergence data was analyzed using chi-squared difference in proportion tests; biomass data was analyzed using one-way ANOVA.

Results and Discussion

The Animal-Plant-Fungal life cycle of sordaria CID 323 as a dung fungus was confirmed through a series of experiments dating back to 2011 and continuing into 2013. CID 323-infected dung was used to show in a greenhouse experiment that fruiting bodies growing on the dung can directly infect cheatgrass foliage in close proximity. Spores were discharged from sordaria's perithecia from the dung onto cheatgrass foliage as confirmed by microscopic examination of leaves as well as spore traps. A low frequency of infection of cheatgrass foliar tissue by CID 323 was confirmed in the laboratory. An experiment in the laboratory showed that spores ejected from CID 323 perithecia can germinate on the surface of cheatgrass leaves and infect the plants directly. This addresses a long standing assumption in the dung-fungi literature that spores germinate primarily in the digestive tracts of herbivores and that plants act primarily as a passive medium for spores on the surface to regain entrance to the digestive tracts of herbivores. By demonstrating that spores can germinate on the leaves of cheatgrass and infect the plant, our experiments support the hypothesis that CID 323 is an endophytic dung fungus, with both animal and plant hosts.

Sordaria CID 323 was also shown in early 2013 to be able to form perithecia directly on cheatgrass foliar tissue in the absence of dung or artificial growth media. Infected tissue was incubated on sterilized, moist sand, and perithecia were observed forming on upper leaf surfaces within 21 days. Similarly, perithecia formed and clustered on the exposed leaf tissue in various artificial media, providing evidence that CID 323 can use senescent foliar tissue as an energy source to mature and complete its life cycle. Experiments are currently being repeated in the greenhouse and laboratory to demonstrate and further explore this phenomenon. Confirmation will again change the conception of sordaria as an obligate dung fungus to a fungus with a much more robust life cycle, which it can complete with or without animal hosts, as an endophyte, and possibly as a saprophyte.

In late 2012, a field experiment was started with collaborators at MPG Ranch in Montana's Bitterroot Valley to determine if inoculation timing has an effect on growth and fecundity of cheatgrass. An experiment was set up as a completely randomized blocked design, with fall and spring applications of CID 323 as treatments and a control (cheatgrass sprayed with water). Materials are currently being processed for this experiment and will produce data on how biomass and relative fecundity (seed mass per plant and number of seeds per plant) vary across treatments and controls. All treatments and controls were replicated in three different locations on the MPG ranch with different elevations, gradients, and orientations. The hypothesis being investigated is that CID 323 will have greater negative effects on cheatgrass when applied to

newly emerged seedlings in late fall than when applied to cheatgrass seedlings after vernalization in the spring.

Experiments to assess the most effective manner of inoculating both cheatgrass and native grasses in the field, laboratory, and greenhouse are ongoing. Biomass and fecundity experiments are ongoing with CID 323's effect on native perennials.

In summer 2012, researchers isolated distinctive communities of fusarium fungi from ventenata and cheatgrass root and stem tissue. Preliminary experiments determined that some fusarium isolates (about 28 distinct strains in two groups, one associated with ventenata and one with cheatgrass) have pathogenic effects on cheatgrass and bluebunch wheatgrass. Ventenata plants from which half of the *Fusaria* were isolated did *not* show signs of disease or reduced growth, whereas cheatgrass plants from which *Fusaria* were isolated were not as healthy as fusarium-free plants. This finding could support a novel-weapons hypothesis related to observed ventenata invasions over the last decade or so: namely, that ventenata may have an endophytic association with strains of fusarium, which are pathogenic to cheatgrass and native grasses, thus facilitating invasion; or, that ventenata is resistant to fusarium-related disease in a manner different from cheatgrass and native grasses, thus facilitating invasion.

Greenhouse experiments have confirmed that ventenata-associated fusarium isolates are pathogenic to bluebunch wheatgrass and cheatgrass, while having neutral or even positive relationships with ventenata itself. Experiments are providing results confirming the hypothesis that ventenata is resistant to fusarium strains that have pathogenic relationships with bluebunch wheatgrass and cheatgrass. Ventenata was shown to have slightly reduced emergence and increased biomass after being treated with combined inoculum from 10 strains of fusarium (*Fusarium ex Ventenata* or FEV) isolated from ventenata in summer 2012. The same inoculum produced markedly different results in bluebunch wheatgrass and cheatgrass. Biomass and emergence of bluebunch wheatgrass were dramatically reduced after treatment with FEV, and seedlings had levels of post emergence mortality approaching 50%. Cheatgrass had reduced biomass, a neutral emergence response, and some post emergence mortality when treated with FEV inoculum. Seeds from all three grass species were also treated with fusarium strains isolated from cheatgrass (*Fusarium ex Bromus* or FEB). Ventenata treated with FEB had increases in biomass and emergence; bluebunch wheatgrass had a negative emergence interaction and significantly reduced biomass with FEB; cheatgrass responded to FEB inoculum with a neutral response in emergence and a significantly negative response in biomass.

Individual strains of fusarium isolated from ventenata and cheatgrass were also used in individual emergence and pathogenicity studies to determine whether particular strains are pathogenic to some plants and tolerated by others. Results from the first round of testing on bluebunch wheatgrass indicated that five individual FEV isolates had significant negative effects on bluebunch wheatgrass emergence, and no FEB isolates had negative effects on bluebunch wheatgrass emergence. When investigating the effects of FEB and FEV isolates on ventenata and cheatgrass, of 10 FEV isolates tested, two had significant *positive* effects on ventenata emergence and three had significant negative effects on cheatgrass emergence. Of 10 FEB isolates tested, three had significant negative effects on ventenata and eight had significant negative results on cheatgrass. Taken together, the bulk inoculum and individual isolate experiments support the hypothesis that ventenata is associated with endophytic fungi from the

Fusarium genus, which act as pathogens towards two major competitors in the invaded range, bluebunch wheatgrass and cheatgrass.

Further experiments are being conducted in order to determine the extent to which fusarium isolates can be vertically transmitted in ventenata. Since there is also preliminary evidence from collaborators in the University of Idaho's College of Agriculture and Life Sciences suggesting that ventenata is apomictic. Vertical transmission of fusarium strains, even at low frequencies, may partly explain ventenata's ability to compete with cheatgrass and native bunchgrasses in the field. Field collections of ventenata from several regions in Idaho have contained fusarium, although identification of strain and pathogenicity will take significant time and laboratory effort. To this point, seeds from four populations of ventenata in two states, Idaho and Washington, have been tested for vertically transmitted filamentous fungi. Percentages of surface-sterilized seeds infected with fusarium vary dramatically between populations (5% to 34%), but these numbers are preliminary and represent conservative estimates. There are other obvious seed-endophytes of ventenata in all populations examined so far, including fungi in the genera *Cladosporium* and *Aureobasidium*. Exploring the relationship between these endophytes is likely to lead to new research in the next year.

Identification of fusarium strains isolated from ventenata and cheatgrass are being conducted by collaborators at Pennsylvania State University.

Management Applications and/or Seed Production Guidelines

Although exploration of the sordaria-cheatgrass-bluebunch wheatgrass system is in the preliminary stages, this work will likely lead to useful information for land managers in the future. Work on fungal endophytes, fusarium endophytes, and rhizosphere pathogens will broaden our understanding of why some native grass plantings fail, how cheatgrass and ventenata successfully invade native perennial grasslands and shrub steppe communities, and ways to potentially reduce cheatgrass and ventenata infestations.

Presentations

Fusarium-Ventenata-Bromus-Pseudoroegneria symbiosis and implications for rangeland restoration and seed production. National Native Seed Conference. 2013 April 8-11; Santa Fe, NM.

Publications

Baynes, M.; (and others). [In preparation]. A manuscript focusing on the effects of endophytic dung fungi (including but not limited to *Sordaria*) on cheatgrass.

Newcombe, G. [In preparation]. Effects of ventenata- and cheatgrass-associated *Fusaria* on emergence, biomass, and fecundity of range grasses, both exotic and native.

Newcombe, G.; Baynes, M.; Griffith, D.; (and others). [In preparation]. The life cycle of *S. fimicola*, re-evaluating the life cycle of the fungus and demonstrating that it is *not* an obligate dung fungus.

Additional Products

Extension presentations on both *Sordaria-Bromus* symbiosis and the *Ventenata-Fusarium* system were made by Dave Griffith and collaborator Tim Prather (University of Idaho's College of Agriculture and Life Sciences) in June, 2013. One presentation focused on ventenata invasion of timothy (*Phleum* spp.) hay fields and control strategies. The second presentation focused on the invasion of Idaho and Washington rangelands by ventenata and was given to interested ranchers, farmers, land managers, and commercial seed producers. Field tours had 15 to 25 participants.

Appendix 1. Seed lots distributed to cooperators in 2013 by USDA FS Rocky Mountain Research Station, Boise, Idaho

Species	Common Name	Seed Origin (county, state)	Affiliation	kg
<i>Achillea millefolium</i>	western yarrow	Ada, Idaho	Boise State University	.03
<i>Achnatherum thurberianum</i>	Thurber's needlegrass	Ada, Idaho	Texas Tech University	.03
<i>Agoseris glauca</i>	pale agoseris	Humboldt, Nevada	Texas Tech University	.005
<i>Artemisia tridentata</i>	big sagebrush	Casper, Wyoming	Texas Tech University	.007
<i>Astragalus filipes</i>	basalt milkvetch	Malheur, Oregon	USDA FS National Seed Laboratory	N/A unclean
<i>Atriplex canescens</i>	fourwing saltbush	Utah	Texas Tech University	1.75
<i>Balsamorhiza hookeri</i>	Hooker's balsamroot	Ada, Idaho	USDA FS National Seed Laboratory	N/A unclean
<i>Balsamorhiza hookeri</i>	Hooker's balsamroot	Ada, Idaho	USDA FS National Seed Laboratory	N/A unclean
<i>Balsamorhiza hookerii</i>	Hooker's balsamroot	Ada, Idaho	Texas Tech University	.015
<i>Balsamorhiza sagittata</i>	arrowleaf balsamroot	Ada, Idaho	Texas Tech University	.016
<i>Ericameria nauseosus</i>	rubber rabbitbrush	Utah, Utah	Texas Tech University	.065
<i>Erigeron pumilus</i>	shaggy fleabane	Eureka, Nevada	Texas Tech University	.001
<i>Eriogonum heracleoides</i>	parsnipflower buckwheat	Boise, Idaho	Texas Tech University	.01
<i>Grayia spinosa</i>	spiny hopsage	Malheur, Oregon	Texas Tech University	.014
<i>Lomatium dissectum</i>	fernleaf biscuitroot	Ada, Idaho	USDA FS National Seed Laboratory	N/A unclean

<i>Lomatium dissectum</i>	fernleaf biscuitroot	Owyhee, Idaho	USDA FS National Seed Laboratory	N/A unclear
<i>Lomatium grayi</i>	Gray's biscuitroot	Ada, Idaho	USDA FS National Seed Laboratory	N/A unclear
<i>Lomatium grayi</i>	Gray's biscuitroot	Gooding, Idaho	USDA FS National Seed Laboratory	N/A unclear
<i>Lomatium triternatum</i>	nineleaf biscuitroot	Ada, Idaho	USDA FS National Seed Laboratory	N/A unclear
<i>Lomatium triternatum</i>	nineleaf biscuitroot	Ada, Idaho	USDA FS National Seed Laboratory	N/A unclear
<i>Penstemon speciosus</i>	royal penstemon	Malheur, Oregon	USDI BLM Birds of Prey NCA	.001
<i>Phacelia hastata</i>	silverleaf phacelia	Malheur, Oregon	Texas Tech University	.006
<i>Poa secunda</i>	Sandberg bluegrass	Owyhee, Idaho	Texas Tech University	1.0
<i>Pseudoroegneria spicata</i>	bluebunch wheatgrass	Asotin, Washington	Texas Tech University	1.55
Total Seed Distributed				4.5

Appendix 2. Utah Crop Improvement Association stock materials tagging information form

UCIA STOCK MATERIALS TAGGING INFORMATION FORM (1/4/12)

Utah Crop Improvement Assn. 4855 Old Main Hill Logan, UT 84322-4855 Ph (435) 797-2082 Fax (435) 797-0642

Please complete this form in detail when requesting certification tags for plant materials sent to growers for stock increase.
Date _____ Propagative type (seeds, plants, cuttings, etc.) _____ Amount sent _____ Date sent _____

Breeder/Developer	
Agency/Company	
Address	
Phone/Cell	Email

Stock Material Recipient	
Address	
Phone/Cell	Email

Species	Common Name
---------	-------------

DEVELOPMENTAL STAGE:

☐ A.	Pre-variety Germplasm (SI, S, or T germplasm not intended for variety release)
☐ B.	Experimental Variety (germplasm being developed for variety release)
☐ C.	Released Variety

DEVELOPMENTAL STAGE DETAILS:

A. **Pre-Variety Germplasm** Source Identified (SI) _____ Selected (S)*₁ _____ Tested (T)*₁ _____

*₁ Developmental details (official release notice or equivalent information) on file with appropriate certification agency

1. PVG Official Release: Completed _____ Intended _____ Not Intended _____

2. Germplasm Identification Term (Germplasm ID): _____ *₂

*₂ Optional for SI, recommended for S, T.

3. Material Transfer Agreement required?*₃ Yes _____ No _____

*₃ If developer wishes to maintain intellectual property rights.

4. Generation of this stock material, and Generation limitation (if specified): G__/G__

5. Stock material lot #: _____ *₄ Seed Certification # _____ (if assigned)

*₄ Unique designation for this particular lot.

6. a) GO Source location if Natural-Track:

County*₅ _____ State*₅ _____ Elevation _____

*₅ Or other geographic designation; pooled plant materials may include more than one county or state; details to certification agency

b) GO indigenous? Yes _____ No _____

c) G1 origin location if Manipulated-Track*₆: County _____ State _____ Elevation _____

*₆ Where germplasm developed (as released)

7. Field production location from which this stock material was produced, if applicable:

County _____ State _____ Elevation _____

B. Experimental Variety

1. Experimental number or designation: _____
2. Material Transfer Agreement required? Yes _____ No _____
3. Certification status equivalent of this stock material:
Breeder _____ Foundation _____ Registered _____
4. Stock material lot #: _____*4 Seed Certification # _____ (if assigned)

C. Released Variety

1. Variety Name _____
2. PVP applied for? Yes _____ No _____
3. Certification status of this stock material:
Breeder _____ Foundation _____ Registered _____
4. Stock material lot #: _____*4 Seed Certification # _____ (if assigned)