Great Basin Native Plant Project
2022 Progress Report

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

GREAT BASIN NATIVE PLANT PROJECT 2022 PROGRESS REPORT

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

March 2023

Cooperators

USDA Forest Service, Rocky Mountain Research Station; USDI Bureau of Land Management; USDI Fish and Wildlife Service; USDA Forest Service, Intermountain Region; USDA Forest Service, Pacific Northwest Research Station; USDA Forest Service, Pacific Northwest Region; USDI Geological Survey, Flagstaff Campus; USDA Agricultural Research Service; Utah Department of Wildlife Resources; University of Nevada, Reno; Utah State University; Brigham Young University; Boise State University; Northern Arizona University; Oregon State University; Oregon State University, Malheur Experiment Station; Great Basin Fire Science Exchange; Great Basin Institute; The Nature Conservancy; Chicago Botanic Garden; The Understory Initiative

Citation

Francis Kilkenny, Jeffrey Ott, Sarah Barga, Jessica Irwin, Kimberly Rizkowsky, Nyika Campbell, Bryce Richardson, Elizabeth Milano, Corey Gucker. 2023. Great Basin Native Plant Project: 2022 Progress Report. Boise, ID: U.S. Department of Agriculture, Rocky Mountain Research Station. 53 p.

This document has been produced in partial fulfillment of reporting requirements for Interagency Agreements with USDI Bureau of Land Management and USDI Fish and Wildlife Service and as a communication between cooperators and stakeholders. Funding for this research came from USDI Bureau of Land Management, USDI Fish and Wildlife Service, USDA-FS Rocky Mountain Research Station, and USDA-FS Intermountain Region. The majority of presented results are preliminary and have not undergone peer-review. The findings and conclusions in this publication are those of the authors and should not be construed to represent an official USDA, USDI or US Government determination or policy.

Contents

Introduction

The Great Basin floristic region spans three Level III ecoregions (Central Basin and Range, Northern Basin and Range, and Snake River Plain) and makes up a large portion of the Intermountain West of the United States. Over 75% of the Great Basin is publicly owned and managed by the US federal land management agencies, with state agencies also managing large areas. The primary human uses of public lands are grazing and recreation, with mining and oil and gas development found in some locations. The Great Basin has a range of mostly arid and semi-arid ecosystems from salt desert through coniferous montane forests, generally distributed along elevational gradients in this topographically complex region. Sagebrush steppe is cold desert shrubland dominated by sagebrush (*Artemesia tridentata*). It is the most common ecosystem in the Great Basin, but also of the most conservation concern due to the loss of nearly half of its area to land conversion and human-mediated and natural disturbances. The Great Basin, particularly the sagebrush steppe ecosystem, is a critical habitat for many wildlife species of conservation concern, including the greater sage-grouse, pygmy rabbits, and a number of pollinator species.

Fire return intervals in most places in Great Basin sagebrush steppe have decreased from 100+ years to less than 30 years, due to ongoing annual grass invasions and increasing drought severity and length. Many plant species, sagebrush in particular, are fire-intolerant, unlike plants in arid shrub ecosystems in other parts of the western US, such as the California chaparral. Natural plant community recovery can take many years, often longer than current fire return intervals. As such, post-fire restoration and revegetation, mostly through seeding, is a critical component of conserving the Great Basin sagebrush steppe.

The Great Basin Native Plant Project (GBNPP) is a partnership between the USDA Forest Service Rocky Mountain Research Station (RMRS), the USDI Bureau of Land Management (BLM), the USDI Fish and Wildlife Service and the USDA Forest Service Intermountain Region to research and develop native plant materials for use in conservation and restoration of Great Basin ecosystems. The GBNPP was started in 2001 and produces science through support of RMRS researchers and of cooperators at other federal science agencies, universities, and NGOs. GBNPP-supported research is focused on the full plant material development and restoration cycle, as outlined by the BLM Plant Conservation Program, and on goals of the National Seed Strategy, primarily goal 2 and 3. In recent years, the GBNPP has concentrated research effort into parts of the plant material development cycle where bottlenecks occur or information is lacking. These goals include: 1) development of species selection and seed collection prioritization tools; 2) seed transfer guideline development based on native plant adaptive variation and genetics; 3) cultivation practice for species that don't fit typical agronomic frameworks; and, 4) seed mix design for long-term restoration of biodiverse Great Basin ecosystems. GBNPP cooperators are currently conducting empirical studies and information syntheses on 30 native plant species from 631 seed sources (Table 1). GBNPP has ongoing projects with 16 institutional partners.

This report focuses primarily on GBNPP research led by RMRS scientists and specialists. Section 1 gives summaries of all RMRS-led projects and sub-projects. Sections 2 through 9 outline these projects and sub-projects. Reports have been added, updated or dropped since the 2018-2021 GBNPP report. In some cases, significant portions of these sections from previous years are relevant and have been maintained with appropriate updates (sections 2, 3), while other sections have undergone significant changes or additions (sections 7, 8). Sections that were in the previous report have dropped for projects or sub-projects that have been completed, and new sections or sub-sections have been added for projects that have recently been initiated (sections 5, 6). Some projects that were listed in the 2018-2021 report under cooperator-led projects have been moved into the purview of the RMRS-led projects (sections 4, 9). This was mostly due to changes in leadership or increased involvement by RMRS scientists or specialists. As always, the line between RMRS-led and cooperator led projects can be fuzzy.

Section 10 gives brief descriptions of other ongoing cooperative projects or sub-projects led by non-RMRS researchers; these projects are all parts of ongoing agreements made through RMRS. Due to timing differences in when reporting is expected, more detailed project reports will be made available in an addendum to this report that will be provided at a later date. Section 11 list the publications that were produced through ongoing or past GBNPP projects. Lastly, the appendix contains a summary table on the species, varieties and sources that have been worked on in 2023. While this report only focuses on ongoing projects, it should be noted that publications often continue to be produced from projects that were completed recently or even years ago. It is important to continue to document the complete impact that the GBNPP has on restoration science in the Great Basin and beyond.

Francis Kilkenny
USDA Forest Service Rocky Mountain Research Station, Boise ID
January 2023

1. Rocky Mountain Research Station Project Summaries

- Workhorse Native Forb Adaptative Genetics and Plant Materials Development for Postfire Restoration of Critical Wildlife Habitat

  Purpose: Develop climate smart seed transfer zones for workhorse restoration forbs with high quality common garden and genetic data, and in alignment with species prioritized for production and use by Great Basin land management agencies

  Cooperators: *USDA Forest Service, Rocky Mountain Research Station:* Francis Kilkenny (overall project lead), Sarah Barga (overall common garden lead), Jessica Irwin (seed collection lead), Kimberly Rizkowsky (Boise crew lead), Nyika Campbell (Boise crew lead), Bryce Richardson (genetics co-lead), Elizabeth Milano, and Kas Dumroese (plant grow-out lead); *USDI Geological Survey, Flagstaff Campus:* Rob Massatti (genetics co-lead), Daniel Winkler, John Bradford; *University of Nevada Reno:* Beth Leger (Reno and Plymouth common garden lead) and Tessa Bartz; *Utah State University:* Andrew Kulmatiski (Twin Creeks common garden lead) and Julia Aaronson; *The Nature Conservancy:* Owen Baughman (Glass Butte common garden lead); *Chicago Botanic Garden:* Conservation and Land Management Program interns. *USDI Bureau of Land Management:* Alison Agneray (species prioritization); *USDI Fish and Wildlife Service:* Sarah Kulpa (species prioritization); *Great Basin Institute:* Jessica Kindred (species prioritization and seed collection); *USDA Forest Service, Intermountain Region:* Dirk Netz and Tova Spector (species prioritization and seed collection)

  Sub-Projects: Seed and tissue collection**;** Common garden array**;** Seed germination study**;** Forb genetics study

  External cooperator agreements: External cooperators help with the primary project and sub-projects, and perform additional associated studies

  - Studying patterns of local adaptation in Great Basin Forbs with Common Garden Experiment; **Cooperating institution:** *University of Nevada Reno*; **Sub-Projects:** Seedling emergence and survival in response to water availability; Competition with cheatgrass
  - Seed transfer development for important restoration forb species; **Cooperating institution:** *The Nature Conservancy*
  - Identifying Mechanisms of Native Plant Success to Improve Restoration Efforts; **Cooperating institution:** *Utah State University*; Effects of climate, soil chemistry, and soil biology on plant performance; Influence of site-specific soil microbial communities and identifying beneficial microbes

- Vegetation Succession in Post-Fire Seeding Treatments

  Purpose: Study the long-term effects of seed-mix design on successional process in plant communities after fire and seeding, with an emphasis on comparisons between conventional (including non-native species) and native-only seed mixes

  Cooperators: *USDA Forest Service, Rocky Mountain Research Station:* Jeff Ott and Francis Kilkenny; *Utah Division of Wildlife Resources:* Danny Summers; *Utah Department of Natural Resources:* Tyler Thompson; *Brigham Young University:* Steve Petersen

- Climate-Smart Restoration Tool

Purpose: Provide tools to select the best native plant seed sources for given restoration sites, both now and under future climates

Cooperators: *USDA Forest Service, Rocky Mountain Research Station:* Bryce Richardson and Francis Kilkenny; *USDA Forest Service, Pacific Northwest Research Station:* Brad St. Clair; *Conservation Biology Institute:* Nikolas Stevenson-Molnar and Brendan Ward

- Fuel treatment effectiveness at the landscape scale: a systematic review of simulation studies comparing treatment scenarios in North America

    Purpose: Synthesize knowledge and define knowledge gaps for forest and rangeland fuel treatment strategies on fire impacts at the landscape level through a review of fire simulation studies

    Cooperators: *USDA Forest Service, Rocky Mountain Research Station:* Jeff Ott, Francis Kilkenny and Terrie Jain

- Seeding Evaluation and Experimental Design Strategies (SEEDS) Project: A Partnership for Learning

    Purpose: Increase the rate learning from post-fire treatments by installing novel experimental treatments into BLM ESR and USFS BAER post-fires seedings and monitoring the full spectrum of ecosystem components and processes, with the goal of making this a standard part of all post-fire seedings in the Great Basin and Intermountain West

    Cooperators: *USDA Forest Service, Rocky Mountain Research Station:* Francis Kilkenny, Jeff Ott and Sarah Barga; *USDI Bureau of Land Management:* Anne Halford, Alison Agneray and Peggy Olwell; *USDA Agricultural Research Service:* Beth Newingham; *University of Nevada Reno:* Beth Leger; *Great Basin Fire Science Exchange*: Corey Gucker and Genie Montblanc; *USDI Fish and Wildlife Service:* Sarah Kulpa; *USDI Geological Survey:* Maddy Case and David Pilliod

- Adaptive genetic variation and seed transfer guidelines for bottlebrush squirreltail (*Elymus elymoides*)

    Purpose: Develop seed transfer zones for bottlebrush squirreltail and assess the fit of commercial germplasm releases to their source environments

    Cooperators: *USDA Forest Service, Rocky Mountain Research Station:* Jeff Ott and Francis Kilkenny; *USDA Forest Service, Pacific Nothwest Research Station:* Bradley St. Clair; *University of Nevada Reno:* Beth Leger; *USDA Agricultural Research Service*: Richard C. Johnson; *USDA Forest Service, Pacific Northwest Region:* Matthew E. Horning

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

    Purpose: Measure local adaptation and plastic trait responses across multiple environments in bluebunch wheatgrass to assess the efficacy of seed transfer zones in predicting adaptive variation across a species range

    Cooperators: *USDA Forest Service, Rocky Mountain Research Station:* Francis Kilkenny (project lead), Jessica Irwin, Kimberly Rizkowsky, Jeff Ott, Bryce Richardson and Kas Dumroese; *USDA Forest Service, Pacific Northwest Research Station*: Holly Prendeville and Brad St. Clair; *The Understory Initiative, Oregon*: Kathryn Prive; *Oregon State University*: Matt Orr and Ron Reuter; *USDI Geological Survey, Flagstaff Campus*: Rob Massatti; *USDA Agricultural Research Service*: Steve Larson and Blair Waldron

- Science Delivery – Great Basin Native Plant Project

Purpose: Disseminate GBNPP-supported science to managers, scientists and other stakeholders

Cooperators: *USDA Forest Service, Rocky Mountain Research Station:* Francis Kilkenny and Paula Silva; *Great Basin Fire Science Exchange*: Corey Gucker

2. Workhorse Native Forb Adaptative Genetics and Plant Materials Development for Postfire Restoration of Critical Wildlife Habitat

Science partners:
USDA Forest Service, Rocky Mountain Research Station: Francis Kilkenny (overall project lead), Sarah Barga (overall common garden lead), Jessica Irwin (seed collection lead), Kimberly Rizkowsky (Boise crew lead), Nyika Campbell (Boise crew lead), Bryce Richardson (genetics co-lead), and Kas Dumroese (plant grow-out lead).
USDI Geological Survey, Flagstaff Campus: Rob Massatti (genetics co-lead), Daniel Winkler, John Bradford
University of Nevada Reno: Beth Leger (Reno and Plymouth common garden lead) and Tessa Bartz
Utah State University: Andrew Kulmatiski (Twin Creeks common garden lead) and Julia Aaronson
The Nature Conservancy: Owen Baughman (Glass Butte common garden lead)

Institutional partners:
Great Basin Native Plant Project (GBNPP); USDI Bureau of Land Management, Great Basin Ecoregion; USDA Forest Service Rocky Mountain Research Station, Lucky Peak Nursery, National Forest System Intermountain Region (Region 4) and Northern Region (Region 1), Western Center for Native Plant Conservation and Restoration; USDI Fish and Wildlife Service, Nevada Office; USDI Geological Survey, Flagstaff Campus; University of Nevada, Reno; Utah State University; The Nature Conservancy; Chicago Botanic Garden; Great Basin Institute; Seeds of Success

Introduction – Restoration efforts that emphasize native germplasm adapted to local environments may be the best approach to ensure long-term ecosystem sustainability. Developing seed transfer zones, using common garden and genomic approaches, is a way to ensure that plant materials used for revegetation are adapted to a given area and that diverse genetic resources are used to enhance ecological stability and resilience. Yet there are no established seed transfer zones for most Great Basin plant species and remarkably little germplasm is conserved for future revegetation needs. At the same time land managers in the Great Basin are faced with changing fire regimes due to annual grass invasions and increasing droughts due to climate change, making sustainable restoration even more challenging into the future. As a result, extensive germplasm collection and seed transfer zone research are urgently needed to abate the erosion of native ecosystems and to improve adaptation of plant materials used for revegetation.

The majority of seed transfer guidelines developed for the Great Basin are for grass and shrub species that play important structural and functional roles in maintaining ecosystem health. However, there are over 5000 plant taxa in the sagebrush biome. Many of these are forb species that are necessary components of the diet of sage-grouse and other wildlife. Additionally, diverse forb communities are the basis of threatened pollinator habitat. Evidence is also building that current revegetation practice using conventional seed mixes containing non-native bunchgrasses, while effective for some revegetation goals, are detrimental to the restoration of biodiverse plant communities and the recovery of sage-grouse and pollinator habitat. Whereas, native-only seed mixes support biodiversity and are promising in moving plant communities toward desired ecological conditions. For native plant restoration to be successful, species will need to be chosen that can be established through seeding, can support wildlife and pollinators across the growing season, and can be cultivated for seed production. A set of forb species that fit these criteria have been identified by the BLM and USFS, and a prioritized species list for seed transfer and plant material development will continue to be curated using ecological and cultivation considerations.

As gaps in existing seed transfer knowledge are defined, common garden work and genomic analyses for identified priority species are being implemented by GBNPP partners and cooperators. Priority restoration species are being tested through a common garden array, where research responsibility is shared with teams across the Great Basin to rapidly assess plant adaptation. The benefit of a common garden array is that it will generate an economy of scale for future seed transfer work, cover a large geographic area effectively, and produce extremely high-quality trait and environmental data. Additionally, these species are being tested using next generation genomics techniques which allows for a complete synthesis of information for each species. The scale of this data collection effort is unprecedented in the Great Basin and is among the highest quality data set of its type in the world. In a time of global change these data will be critical in restoring ecosystems in the face of mounting disturbances.

Seed and tissue collection – In 2022 the RMRS Boise lab coordinated the collection of forb seed from across the Columbia, Snake and Great Basins. During this time, a total of 51 wildland collections were made, representing 4 taxa. A variety of factors were considered in selecting species for collection which include their value as sage-grouse forage, wide geographic distribution, common-ness across their range, and ease of field identification or relative distinctness from other species. The species collected include *Lomatium dissectum*, *Eriogonum umbellatum*, genus *Sphaeralcea*, and *Tetradymia spinosa*.

This year marked the final year of targeted collections for *Sphaeralcea*, which had been an ancillary target for collections since 2018. As such, significant time was spent attempting to relocate populations and fill geographic gaps. One such gap, comprising the whole of shrublands in Oregon and Washington, proved especially onerous. Despite herbarium records showing a well distributed *Sphaeralcea munroana* in this area, populations large enough to yield seed at any quantity were rare and localized.

Differential effects of spring rainfall across our study region complicated efforts to locate viable populations of target species. There appears to have been a significant transition zone of wet year versus dry year effects along a north-south axis centered at approximate 42° north latitude and varying by about 30 miles in either direction, depending on location. South of this axis, plant populations showed reduced biomass and reproduction, compared to north of the axis. Furthermore, phenological cycles were up to two weeks behind in the north, when compared to analogous habitats in the south.

Table 1. Number of field collections by RMRS Boise lab in 2022. Once seed collection each was made for Eriogonum umbellatum and Tetradymia spinosa and these were grouped under ‘Miscellaneous collections’.

Activity	#
Sphaeralcea seed collections	21
Miscellaneous Seed collections	2
Eriogonum tissue collections	22
Lomatium dissectum tissue collections	6
Unique locations	45

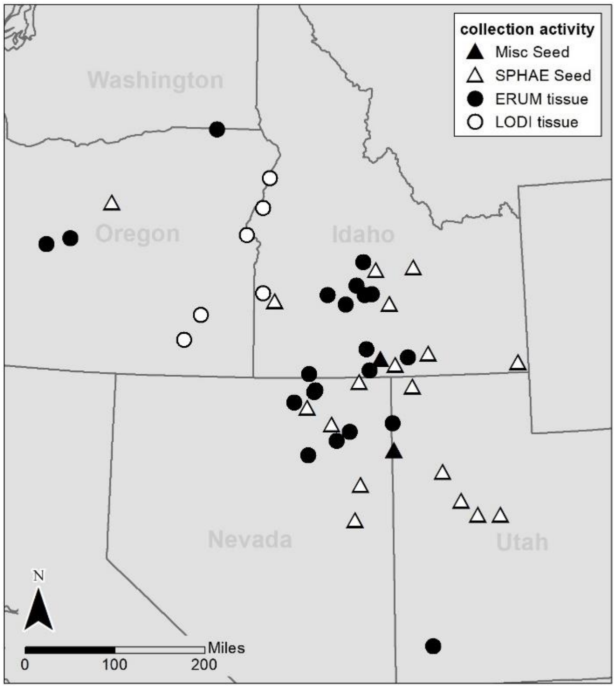


Figure 1. 2022 research collections.

Forb Common Garden Array: This is a large-scale effort being carried out by the GBNPP with the goal of examining how flexible populations of native forb species are to being moved into novel locations. To test this, and large common garden array has been installed and is being monitored throughout the growing season. This research will provide tools and information to help practitioners successfully incorporate forbs into their restoration seed mixes. With the hope of increasing the availability of genetically appropriate native plant materials and improving success in restoring native plant communities across the Great Basin.

Focal plants - Species in the common garden array include: installed 2019 - *Machaeranthera* (*Dieteria*) *canescens*, *Chaenactis douglasii*, and *Crepis accuminata*; installed 2020 - *Erigeron pumilus*; installed 2021 - *Phacelia hastata*; installed 2022 - *Balsamorhiza sagittate*; being installed in 2023 - *Crepis accuminata*; being installed in 2024 - *Sphaeralcea spp*. Experimental plants were grown at the RMRS Moscow greenhouses. Due to extenuating circumstances, the 2019 planting of *Crepis acuminata* was unsuccessful; we are partnering with Beth Leger (UNR) to attempt a second grow-out and installation in 2023.

Table 2. Plant species and populations grown for installation into the common gardens

Species	Number of Populations
Machaeranthera canescens	112
Chaenactis douglasii	89
Erigeron pumilus	39
Phacelia hastata	37
Balsamorhiza sagittata	67
Crepis acuminata	~71
Sphaeralcea spp.	~50

Common garden locations - As of fall 2022, we have installed 9 forb common gardens in 4 states across the Great Basin (Figure 2). Two of these gardens were installed in fall 2022 (Lucky Peak, Little Valley). We specifically selected sites that represent a gradient in environmental characteristics related to moisture and temperature.

Data Collection and Analysis - We selected a suite of relevant plant traits to monitor including fitness measures, like seed weight and inflorescence number, a variety of pheno-phase measures, and morphological characteristics related to local adaptation, fitness, and general performance. Monitoring of *M. canescens* and *C. douglasii* occurred in Glass Butte, Orchard, Orovada, Reno, Richfield, and Twin Creeks sites in 2020. Monitoring of *M. canenscens* continued into 2021 in Orchard and Reno sites with low survival and limited collection. Monitoring of *E. pumilus* began in 2021 and continues in Glass Butte, Orchard, Orovada, Plymouth, Reno, and Richfield sites with moderate survival. Monitoring of *P. hastata* began in 2022 in Glass Butte, Orchard, Plymouth, Reno, and Richfield sites with successful survival in all sites except Glass Butte. In the fall of 2022 we completed the installation of over 6,000 *B. sagitta* plants in Glass Butte, Orchard, Plymouth, Reno, Richfield, and Twin Creeks sites as well as in two new gardens, Lucky Peak and Little Valley.

We will continue monitoring all installed species as long as plant survival permits. Monitoring generally occurs weekly during the height of the growing season and bi-weekly during spring and fall seasons. In 2021 we began collecting data with Survey 123, enabling more accurate data collection, and streamlining the quality assurance and control process. Older data is currently managed using an Access relational database while recent data is stored in ArcGIS Online products. Processing of collected samples continues in the lab as does compilation of past data in preparation for data analysis in 2023. Table 3 shows a preliminary breakdown of planting size and survival, by site, species, and monitoring date.

First year data (for *M. canenscens* and *C. douglasii*) was collected using an outdated platform and data manipulation is taking place to reformat the data for analysis. Data reformatting took place in 2022 and should be completed this winter; data analysis will begin soon afterward. We will be working with a RMRS Statistician to create models predicting relationships between climate and population-level performance.

Table 3. Survival and planting size by species, site, and year. Generally survival was high in following installation and decreased in subsequent years. While some sites had higher survival than others the effect varied by species. Two rounds of *C. douglasii* planting resulted in negligible survival and were deemed unsuccessful. The first planting of *M. canescens* at Orchard occurred in 2019, while a second took place in 2020 yielding only a 2021 survival rate.

C. douglasii			
Site	**Total Planted**	**Survival 2020**	**Survival 2021**
Glass Butte	648	38.7%	0.0%
Orchard #1	728	Unsuccessful	
Orchard #2	47	Unsuccessful	
Orovada	375	57.6%	0.0%
Reno	600	75.5%	0.0%
Richfield	568	34.5%	0.0%
Twin Creeks	552	54.0%	1.6%

M. canescens			
Site	**Total Planted**	**Survival 2020**	**Survival 2021**
Glass Butte	832	45.2%	0.0%
Orchard #1	888	27.9%	4.2%
Orchard #2	560	-	17.9%
Orovada	768	79.9%	0.5%
Reno	872	85.3%	5.8%
Richfield	824	16.9%	0.0%
Twin Creeks	800	43.6%	0.0%

E. pumilus			
Site	**Total Planted**	**Survival 2021**	**Survival 2022**
Glass Butte	532	21.2%	7.7%
Orchard	546	89.7%	13.2%
Orovada	476	34.0%	6.5%
Plymouth	434	56.2%	42.6%
Reno	546	90.3%	73.3%
Richfield	476	89.9%	18.9%

P. hastata		
Site	**Total Planted**	**Survival 2022**
Glass Butte	378	3.2%
Orchard	410	46.8%
Plymouth	257	37.0%
Reno	390	31.8%
Richfield	335	47.5%

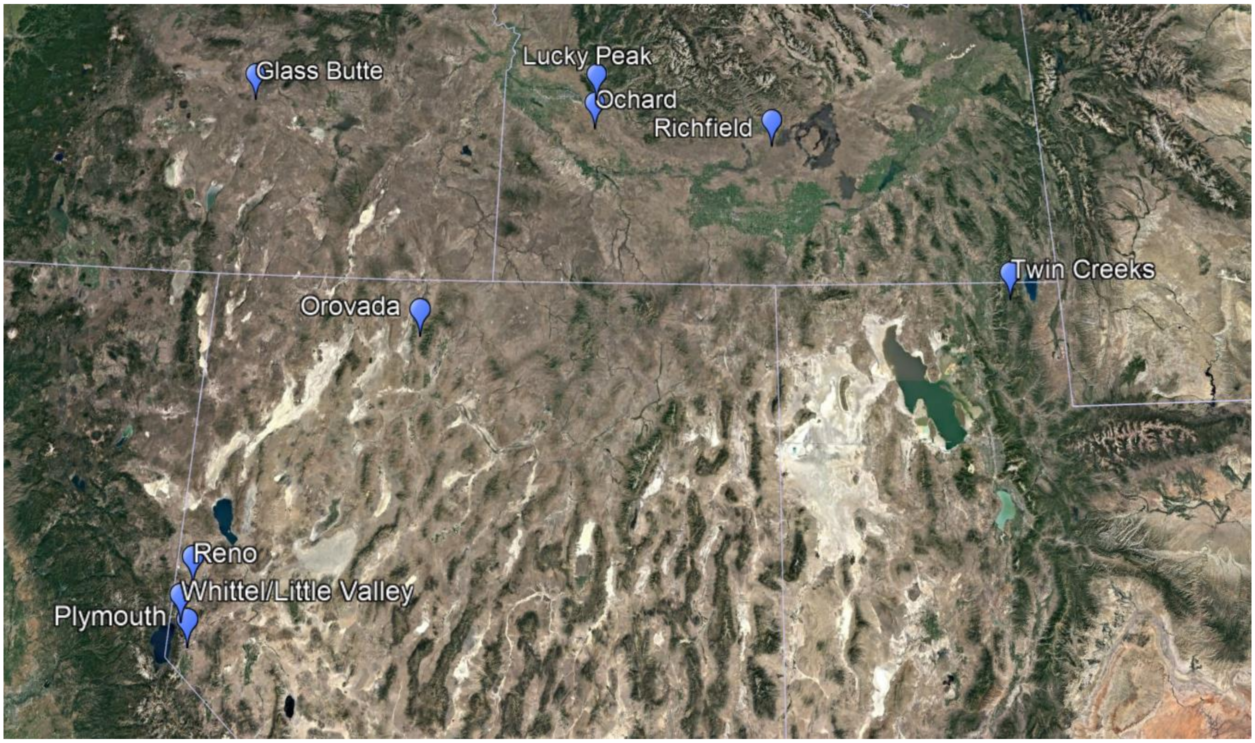


Figure 2. Map of nine forb common garden locations that are included in this study, including two additional gardens (Little Valley and Lucky Peak) installed for *B. sagittata* in 2022.

Monitoring Partners and Additional Complementary Research – We have partnered with multiple organizations to help with monitoring the common gardens in different locations, including: The Nature Conservancy (Glass Butte, OR), Utah State University (Twin Creeks, UT), and University of Nevada, Reno (Plymouth, Reno, and Little Valley, NV). The RMRS Boise lab and our academic project collaborators are also conducting complementary research to add value to the forb common garden study (Table 4).

Table 4. Complementary research conducted by RMRS and academic partners

Researcher/Monitoring Partner	Monitoring and Complimentary Research
RMRS Boise Lab	• Monitor Orovada, Orchard, Richfield, Lucky Peak • Seed dormancy and germination
The Nature Conservancy – Glass Butte, OR (Owen Baughman, Christina Billie)	• Monitor Glass Butte
Utah State University – Logan, UT (Julia Aaronson, Andrew Kulmatiski)	• Monitor Twin Creeks • Effects of climate, soil chemistry, and soil biology on plant performance • Influence of site-specific soil microbial communities and identifying beneficial microbes
University of Nevada – Reno, NV (Tessa Bartz, Beth Leger)	• Monitor Plymouth, Reno, Little Valley • Seedling emergence and survival in response to water availability • Competition with cheatgrass

Seed germination study- The ability to germinate under cold conditions may be beneficial for populations coming from areas with shorter growing seasons. Although it is generally easy to germinate the seeds in an agronomic setting (e.g. seed increase), there may be population-level variation in adaptations that allow for early germination, under natural winter conditions. This may be linked to seed source climate and may be important to consider when selecting a population for restoration.

We are conducting germination studies for each species comparing 4 different cold stratification treatments (0, 2, 6, and 10 weeks at 2C) for 14 weeks total, across a selection of 19-20 populations representing a variety of environmental conditions. Germination studies for *C. douglasii* and *M. canescens* have been completed. In November 2022 we began the germination study for *E. pumilus* and monitoring us underway.

Data processing for *C. douglasii* began in 2022. Data for *C. douglasii* is currently being analyzed and data for *M. canescens* is being formatted for analysis. The analyses will be completed this winter and presented at the National Native Seed Conference. We will be investigating population-variation in germination response to four treatments and relationships to the environment at the population origin. Preliminary results of germination studies on *C. douglasii* and *M. canescens* produced the following results:

- *C. douglasii*: while seeds generally germinated in warm conditions after periods of cold, seeds from some populations germinated under cold conditions

- *M. canescens*: while dormancy is generally low and seeds do not require cold stratification, seeds from some populations germinated under cold conditions

Forb Genetics Study – Work continues, revealing the species boundaries, genetic structure and cytogeography of the selected forb species. The project workflow for each focal species begins by extracting DNA from collected leaf tissue. Nuclei are run through flow cytometry to determine ploidy level variation between source populations, and through genomic sequencing to determine genotypes for each source population. Analyses are performed on the sequencing data to understand how genotypes vary within and between source populations and across geographic regions. Twelve individuals are sampled per population and populations are selected to match the populations used in the common garden array. Journal articles are planned for each species and these data will also be used in analyses of the common garden array data. Links to published articles and progress can be found in Table 5.

Table 5. Progress in genomics work for forb species from 2017-2022.

Species	DNA Extraction	Flow Cytometry	Sequencing	Analysis	Journal Article
Erigeron speciosus	Completed	Completed	Completed	Completed	Completed
Machaeranthera canescens	Completed	Not Needed	Completed	Completed	In Prep
Chaenactis douglasii	Completed	Completed	Completed	In Progress	Not Started
Erigeron pumilus	Completed	In Progress	Completed	In Progress	Not Started
Crepis acuminata	Completed	Completed	Completed	In Progress	In Prep
Sphaeralcea spp.	Completed	In Progress	In Progress	Not Started	Not Started
Phacelia hastata	Completed	Not Needed	Completed	In Progress	Not Started
Balsamorhiza sagittata	Completed	Not Needed	Completed	In Progress	In Prep

An understanding of genetic variation will help to:

- Inform seed transfer zones by replacing simple division along ecoregional lines with division based on related genetic clusters.
- Avoid outbreeding depression by using sources that are within the same genetic clusters as local populations and with the same ploidy levels.
- Avoid inbreeding depression by selecting sources that have reasonable levels of genetic variation.
- Provide genetic resilience to climate change and other disturbances by using sources with enough genetic variation to allow for continued natural selection.
- Identify unique populations that could be of conservation interest.
- Determine whether genomic signatures of adaptation are sufficient to develop seed transfer zones without the need for common garden studies.

Preliminary results suggest that *Crepis acuminata* and sister taxa (e.g. *Crepis occidentalis*) can be difficult to identify in the field. Despite these morphological similarities among species, most species appear to be distinct based on genomic analysis, with the exception of *C. intermedia*. Figure 3 shows a principal component analysis plot of *Crepis* collections. The x-axis (PC1) shows separation of distinct species clusters, while PC2 on the right side of the plot show genetic variation within *C. acuminata*. Results from flow cytometry indicate ploidy is variable across populations, ranging from 1 to 3 distinct ploidy levels within sampling locations (Figure 4). This adds to the complexity of characterizing genomic variation across the species range.

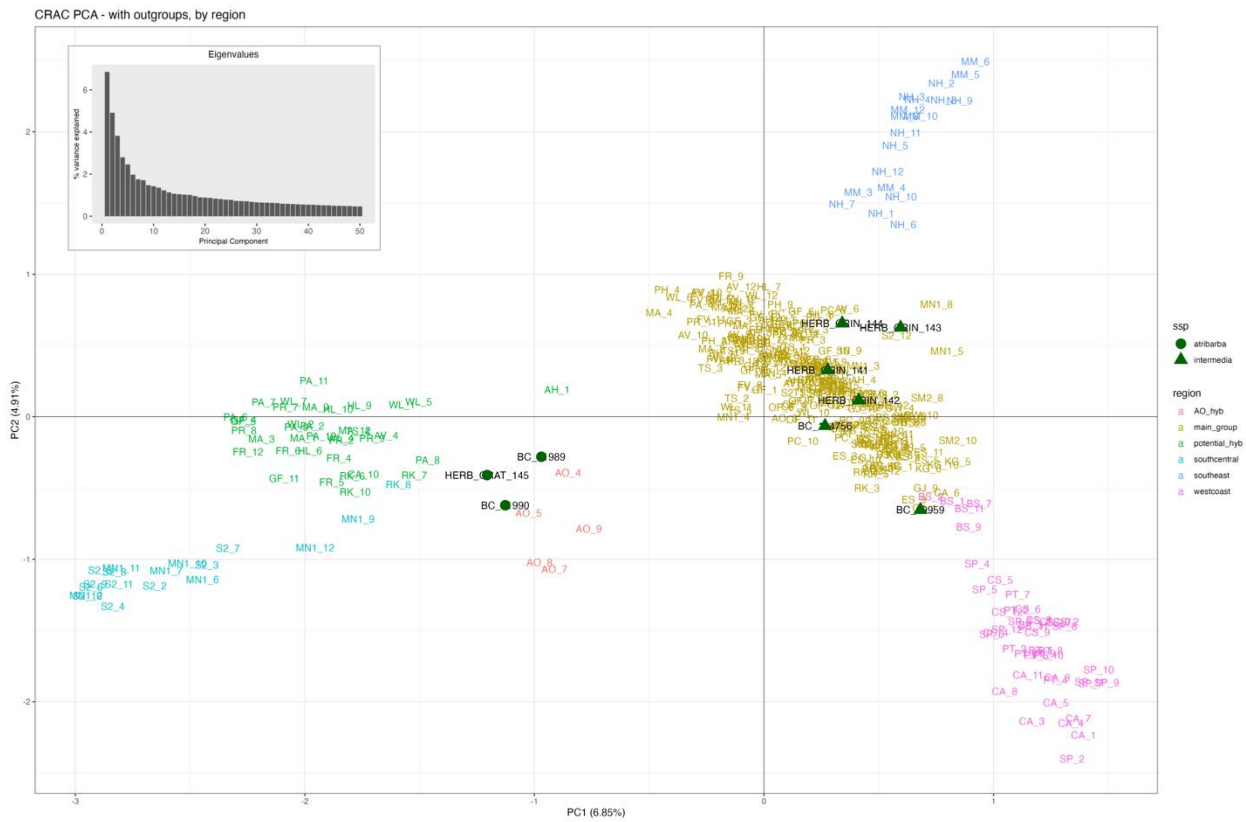


Figure 3. Preliminary principal component analysis of *Crepis acuminata* and congeners. Text labels on the plot represent sample IDs; letters indicate population identity and numbers indicate sample ID within population. Solid green symbols show sister species *C. atribarba* and *C. intermedia*. The blue, umber, and pink colors show distinct geographic regions of *C. acuminata*. Aqua, green, and red colors suggest different species that were included as putatively misidentified samples within the *C. acuminata* collections. Inset plot shows the percent of total genomic variance explained by the first 50 principal component axes.

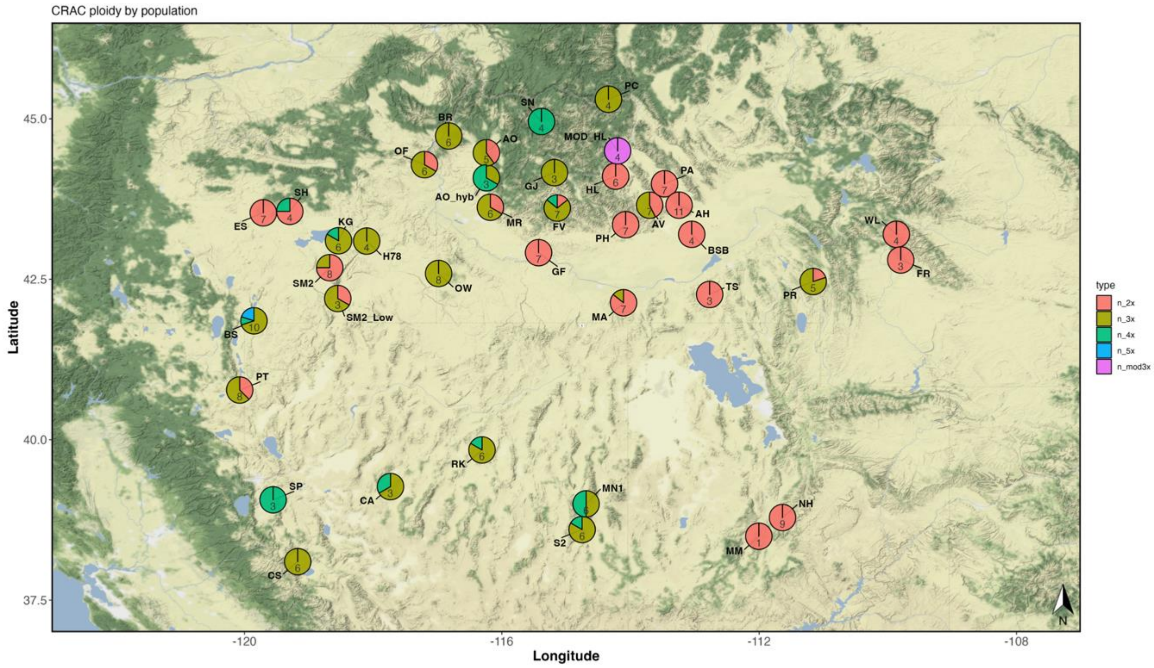


Figure 4. Ploidy variation across sampled populations of *Crepis acuminata* and congeners. Each pie represents a sampling location and colors indicate proportion of distinct ploidy levels. Number inside pie indicates sample size. The pink color represents a collection of *C. modocensis* that neighbors the originally sampled "HL" population.

Similar challenges exist with *Balsamorhiza sagittata*, however *B. sagittata* is confounded with putative hybridization with *B. hookeri* (Figure 5). Hybridization appears common in populations in central and northern Nevada and southwest Idaho.

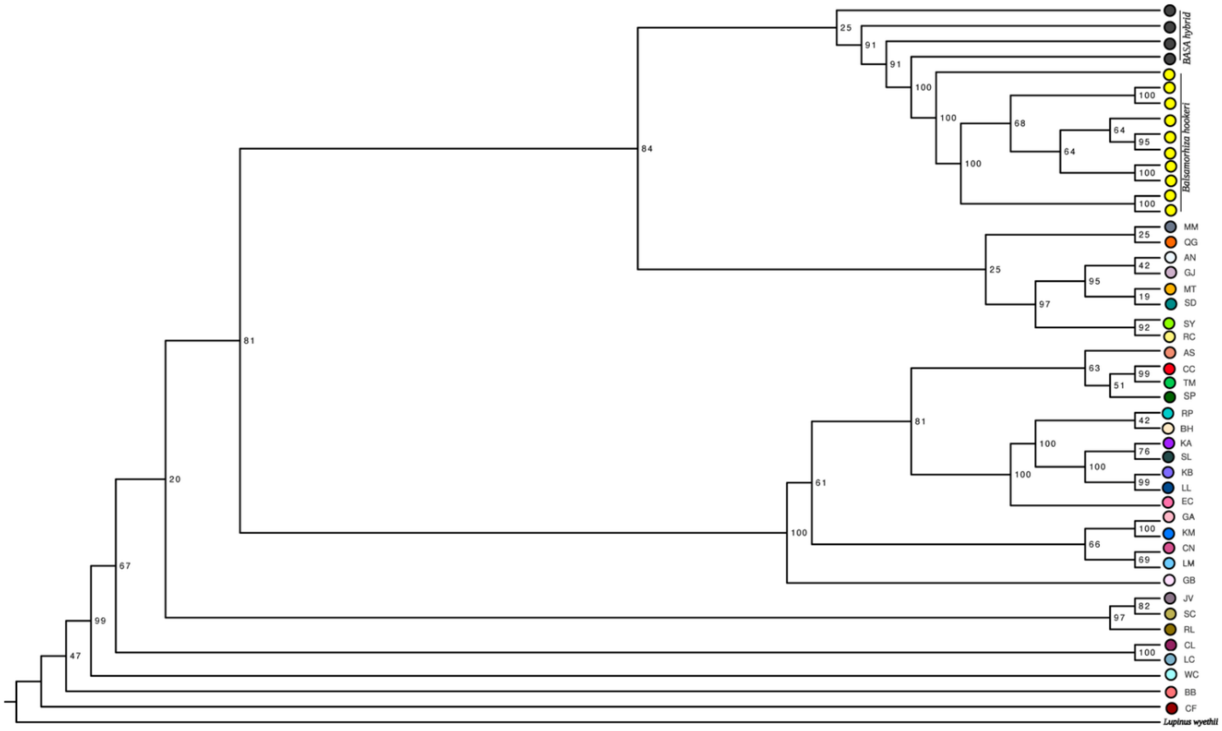


Figure 5. A phylogenetic tree of *Balsamorhiza sagittata* populations and *B. hookeri* collections. *B. sagittata* populations are found both within their own distinct clade and within a clade with *B. hookeri*. The tree is rooted with sister taxa *Wyethia amplexicaulis*.

Overall, this project will result in the following products:

- Establishment of a common garden array
- General Technical Report: common garden design and installation
- Seed accessions representing many populations of native species used in arid land restoration
- Identification of ploidy and genetic clusters for focal native plant species
- Geospatial seed transfer guidance for use in online tools
- Several publications describing population-level variation in:
  seed germination, soil interactions, drought tolerance, and competition with invasive species

The Bureau of Land Management, US Fish and Wildlife Service, and US Forest Service Intermountain Region are concurrently increasing these focal forb species through IDIQs. This means that once seed zones are established there will already be some seed that corresponds to the established seed zones. So, we are developing seed transfer zones that will be used immediately by placing these seeds into a more accurate adaptive framework.

3. Vegetation Succession in Post-Fire Seeding Treatments

Science Partners:
USDA Forest Service, Rocky Mountain Research Station: Jeff Ott and Francis Kilkenny
Utah Division of Wildlife Resources: Danny Summers
Utah Department of Natural Resources: Tyler Thompson
Brigham Young University: Steve Petersen

The objective of this research is to evaluate long-term (15+ years) outcomes of post-fire seeding with conventional and native seed mixes in sagebrush and pinyon-juniper ecosystems of the Great Basin, using a pre-established seeding experiment in Tintic Valley, Utah as a case study. The experiment had been set up following a wildfire that burned across the valley in 1999. Four different seed mixes, plus a non-seeded control, had been applied in landscape-scale replicates. Two 'conventional' mixes contained commonly seeded non-native (Eurasian) species such as crested wheatgrass, and the other two mixes were comprised of native species at two levels of diversity and seeding rate. We sought to extend the original three-year evaluation of this experiment (reported by Thompson et al. 2006[1]) to a longer timeframe by re-measuring vegetation attributes 16-18 years after the fire. We have used these data to document successional trends and assess the degree to which restoration objectives are being met on the longer term.

Research was initiated in 2015 through a grant from the Joint Fire Sciences Program, which provided three years of funding, and follow-up work has continued through the Great Basin Native Plant Project. Data were collected in 2015 in partnership with the Utah Division of Wildlife Resources and 2016-2017 in partnership with Brigham Young University. Data have subsequently been analyzed and results have been presented in multiple formats, including nine formal presentations at scientific conferences or other meetings[2], two webinars[3], a final report to the Joint Fire Science Program[4], and a paper published in the journal Rangeland Ecology and Management in 2019[5]. The latter paper integrated 2015 data with earlier data from 2002 to reveal the degree of vegetation change and persistence of seed mixes during the intervening period. This paper has been cited by 21 subsequent papers to date (Google Scholar) and has been downloaded 500 times according to USFS records[6]. Another paper, published in the journal Applied Vegetation Science in 2022[7], incorporates data from all years to examine successional trajectories of the post-fire seeding treatments and their similarity to reference state communities. A third paper, soon to be submitted for publication, takes a closer look at treatment cost-effectiveness and the way in which individual seeded species contributed to restoration objectives (Figures 1-3). Findings of these studies are relevant to land management in the Great Basin given the continuing application of post-fire seeding with increasing use of native plants.

In our evaluation of these seeding treatments, we point out that restoration success depends not only on what is seeded, but also on how success in defined and measured in relation to overall restoration objectives. Measures of seeded species establishment and growth, such as percent cover, provide a simple and direct way to assess seeding success, but do not by themselves indicate seeded species contributions to specific restoration objectives such as controlling weeds, facilitating desirable species, or restoring a reference community. Furthermore, information on monetary costs can be integrated into evaluations of restoration success to provide a more complete picture of the costs and benefits of seeding a given species or seed mix. We developed methods for quantifying seeded species contributions to multiple restoration objectives and integrating monetary costs into measures of restoration success. Figures 1 -2 illustrate results of these methods applied to individual seeded species from each of the four seed mixes at the two study sites, and Figure 3 shows the net contributions of all seeded species in each mix toward meeting four distinct restoration objectives (seeded plant establishment/cover, restoration of target reference communities, suppression of invasive annual weeds, and enhancement of non-seeded native perennial forbs).

When measuring success on the basis of cover, the most successful species of the seed mixes were non-native grasses including crested/Siberian wheatgrass (*Agropyron* spp.), intermediate wheatgrass (*Thinopyrum intermedium*), and smooth brome (*Bromus inermis*); and native grasses including western wheatgrass (*Pascopyrum smithii*) and bluebunch wheatgrass (*Pseudoroegneria spicata*) (Figure 1). With the exception of bluebunch wheatgrass, these grass species were also the most cost-effective in terms of cover per dollar spent, although cost-effectiveness varied depending on the year of the cost estimate (Figure 1). Cost-effectiveness of the non-native grasses declined from 1999 to 2017 as their inflation-adjusted seed price rose during this time interval, while cost-effectiveness of western wheatgrass and most other native grasses increased during this same timeframe as their seed prices dropped (Figure 1).

In contrast, higher cover did not necessarily equate to greater success when the objective involved restoring a reference community (Figure 2). Using reference communities of locally-mapped Ecological Sites as restoration targets (Ott et al. 2022), we demonstrated that some seeded species contributed positively while others detracted from reaching this objective. Our metric for measuring species' contributions (target matching cover) can be positive or negative depending on the degree to which a species' actual cover matches its hoped-for target value. Cover that was less than or equal to the maximum cover expected in the target community was given a positive value, and any cover exceeding the maximum was given a negative value that, if large enough, could cancel out the positive. Such was the case for western wheatgrass, whose cover in seeded treatments exceeded its target leading to a net negative value for target matching cover (Figure 2). All non-native species also had negative target matching cover (Figure 2) because they were not present in the reference communities and thus had target cover of zero. Species with positive target matching cover included bluebunch wheatgrass, big sagebrush (*Artemisia tridentata*), fourwing saltbush (*Atriplex canscens*) and needle-and-thread grass (*Hesperostipa comata*) (Figure 2). Although more expensive to seed, species with positive target matching cover were ultimately more cost-effective from the standpoint of restoring reference communities (Figure 2).

The overall contributions of each seed mix varied depending on the objective being measured as well as the study site, as shown in Figure 3. Note that Figure 3a-b displays the sum total of seeded species cover values by seed mix from Figure 1, and Figure 3c-d displays target matching cover values from Figure 2 in the same way. Sum totals for two additional metrics, the weed suppression index and forb enhancement index, are shown in Figure 3e-h. Total cover of seed mix species was generally lower, with greater variation among mixes, at the Jericho site than at Mud Springs (Figure 3a). At both sites, the conventional mixes (ARS, BLM) were less successful than the native-only mixes (NH, NL) in terms of reference matching cover (Figure 3c). Invasive annual weeds were more abundant at Jericho than Mud Springs, while native perennial forbs were more abundant at Mud Springs, leading to high values of the weed suppression index and forb enhancement index, respectively, at these sites (Figure 3e, 3g). At Jericho, the weed suppression index was highest for the conventional mixes (Figure 3e), indicating that species of the conventional mixes had a stronger competitive effect on invasive annuals than species of the native-only mixes. On the other hand, the facilitative effect of seeded species on perennial forbs at Mud Springs was greater for the native-only mixes and the ARS mix in comparison to the BLM mix, as indicated by different forb enhancement index values (Figure 3g). When these metrics were weighted by cost, the patterns that emerged were similar to those of the unweighted metrics, but differences between seed mixes tended to be more accentuated, especially when based on seed costs in 1999 (Figure 3b, 3d, 3f, 3h). For example, the BLM mix was noticeably more cost-effective than any other mix in terms of cover and weed suppression in 1999, but in 2017, cost-effectiveness of the BLM mix had dropped to a level roughly equivalent to the NL mix, whose cost-effectiveness had risen (Fig. 3b, 3f). These results demonstrate the importance of examining seeding outcomes from multiple angles, and using results from studies such as this one to inform subsequent decisions regarding which species to seed.

[1]Thompson TW, Roundy BA, McArthur ED, Jessop BD, Waldron B, Davis JN. 2006. Fire rehabilitation using native and introduced species: A landscape trial. Rangeland Ecology & Management 59:237–248.

[2]Presentations at Conferences/Meetings:

- Ott JE. 2020. Long-term outcomes of a post-fire seeding experiment in Tintic Valley. Invited oral presentation, Utah Society for Range Management 2020 Annual Meeting (virtual), Nov 10-12, 2020.
- Ott JE, Kilkenny FF, Summers DD, Thompson TW. 2020. Vegetation succession following post-fire seeding with conventional and native seed mixes in the Great Basin. Invited oral presentation, 47th Natural Areas Conference (virtual), Oct 14, 2020.
- Ott JE. 2019. Outcomes of post-fire seeding experiments using native seed mixes in the Great Basin. Invited oral presentation, Eighth Western Native Plant Conference, Olympia, WA, Nov 12-14, 2019.
- Ott JE. 2019. Post-fire seeding experiments with native seed mixes. Invited oral presentation, Intermountain Native Plant Summit IX, Boise, ID, Nov 5-6, 2019.
- Ott JE. 2019. Long-term evaluation of seed mixes for post-fire seeding. Invited oral presentation, Utah Partners for Conservation and Development-Watershed Restoration Initiative Regional Partnership Workshop, Richfield, UT, May 29, 2019.
- Ott JE, Shaw NL, Kilkenny FF. 2018. Post-fire seeding as a restoration tool: competitiveness and resilience of native seedings in shrub steppe ecosystems of the Great Basin. Invited oral presentation, Society for Ecological Restoration Joint Regional Conference, Spokane, WA, Oct 15-18, 2018.
- Ott JE, Kilkenny FF, Summers DD, Thompson TW. 2018. Effects of seeding treatments on vegetation succession following fire in semiarid ecosystems of the Great Basin. Poster presentation, International Association for Vegetation Science 61st Annual Symposium, Bozeman, MT, Jul 22-27, 2018.
- Ott JE, Kilkenny FF, Summers DD, Thompson TW. 2018. Long-term effects of post-fire seed mixes: revisiting a large-scale seeding experiment in Tintic Valley, Utah. Oral presentation, 71st Society for Range Management Annual Meeting, Sparks, NV, Jan 28-Feb 2, 2018.
- Ott JE. 2017. Strategies and equipment for large-scale, multi-species native seedings in North American drylands. Invited oral presentation, VII World Conference on Ecological Restoration, Foz do Iguaçu, Brazil, Aug 27-Sep 1, 2017.

[3]Webinars:

- Kilkenny FF, Ott JE. 2020. Evaluating native seed mixes for post-fire seeding in the Great Basin. Webinar hosted by Natural Areas Association, Jul 28, 2020.
- Kilkenny FF, Ott JE. 2020. Seed mix matters! Webinar hosted by USDA Forest Service, Rocky Mountain Research Station, May 20, 2020.

[4]Kilkenny FF, Ott JE, Summers DD, Thompson TW. 2018 Vegetation Succession in Post-fire Seeding Treatments: Final Report to the Joint Fire Science Program.

[5]Ott JE, Kilkenny FF, Summers DD, Thompson TW. 2019. Long-term vegetation recovery and invasive annual suppression in native and introduced postfire seeding treatments. Rangeland Ecology & Management 72:640-653.

[6]U.S. Forest Service Research & Development, publication specific page views: https://www.fs.fed.us/research/ga-service/rd_national_site_view_publication.php?breadcrumb_id=3&rits_prd_id=94082

[7]Ott JE, Kilkenny FF, Summers DD, Thompson TW, Petersen SL. Post-fire succession of seeding treatments in relation to reference communities in the Great Basin. Applied Vegetation Science, 25:e12633.

Figure 1. Contributions of seeded species to vegetation cover measured 16-18 years after seeding in four seed mix treatments (ARS, BLM, NH, NL) at two sites (Mud Springs and Jericho) in Tintic Valley, Utah. Solid bars are means and error bars are 95% bootstrap confidence intervals. Panels on left show cover values; panels on right show cover values divided by seed costs per ha for each species, using inflation-adjusted cost values from two different years (1999 and 2017). ARS = Agricultural Research Service mix; BLM = Bureau of Land Management mix; NH = native high-diversity mix; NL = native low-diversity mix.

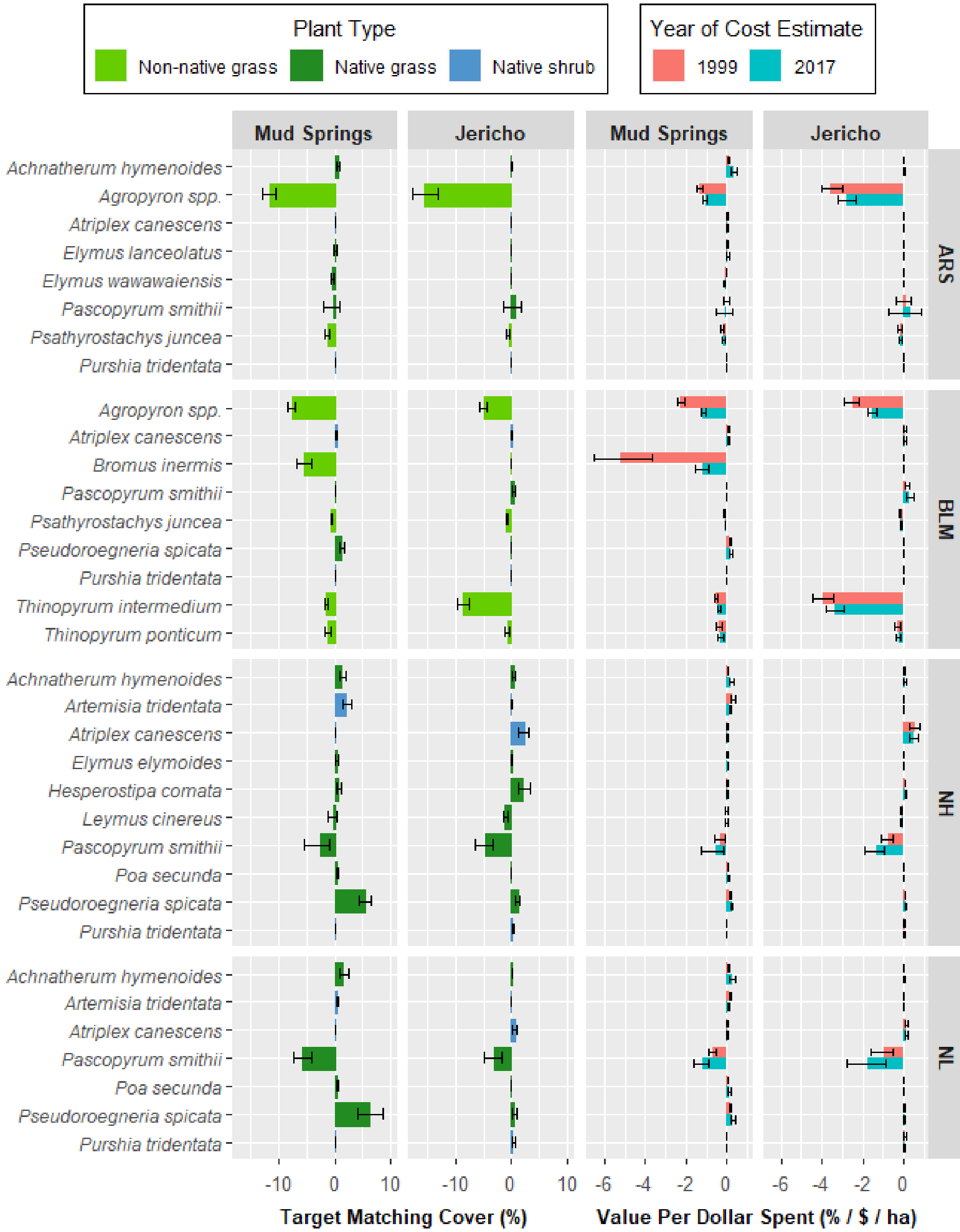


Figure 2. Contributions of seeded species toward restoring reference community targets, as measured 16-18 years after seeding in four seed mix treatments (ARS, BLM, NH, NL) at two sites (Mud Springs and Jericho) in Tintic Valley, Utah. Solid bars are means and error bars are 95% bootstrap confidence intervals. Panels on left show target matching cover (degree of match between actual cover and target cover, see text); panels on right show target matching cover divided by seed costs per ha for each species, using inflation-adjusted cost values from two different years (1999 and 2017). ARS = Agricultural Research Service mix; BLM = Bureau of Land Management mix; NH = native high-diversity mix; NL = native low-diversity mix.

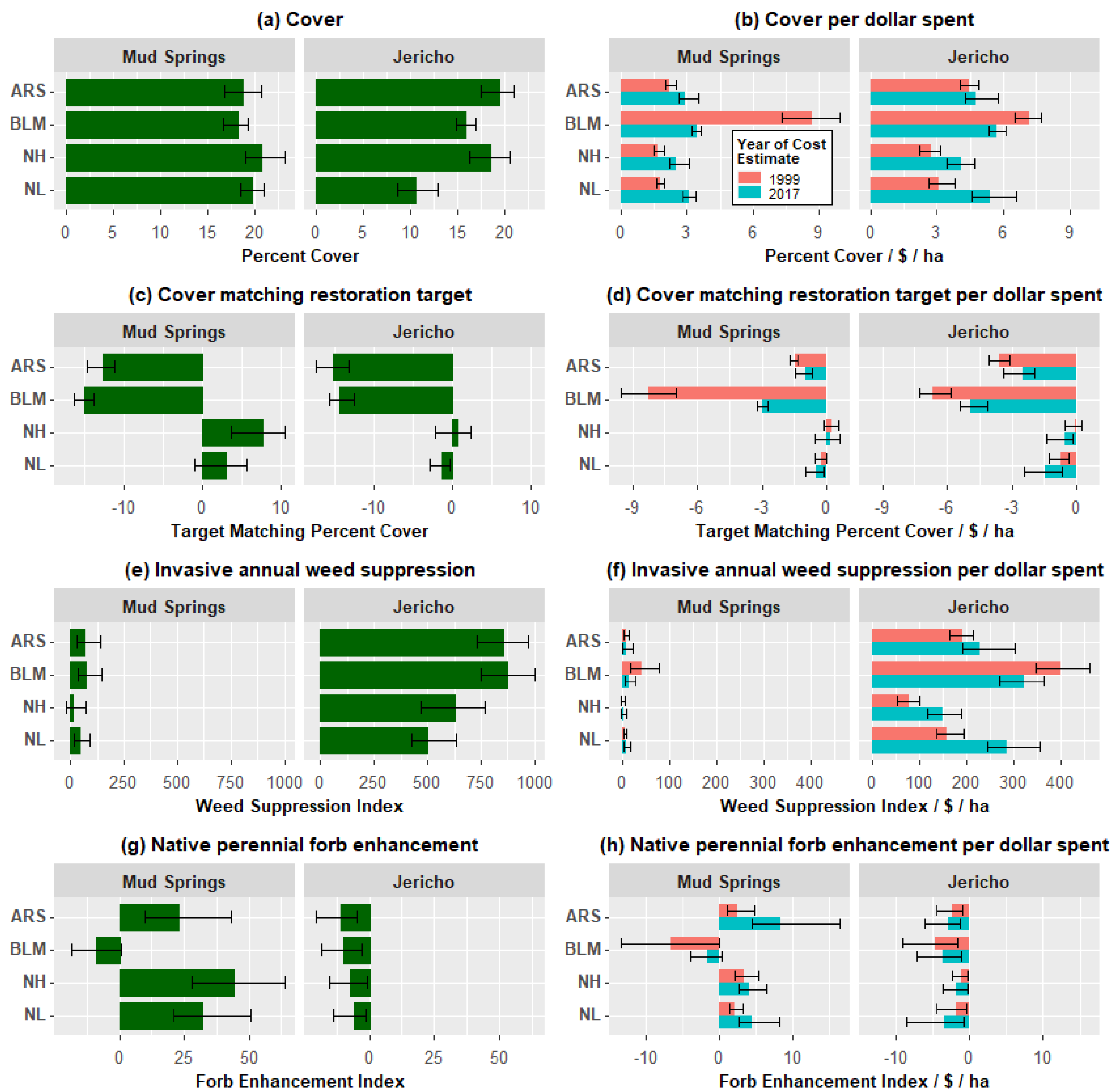


Figure 3. Contributions of seed mixes toward multiple restoration objectives measured 16-18 years after seeding at two sites (Mud Springs and Jericho) in Tintic Valley, Utah. Solid bars are means and error bars are 95% bootstrap confidence intervals. Panels on left show raw values of success measures (cover, target matching cover, weed suppression index, forb enhancement index); panels on right show values divided by seed costs per ha for each mix, using inflation-adjusted cost values from two different years (1999 and 2017). ARS = Agricultural Research Service mix; BLM = Bureau of Land Management mix; NH = native high-diversity mix; NL = native low-diversity mix.

4. Climate-Smart Restoration Tool

Reporting Period: 10/1/2020-9/30/2021
Cooperators: Brad St. Clair, Research Geneticist, US Forest Service Pacific Northwest Research Station; Nikolas Stevenson-Molnar, Software Engineer, Conservation Biology Institute; Brendan C. Ward, Chief Software Engineer, Conservation Biology Institute; Francis Kilkenny, Research Biologist, US Forest Service Rocky Mountain Research Station; Bryce Richardson, Research Geneticist, US Forest Service Rocky Mountain Research Station

The Climate-Smart Restoration Tool (CSRT) is an interactive web-based application that allows users to match current seed sources with future climate conditions. Natural resource managers must match the climatic adaptability of their seed sources to the climatic conditions of their restoration sites in order to better ensure successful long-term restoration outcomes. There is an urgent need to adopt climate-smart approaches to ecosystem management, but progress has been slow because landowners and natural resource managers lack readily available, site-specific information on which to act. Existing scientific information has been unavailable at the scale needed by natural resource managers and restoration practitioners. The CSRT is designed to (1) easily incorporate new scientific information (e.g., climate projections, physiological thresholds) and (2) allow users to select parameters of interest (e.g., climate change scenarios, and time periods). Climates associated with existing ecoregions and seed zones are displayed so that natural resource managers can choose the appropriate seed source for their restoration site, or decide where seed from a particular source can be planted in the future. Managers ware also able to view spatial maps of current and future climates, seed zones, ecoregions, and other contextual map layers. The CSRT provides the ability to download outputs of the tool to PowerPoint slides, PDF documents, and GeoTIFF files in order to share those results with others and perform additional analysis within desktop data processing environments.

The CSRT delivers information on current and future climate and seed zones. Information on species distributions (i.e., potential future habitats) can be incorporated in this tool in the future. Climate associated with existing ecoregions and seed zones are displayed so that natural resource managers can choose the appropriate seed source for their restoration site, or decide where seed from a particular source can be planted in the future. Because of the uncertainty in climate change projections, the tool is primarily intended as a planning and educational tool. It can be used to explore alternative future conditions, assess risk, and plan potential responses. The tool allows the user to control many input parameters so the results are appropriate for the management practices, climate change assumptions, and risk tolerance of the user.

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

Bluebunch wheatgrass and mountain big sagebrush genecological functions and species distribution models were added to the CSRT (Figure 1). Progress was also made on the Seedlot Selection Tool including the ability to compare multiple seedlots. This has not yet been implemented into the CSRT.

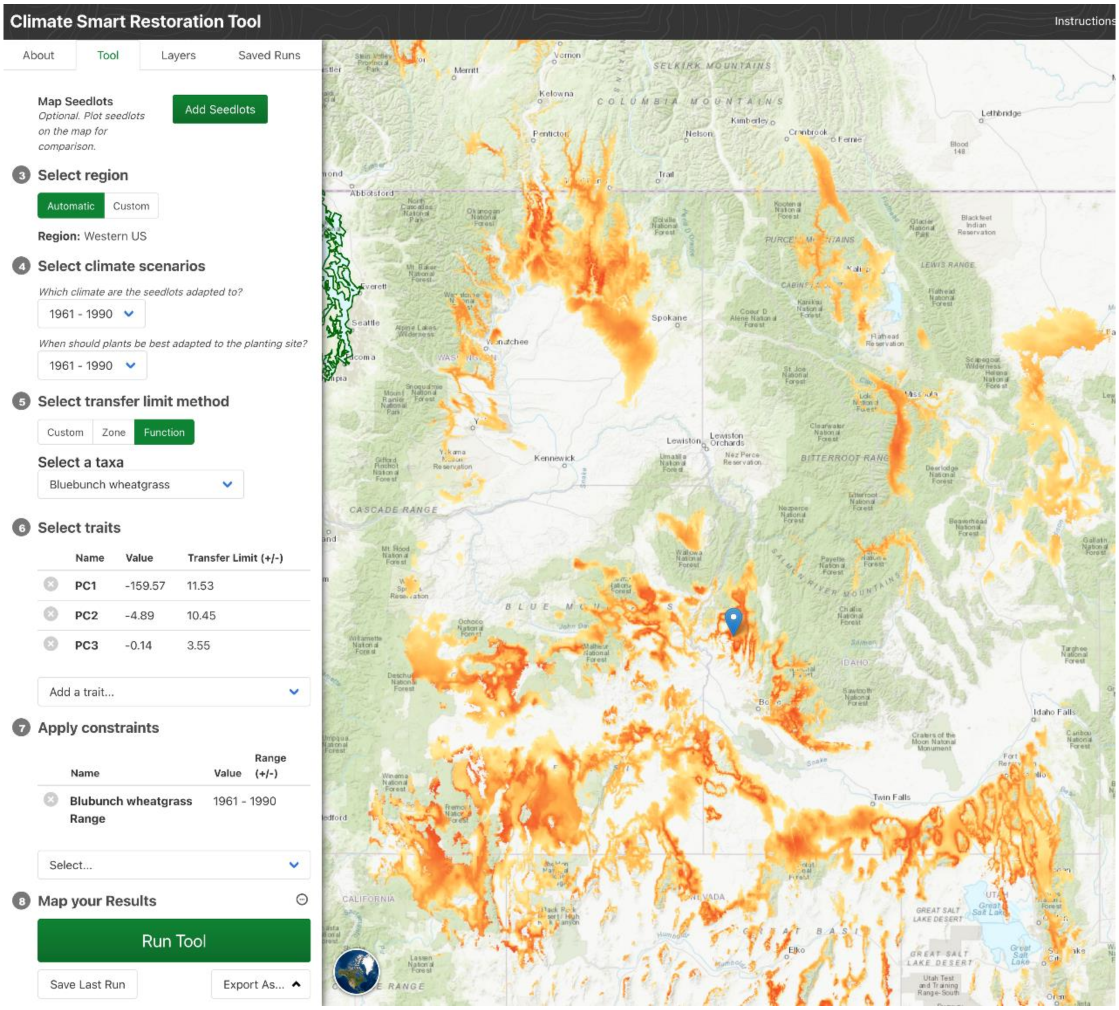


Figure 1. An example of the seed transfer for bluebunch wheatgrass under contemporary climates. Yellow to red polygons indicate were seed could be acquired for the selected restoration site (blue pin).

CSRT: https://climaterestorationtool.org/csrt/

Publication:
St Clair, John; Richardson, Bryce; Stevenson-Molnar, Nikolas; Howe, Glenn; Bower, Andrew; Erickson, Vicky; Ward, Brendan; Bachelet, Dominique; Kilkenny, Francis; Wang, Tongli. Seedlot Selection Tool and Climate-Smart Restoration Tool: web-based tools for sourcing seed adapted to future climates. In review for Ecosphere

5. Fuel treatment effectiveness at the landscape scale: a systematic review of simulation studies comparing treatment scenarios in North America

Science partners:
USDA Forest Service, Rocky Mountain Research Station: Jeff Ott, Francis Kilkenny, Terrie Jain

(*Abstract from article in press*)

Background:
The risk of destructive wildfire on fire-prone landscapes with excessive fuel buildup has prompted the use of fuel reduction treatments to protect valued resources from wildfire damage. The question of how to maximize the effectiveness of fuel reduction treatments at landscape scales is important because treating an entire landscape may be undesirable or unfeasible. We reviewed 86 simulation studies that examined landscape-scale fuel reduction treatment effectiveness for landscapes of the USA or Canada. Each of these studies tested effects of fuel reduction treatments on wildfire through comparisons of landscape scenarios differing by treatment design or other attributes. Results from these studies were summarized to assess what they reveal about factors determining fuel treatment effectiveness at landscape scales.

Results:
Qualifying studies focused primarily but not exclusively on forested landscapes of the western United States and ranged in size from 200 to 3,400,000 ha. Most studies showed that scenarios with fuel reduction treatments had lower levels of wildfire compared to untreated scenarios. Damaging wildfire types decreased while beneficial wildfire increased as a result of treatments in most cases where these were differentiated. Wildfire outcomes were influenced by five dimensions of treatment design (extent, placement, size, prescription, and timing) and other factors beyond the treatments (weather, climate, fire/fuel attributes, and other management inputs). Studies testing factorial combinations showed that the relative importance of these factors varied across landscapes and contexts.

Conclusions:
Simulation studies have highlighted general principles of effective fuel treatment design at landscape scales, including the desirability of treating extensive areas with appropriate prescriptions at sufficient frequency to reduce wildfire impacts even under extreme conditions that may be more prevalent in the future. More specific, context-dependent strategies have also been provided, such as a variety of placement schemes prioritizing the protection of different resources. Optimization algorithms were shown to be helpful for determining treatment placement and timing to achieve desired objectives under given constraints. Additional work is needed to expand the geographical scope of these studies, further examine the importance and interactions of driving factors, and assess longer-term effects of fuel reduction treatments under projected climate change.

Project Publications:

Ott JE, Kilkenny FF, Jain TB. 2023. Fuel treatment effectiveness at the landscape scale: a systematic review of simulation studies comparing treatment scenarios in North America. Fire Ecology 19:10. https://www.fs.usda.gov/research/treesearch/65797

Jain TB, Abrahamson I, Anderson N, Hood S, Hanberry B, Kilkenny F, McKinney S, Ott J, Urza A, Chambers J, Battaglia M, Varner M, O'Brien JJ. 2021. Effectiveness of fuel treatments at the landscape scale: State of understanding and key research gaps. PROJECT ID: 19-S-01-2. Boise, ID: Joint Fire Sciences Program. 65 p. https://www.fs.usda.gov/research/treesearch/63869

6. Seeding Evaluation and Experimental Design Strategies (SEEDS) Project: A Partnership for Learning

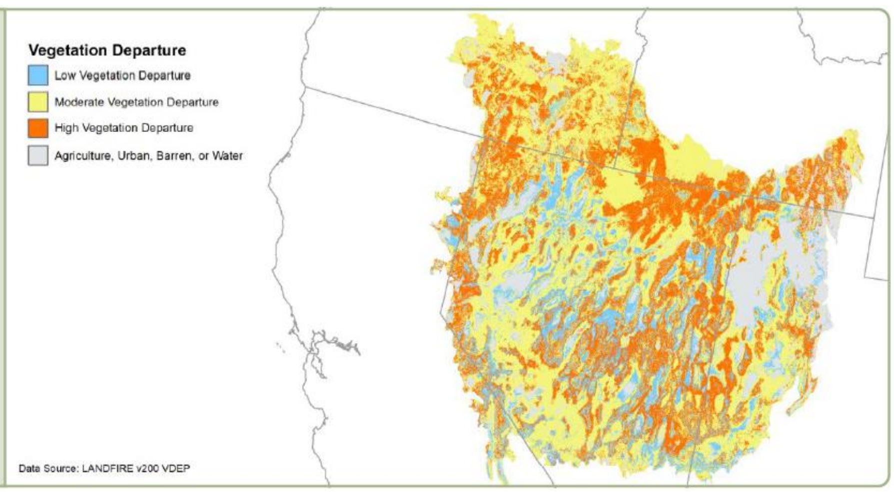
The Problem:
Non-native annual grasses, wildfire, and climate change have contributed to substantial and widespread vegetation change in the Great Basin (Fig. 1), making post-fire rehabilitation and restoration critical management priorities. Post-fire rehabilitation treatments are applied to millions of acres each year. Tens of millions of dollars are spent annually by state and federal agencies (e.g., Bureau of Land Management's Emergency Stabilization and Rehabilitation Program [ESR] and Forest Service's Burned Area Emergency Response Program [BAER]) to facilitate post-fire recovery.[1] These efforts have provided site stabilization but often fail to recover key plant community components necessary to meet biodiversity, pollinator, and wildlife needs,[2] partly because only a small subset of potential treatments are used.[3]

The Opportunity:
Hundreds of post-fire rehabilitation and restoration treatments are applied across the western US each year. Every fire and post-fire seeding project offers an opportunity to test and compare novel and innovative treatments. This can be accomplished by creating "leave" areas within each burn perimeter where experimental treatments would be tested by an independently funded research team working with land managers. By pairing land management treatments and scientific experimentation, we can rapidly advance restoration practice by finding novel seeding treatments that work[5] (Figs. 2 and 3). This project aligns directly with sections 40803 (Wildfire Risk Reduction) and 40804 (Ecosystem Restoration) of the 2022 Bipartisan Infrastructure Law[6] and agency plans for implementation of the BIL investments in post-fire wildfire restoration activities,[7,8] where:

- A national revegetation effort will be established and implemented following the National Seed Strategy for Rehabilitation and Restoration guidance.[9]
- Projects utilizing revegetation with native plants and pollinator-friendly wildflowers are prioritized.
- Ecosystem restoration work focuses on setting landscapes on a path toward natural recovery and climate resilience.

Figure 1.

The LANDFIRE Vegetation Departure spatial layer depicts the difference between a pre-European colonization reference condition and current conditions.[4] Vegetation departure is an indicator of ecosystem degradation, which is a product of land use, nonnative grass dominance, increased fire frequency, and climate changes in the Great Basin.



The Solution:
A self-contained and independently funded team of researchers and managers using a co-produced master study design will constitute the framework for revolutionizing restoration and will:

- *Coordinate and leverage new and existing resources* with local agency field offices without encumbering local ESR or BAER funding, staff time, or priorities.
- *Design, implement, and monitor innovative experiments* that evaluate and compare post-fire seeding practices alongside regular ESR and BAER treatments.
- *Evaluate novel seeding practices*, such as varied seed mix compositions, seed sources, seeding rates and timing, site preparation techniques, and post-seeding management to expand the restoration tool kit and broaden knowledge on achieving resto-ration goals (Figs. 2 and 3).
- *Holistically monitor and analyze treatment effects* and outcomes within relevant environmental con-texts, from soil to climate, to determine which treatments impact ecosystem function most (Fig 4).
- *Rapidly adapt future experiments and treatments* based on early findings, leading to true adaptive management practices that can be implemented across the landscape (Fig. 4).

Figure 2.

More experimental replication across the landscape will increase restoration knowledge and project success, especially for conservation goals that have been less studied historically.

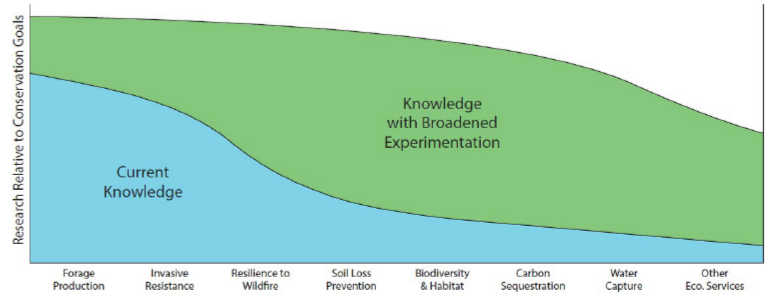
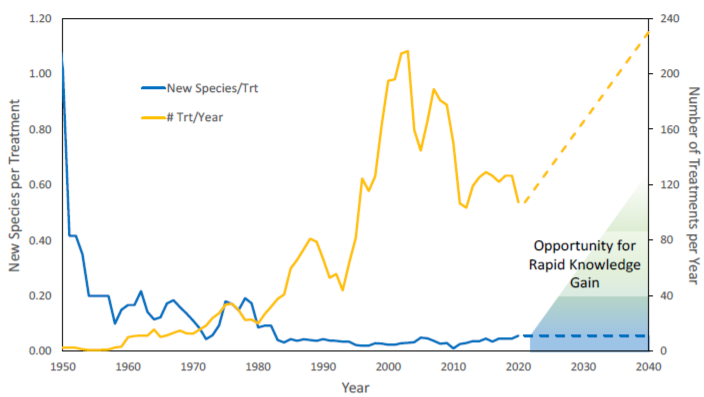


Figure 3.

Adding experimental post-fire treatments will generate learning opportunities. For example, the rate of new species in seeding treatments has remained flat since the mid-1980s.[10] Given the large number of post-fire seeding treatments implemented each year, increasing the experimental use of new species, even minimally, will produce rapid knowledge gains. Data above represent 5-year moving averages.



The Future:

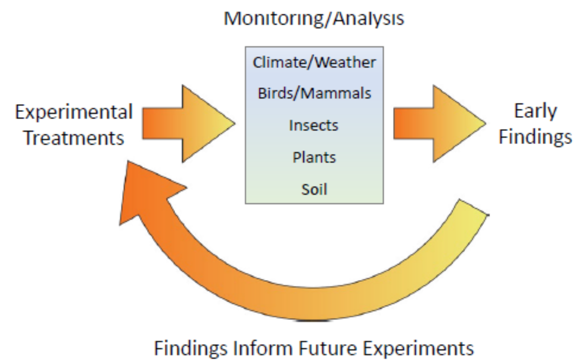
Implementation of this experimental restoration framework can move management options toward strategic treatments that increase project success, reduce the need for repeated treatments, and reduce costs.

We will restore functional and resilient Great Basin ecosystems through, 1) experiments using local management and researcher knowledge, 2) monitoring a suite of integrated ecosystem processes, 3) determining successful restoration outcomes, and 4) increasing the effectiveness of adaptive management by incorporating experimental findings into future treatments.

Restoration that addresses ecosystem processes will lead to diverse and resilient wildlife and plant communities and support diverse socioeconomic groups.

Figure 4.

Following the installation of experiments, treatment responses from soil to climate will be monitored and analyzed. Early findings will be considered when proposing new treatments on the next burned site.



[1] U.S. Department of the Interior, Bureau of Land Management [DOI BLM].2019. Public Land Statistics 2019.

[2] Arkle, R.S.; Pilliod, D.S.; Hanser, S.E.; Brooks, M.L.; Chambers, J.C.; Grace, J. B.; Knutson, K.C.; Pyke, D.A.; Welty, J.L.; Wirth, T.A.. 2014. Quantifying restoration effectiveness using multi-scale habitat models: implications for sage-grouse in the Great Basin. Ecosphere. 5(31).

[3] Pilliod, D.S.; Welty, J.L.; Toevs G.R. 2017. Seventy-five years of vegetation treatments on public rangelands in the Great Basin of North America. Rangelands. 39:1–9.

[4] Swaty, R.; Blankenship, K.; Hall, K.R.; Smith, J.; Dettenmaier, M.; Hagen, S. 2022. Assessing ecosystem condition: Use and customization of the vegetation departure metric. Land. 11(1):28.

[5] Ott, J.E.; Kilkenny, F.F.; Summers, D.D.; Thompson, T.W.; Petersen, S.L. 2022. Post-fire succession of seeding treatments in relation to reference communities in the Great Basin. Applied Vegetation Science. 25:e12633.

[6] H.R.3684–117th Congress (2021-2022): Infrastructure Investments and Jobs Act. (2021, January 3).

[7] U.S. Department of Agriculture, Forest Service. 2022. Wildfire Crisis Strategy. FS-1187a. Washington, DC.

[8] U.S. Department of Interior, Bureau of Land Management. 2022. Infrastructure Investment and Jobs Act - Wildfire Risk Five-Year Monitoring, Maintenance, and Treatment Plan. Washington, DC.

[9] Plant Conservation Alliance [PCA]. 2015. National seed strategy for rehabilitation and restoration 2015-2020. Washington, DC: U.S. Department of Interior, Bureau of Land Management. 52 p.

[10] Pilliod, D.S.; Welty, J.L.; Jeffries, M.I. 2019. USGS Land Treatment Digital Library data release: A centralized archive for land treatment tabular and spatial data (ver. 3.0, November 2020): U.S. Geological Survey data release.

7. Adaptive genetic variation and seed transfer guidelines for bottlebrush squirreltail (*Elymus elymoides*)

Science partners:
USDA Forest Service, Rocky Mountain Research Station: Jeff Ott and Francis Kilkenny
USDA Forest Service, Pacific Nothwest Research Station: Bradley St. Clair
University of Nevada Reno: Beth Leger
USDA Agricultural Research Service: Richard C. Johnson
USDA Forest Service, Pacific Northwest Region: Matthew E. Horning

Introduction – Empirical seed transfer zones are tools that can help land managers make informed decisions on seed sourcing and have commonly been modeled using transfer functions, regressions of trait × environment relationships. While transfer functions are relatively straightforward to model, delineating actual seed transfer zone boundaries requires additional methods and depends on both model outputs and management goals that are not always made explicit. Managers may benefit from flexible zone delineations that can be adjusted to encompass broader or narrower transfer criteria, thereby accommodating various transfer risk levels and practical constraints. An under-utilized method for developing seed transfer zones involves multivariate regression trees. Regression tree modeling offers a data-driven approach for determining zone boundaries and an intuitive decision-tree framework for understanding the relative importance of different predictor variables and their interactions. Because of the hierarchical structure of regression tree models, the number of zones is not fixed but can vary depending on stopping criteria, which can be quantitative or practical. Another advantage of regression trees is their ability to directly incorporate categorical variables when developing seed transfer zones.

Intraspecific taxonomic diversity is common in plants and can have important conservation implications, including the complexity it can add to seed sourcing efforts in important restoration species. For species with recognized subspecies, varieties, or phylogenetic structure a central question is whether these intraspecific taxa have different trait × environment relationships and ought to be treated individually when developing seed transfer zones. The regression tree approach provides a way to deal with this issue when developing seed transfer zones, by treating taxonomic or phylogenetic identity as a categorical variable, as we demonstrate for a grass species with multiple intraspecific taxa.

In this study, we characterize adaptive genetic variation in bottlebrush squirreltail (*Elymus elymoides*), a short-lived, self-pollinating, perennial bunchgrass of restoration importance, found in semi-arid regions of western North America, across a core section of its range in the northern Great Basin and Intermountain West region. We present seed transfer zones developed through a regression tree modeling. We use these models and accompanying map projections to assess the relative importance and interacting effects of tested predictor variables, and to highlight a hierarchical interpretation of seed transfer zones that allows flexibility in practical application.

Population Sampling and Experimental Design – Seed was collected between 2007 and 2010 from 110 wildland Elymus populations located in the Intermountain region, western USA, across an area spanning five states and ten EPA Level III Ecoregions. In 2011 seedlings were germinated in growth chambers, then grown in a greenhouse at Oregon State University. Plants were transplanted to common gardens in fall 2011 at three test sites: Central Ferry, Washington; Powell Butte, Oregon; and Reno, Nevada.

Trait Measurements and Analyses – Traits were measured at common gardens in 2013 after a year of growth and acclimatization. Measured traits assessed plant growth, reproduction, leaf morphology, and phenology. Plants were identified to subspecies, based on morphological characteristics, where possible. Relationships between trait variation and climates of population source locations were modeled using a multivariate regression tree (MRT) approach to define seed transfer zones. the MRT algorithm partitions response variables by identifying, at each node in the tree, the predictor variable that minimizes sums variation within groups while maximizing it between groups. Two models were developed, one was ‘climate-only’ that ignored taxonomy and one ‘climate-taxonomy’ that used subspecies as a predictor. MRT models were projected geographically onto climate spatial layers. The mapping area consisted of the EPA Level III Ecoregions where one or more populations had been collected plus the climatically-similar Columbia Plateau ecoregion where the Central Ferry common garden site is located.

Taxonomic and Trait Variation – Four subspecies of *E. elymoides* were identified among the populations grown in common gardens: ssp. *elymoides* (57 populations), ssp. *brevifolius* (16 populations), ssp. *californicus* (9 populations), and ssp. *hordeoides* (8 populations). Site and population were major contributors to variation for most measured traits. When broken into components, much of the explained trait variation was due to site effects, ranging from 23% (leaf ratio) to 72% (plant height). Percent variation explained by population ranged from 3% (leaf length) to 24% (heading date).

Zonation Based on Climate Only – MRT modeling resulted in a tree model with 13 terminal nodes, each represented by 5-13 populations (Figure 1). When projected onto the mapping region (Figure 2), this ‘climate-only’ model defined seed transfer zones that we grouped at three levels of the tree hierarchy. The first level contained three primary zones (A, B, C) differentiated by temperature differential and mean warmest month temperature at the first two partitions of the tree. Each primary zone was further partitioned into 2-3 secondary zones (1, 2, 3) and up to three tertiary zones (a, b, c) differentiated by a variety of precipitation, temperature, degree-day, frost and other climate variables. Zones of the climate-only model occupied distinct geographic areas and elevational bands within the mapping region (Figure 2). The A zones were located primarily on the western side of the region in the vicinity of the Sierra Nevada, Cascades, and western flank of the Blue Mountains. Within this area, A1 occupied higher-elevation, colder/wetter climates than A2. The B2 zones were also concentrated on the western side of the region in areas with relatively low temperature differential and relatively high minimum winter temperatures, though not as high as nearby A2. Farther east, zones B1, B3, C1, and C2 were positioned sequentially along a gradient from colder, snowier climates at higher elevations of interior mountain ranges to warmer, more arid climates at lower elevations. Further subdivisions of the B and C zones were aligned with elevation and/or other geographic features associated with contrasting temperature, or radiation intensity.

Zonation Based on Climate and Taxonomy – When subspecies was included as a predictor variable in the ‘climate-taxonomy’ MRT model, it was the first variable identified for partitioning (Figure 3). Populations belonging to *E. elymoides* ssp. *brevifolius* and ssp. *californicus*, plus three populations not identified to subspecies, came together in one side of the primary partition, labeled ‘bc’, opposite the group ‘eh’ comprised of ssp. *elymoides*, ssp. *hordeoides*, and seven other unidentified populations. Subsequent partitions were determined by climate variables, especially variables measuring temperature or degree-days. The bc group was subdivided into 4 secondary groups, one of which was further partitioned into two tertiary groups, leading to 5 terminal nodes. Separate zone maps were developed for the bc and eh groups by projecting their respective secondary and tertiary subdivisions onto the mapping region (Figure 3). These maps showed that zonation patterns based on trait-climate relationships were similar for both groups of subspecies even though zone boundaries were not identical. These seed transfer zones were also similar to the ‘climate-only’ seed transfer zones, with the more complex ‘climate-only’ model appearing to be similar to what a combination of the two ‘climate-taxonomy' seed transfer zones would be if intersected.

Traits in Relation to Zones, Climate and Taxonomy – Mean trait values of populations originating in each zone provided a basis for interpreting trait-climate and trait-taxonomy relationships. Patterns of trait expression differed at each common garden site, but in general, plants from cooler/wetter climates were larger, produced more inflorescences, and had wider leaves and later phenology than those from warmer/drier climates. The pattern of large size, high inflorescence number, wide leaves and late phenology was more prominent in the bc subspecies group than eh. Leaves were widest in populations from higher elevation areas in the western and central part of the region, and narrowest in lower elevation areas. Biomass, plant height, inflorescence number, heading date and maturation date were highest/latest in populations from western locations with moderately high precipitation and low temperature differential. The earliest heading and maturation dates were observed in populations from the lowest/driest areas. Biomass, plant height and inflorescence number also tended to be lowest in populations from relatively arid areas, except at Reno where plants from some of the most arid zones were relatively large and produced more inflorescences than plants from elsewhere.

Conclusions –

- Squirreltail trait × environment relationships follow similar patterns to other Great Basin and Intermountain West bunchgrasses, indicating similar spatial patterns of natural selection across these taxa.
- Squireltail has highly plastic trait expression, which might allow for seed sources to establish and persist in areas where they are somewhat maladapted. More research is needed on this.
- Subspecies groupings were an important variable in developing seed transfer zones, although similarities between zonation suggest that the 'climate-only' model may be sufficient for management seeding decisions.
- Multivariate regression trees successfully provided a logical hierarchical structure that will allow managers to combine seed transfer zones for practical purposes.

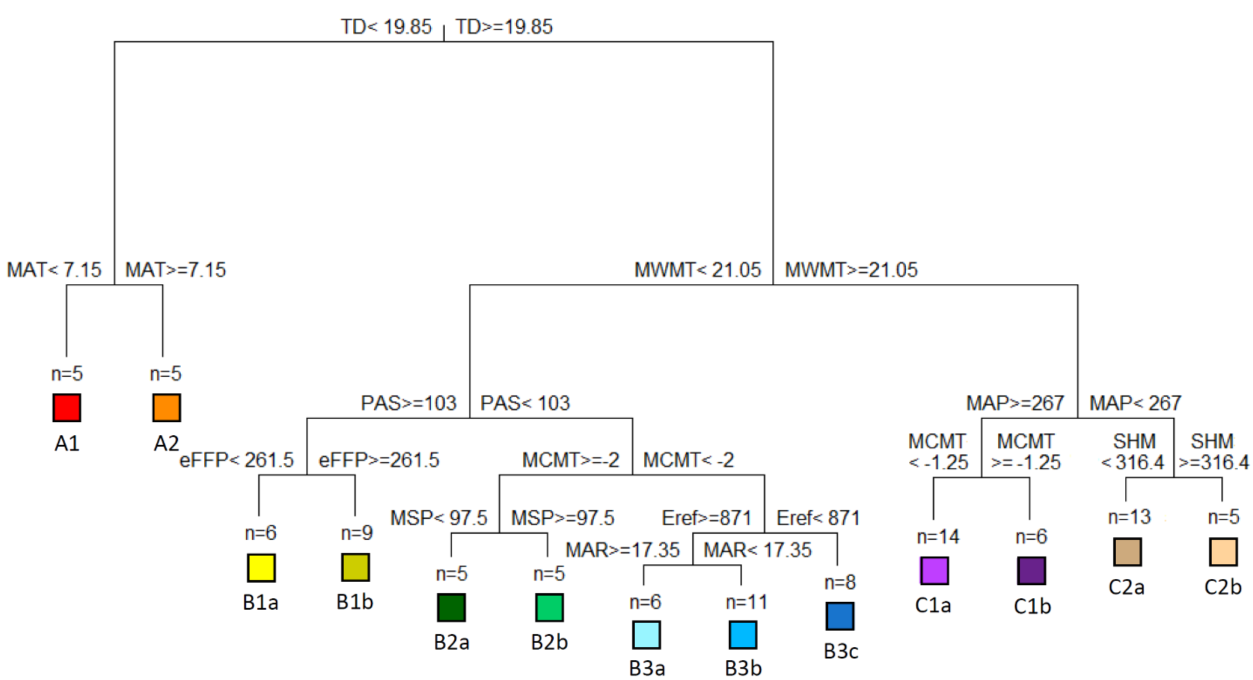


Figure 1. Multivariate regression tree model identifying seed transfer zones based on relationships between climate variables of source locations and traits of 98 *Elymus elymoides* populations measured at three common garden sites. Each partition separates populations differing by principal component (PC)

axes of trait values by site at the indicated threshold value of the most strongly correlated predictor variable. Bars show relative values of PC axes 1-18 from left to right, and n indicates the number of populations represented in each terminal leaf. Colors and code names at terminal leaves correspond to seed transfer zones mapped in Figure 2

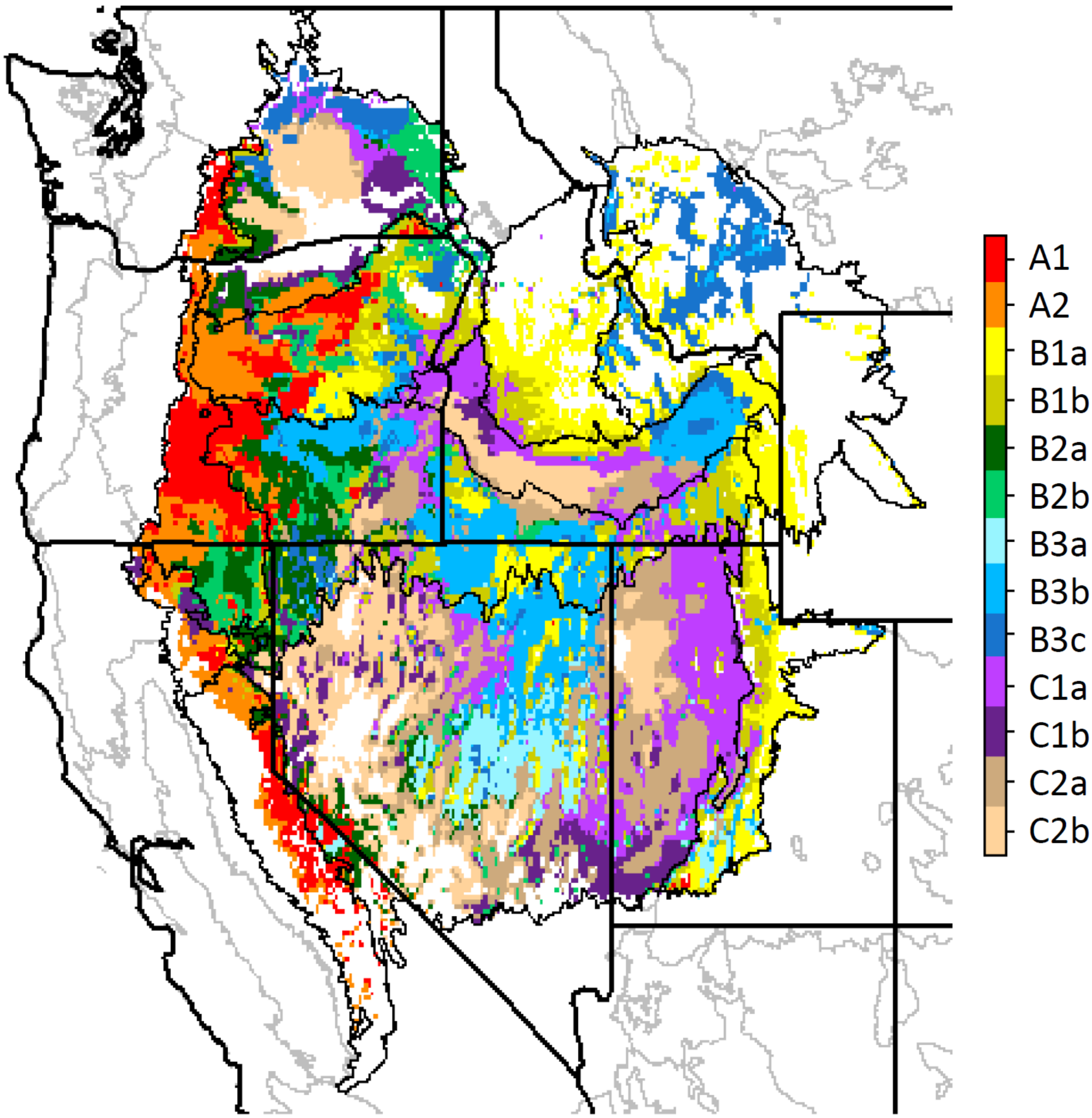


Figure 2. Seed transfer zone map for *Elymus elymoides* based on multivariate regression tree modeling of trait × climate relationships. Zone colors and code names correspond to terminal leaves of model shown in Figure 1. Mapped area is defined by EPA Level III Ecoregions, omitting areas beyond 1 standard deviation of sampled range of climate variables in the study.

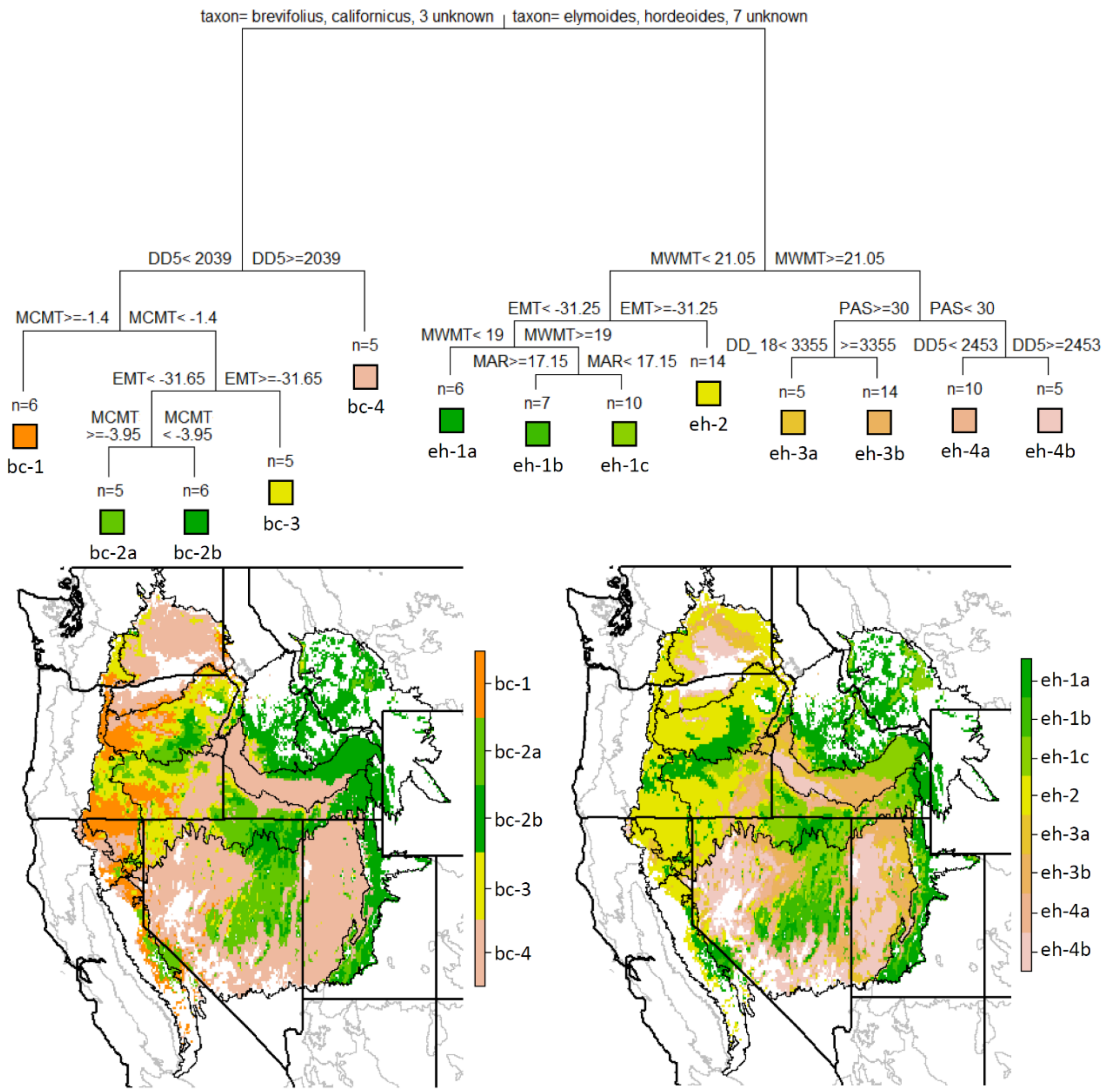


Figure 3. Seed transfer zones for *Elymus elymoides* based on a multivariate regression tree model with taxonomic and climate variables as predictors of trait variables (upper graph), projected onto in the Intermountain region of western North America (lower graphs). Colors at terminal leaves of regression tree correspond to mapped zones. The model shows relationships between predictors (subspecies identity and source-location climate) and traits measured at three common garden sites for 98 populations. Each partition separates populations differing by principal component (PC) axes of trait values by site at the indicated threshold value of the most strongly correlated predictor variable. Bars show relative values of PC axes 1-18 from left to right, and n indicates the number of populations represented in each terminal leaf. Colors and code names at terminal leaves correspond to seed transfer zones mapped in lower graphs. Left map shows zones for branch containing ssp. *brevifolius* and ssp. *californicus* (abbreviated bc); right map, ssp. *elymoides* and ssp. *hordeoides* (abbreviated eh). Mapped area is defined by EPA Level III Ecoregions, omitting areas beyond 1 standard deviation of sampled range, for each subspecies branch, of each climate variables in this study.

2022 Update: A manuscript presenting the findings outlined above is nearly complete and will be submitted for publication in the first half of 2023, likely to Evolutionary Applications. Additionally, analyses were performed on the germplasm releases and a manuscript has been developed that will be submitted to Ecological Restoration. Here is the main text of that manuscript with primary figures included and references and supplementary material removed:

The provenance of seed sources, particularly the climate of origin, can affect the success of plant community restoration, due to the likelihood that source populations are adapted to local site conditions where they have persisted through evolutionarily relevant time periods. Given the potential importance of local adaptation, the choice of provenance is seen by the international restoration community as a key decision in the restoration process. However, strict local provenancing, where selection of seed sources is limited to a small area near a restoration site, may lead to difficulties in procuring sufficient seed for restoration needs if local populations have low reproductive output. Use of strictly local populations may also be detrimental to restoration success if local populations have experienced loss of adaptive alleles through genetic drift, express deleterious alleles due to inbreeding depression, or do not harbor enough genetic diversity to respond to novel selection pressures that may arise from seed transfer itself or from changing environmental conditions.

Seed transfer zones (STZs) are developed from transfer functions that model climate-trait relationships across a plant species' range, and are mapped as either a set of bounded regions or as climate suitability gradients matching source locations or restoration sites (floating or focal-point STZs). STZs relax the need for strict local provenancing by defining larger regions within which seed sourcing and use is likely to be successful. To that end, there are concerted regional and international efforts to develop STZs for native "workhorse" restoration species and to develop generalized STZs for use in cases where genetic information is lacking. Governmental agencies are also adopting policies and strategies that encourage or require the use of STZs in restoration seed sourcing and the use of appropriate STZ frameworks have been called for in international standards for restoration seed trade and use. While STZs can guide the use of seed sources developed within STZs frameworks, it is less clear how plant materials that were developed outside of STZ frameworks might fit into provenancing decisions.

Plant material development programs that produce commercial germplasm releases have not always been concerned with local adaptation as a development criterion, and sometimes select, either by favoring sources with desired phenotypes or by artificial selection within germlines, for traits that are negatively correlated with population persistence in natural environments. Additionally, inadvertent selection or genetic drift may occur over multiple generations in agronomic or nursery production and result in trait shifts that lead to maladaptation at restoration sites. Nevertheless, the scale of seed needs in many global regions is increasing and may require pragmatic approaches that leverage existing resources. Due to economies of scale in seed production, commercial germplasms are usually the most readily available seed for restoration projects. Therefore, it is important to define regions where commercial germplasms are most likely to be useful by incorporating existing plant materials into STZ frameworks.

Here we use bottlebrush squirreltail (*Elymus elymoides*), a native workhorse restoration species in the intermountain region of the western United States, to demonstrate how previously developed plant materials could be incorporated into an STZ framework. We grew commercially-available and commonly-used germplasms of bottlebrush squirreltail (and its congener big squirreltail, *E. multisetus*) (Table 1) alongside individuals from wildland populations in common gardens to compare traits of these germplasms with background trait variation in the wild. Traits related to growth, reproduction, phenology and leaf morphology were measured for both groups. Trait data from wildland populations were used to develop a seed transfer model, first by converting trait variation to an orthogonal multidimensional trait space using principal components analysis, then modeling relationships with climate variables at population source locations for each dimension. We then examined the actual versus predicted positions of each population in both trait space and geographic space. This same exercise was also carried out for the germplasms, which although not used to develop the models, could be projected onto the spaces defined by the models using their measured trait values and reported geographic origins.

We found that the distance between actual and predicted positions in trait space was higher for germplasms than for wildland populations in most cases (Fig. 4). All but one of the six germplasms was an outlier in comparison to the wildland populations, and two of the germplasms (Sand Hollow and Pleasant Valley) had values over 5 times larger than the median (Fig. 4b). These patterns were driven by some traits more than others in ways that varied among germplasms (Fig. 5). For example, actual values of biomass, plant height, inflorescence number, heading date, and/or seed maturation date were noticeably higher/later than predicted values for Pleasant Valley and Sand Hollow; while Rattlesnake and Toe Jam Creek had noticeably lower actual leaf width and higher actual leaf-width ratio than predicted (Fig. 5).

Discrepancies between actual versus predicted positions were also evident when climatic suitability models were projected onto geographic space via the transfer function (Fig. 6). Predicted suitability based on similarity to climates at locations where germplasm material was originally collected differed from suitability calculated from actual trait values of each germplasm. Germplasms with higher divergence in trait space (e.g., Sand Hollow, Pleasant Valley) displayed large areas of high difference between actual and predicted climatic suitability, and these differences tended to be greater at lower elevations (Fig. 6) where restoration in the intermountain region is more difficult.

All of the bottlebrush squirreltail germplasm releases evaluated here are certified as selected class, natural track, pre-variety germplasms (see citations in Table 1), which means that they were developed from one to several wild collected source populations and put through minimal development processes with no artificial selection within germlines. We obtained these sources from stock seed repositories or the developers themselves, so the generation tested should be equivalent to the initial releases, meaning that our findings are likely not indicative of what might occur after release and during commercial production. The divergence in trait space between wild seed sources and germplasm releases suggests that evolution has occurred, either intentionally or inadvertently, during the collection and development process itself (Sand Hollow has been identified as *E. multisetus*, which may partially explain its trait discrepancies). Inadvertent selection or genetic drift during plant material development is one potential explanation for this difference, though plant material developers in the intermountain region usually take measures to avoid this issue, including the use of large initial seed collections to avert genetic bottlenecks, as well as iterating through a minimal number of generations, which may not be rapid enough for evolutionary change, before releasing seed to commercial growers.

Another potential explanation for these patterns is that seed collectors and plant material developers are seeking and selecting populations with certain characteristics. So that, while no artificial selection is performed within germlines, selection still occurs across a suite of accessions, both during wildland collecting, where desired phenotypes are likely to be sought, and during the development process, where multiple accessions are usually evaluated in comparison to one another and then chosen based on trait expression. Indeed, the primary traits that have been selected for in intermountain region plant material development are greater biomass and seed production, also shown in our data (Fig. 5), which support economic values (grazing, commercial seed production) but may not be optimal traits for supporting fitness in the wild. In bottlebrush squirreltail there are trade-offs between growth traits and traits that tend to increase long-term survival, such as drought resistance, in some environments. The potential for generating mismatches between traits and climates of use should be considered during the plant material development process, especially as a greater emphasis on artificial selection is being advocated as a response to global change.

While the germplasm releases studied here are generally unrepresentative of the locations where they were initially collected, they still display trait combinations that are within the range of variation of wild populations (Fig. 4a). By using a trait-based, rather than a geographic, approach to transfer function modeling, these germplasms can be placed into an STZ framework; to our knowledge a novel use of this methodology. In this case, three of the six germplasms (Fish Creek, Rattlesnake, Toe Jam Creek) appear to maintain some utility across the intermountain region, while the other three (Sand Hollow, Pleasant Valley, Antelope Creek) match more restricted areas. These methods can be incorporated into existing transfer function-based tools to help restoration practitioners consider and compare a wider array of plant material sources, including plant materials that were not developed within STZ frameworks, allowing for greater flexibility in provenancing decisions.

Table 1. Squirreltail germplasms grown alongside wildland populations at common gardens.

		Collection Source Location					
Germplasm	Taxon	County, State	Elevation (m)	Lat., Long. (dd)	Collection Year	Release Year	Citation
Antelope Creek	*Elymus elymoides* ssp. "C"	Wasco, OR	1111	44.9, -120.6	2003	2009	Jones et al. 2014
Fish Creek	*Elymus elymoides* ssp. *elymoides*	Blaine, ID	1450	43.343, -113.863	1995	2003	Jones et al. 2004a
Pleasant Valley	*Elymus elymoides* ssp. "C"	Baker, OR	1166	44.67, -117.62	2002	2010	Jones et al. 2014
Rattlesnake	*Elymus elymoides* ssp. *elymoides*	Elmore, ID	1169	43.289, -115.836	1995	2007	Jones 2010
Sand Hollow	*Elymus multisetus*	Gem, ID	830	43.846, -116.464	1984	1996	Jones et al. 1998
Toe Jam Creek	*Elymus elymoides* ssp. *californicus*	Elko, NV	1829	41.299, -116.464	1986 or before	2003	Jones et al. 2004b

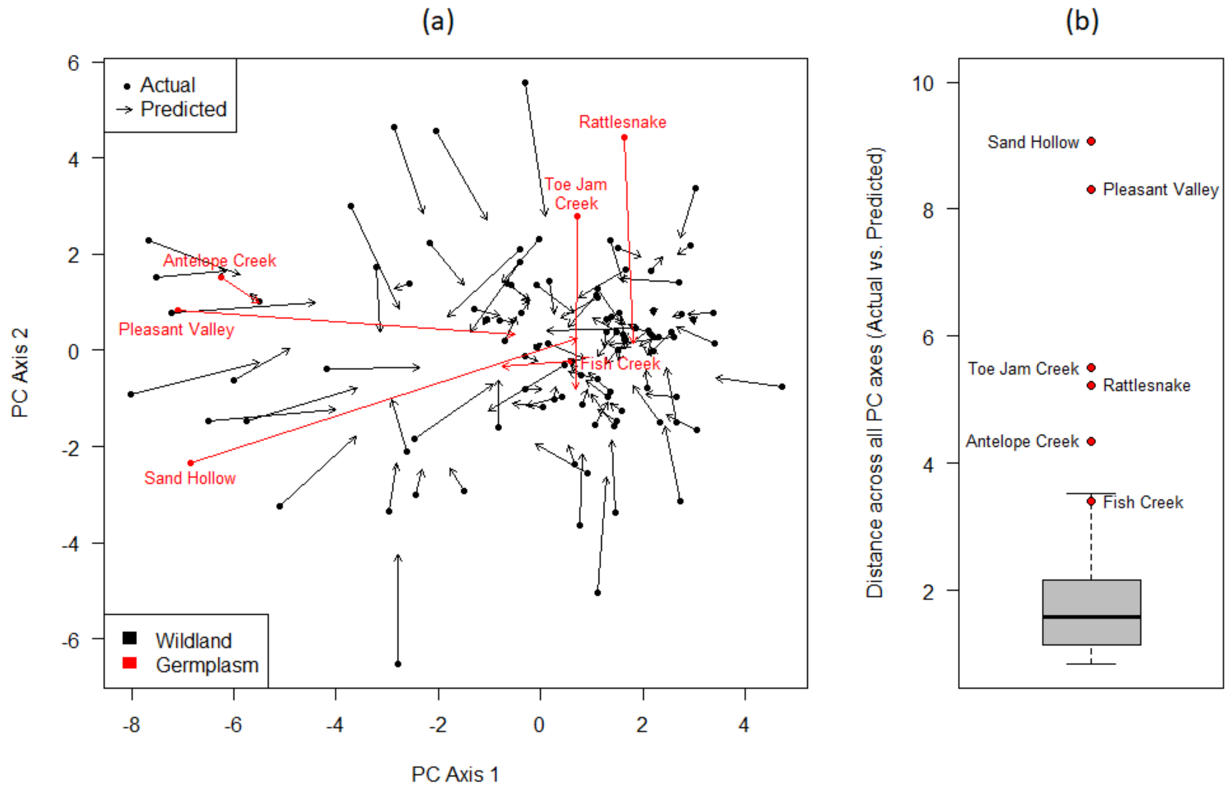


Figure 4. Distance in multidimensional trait space between actual trait values (averages of measurements in common gardens) and predicted values at source locations (calculated via a transfer function) for wildland populations and germplasms of squirreltail (*Elymus elymoides* and *E. multisetus*) from the intermountain western USA. The multivariate trait space is defined by principal component (PC) axes that represent variation among seven traits (see Fig. 2) at three common garden sites. PCs and their associated transfer function were built using data from wildland populations only (all *E. elymoides*) and germplasms were subsequently projected onto the PC axes (see Appendix S1). (a) Ordination of PC axes 1 and 2, showing distances as arrows from actual to predicted positions along these axes, with germplasms colored and labeled in red. (b) Boxplot of multidimensional Euclidean distances across all PC axes, showing points for each germplasm. All but one of the germplasms, but none of the wildland populations, were outliers.

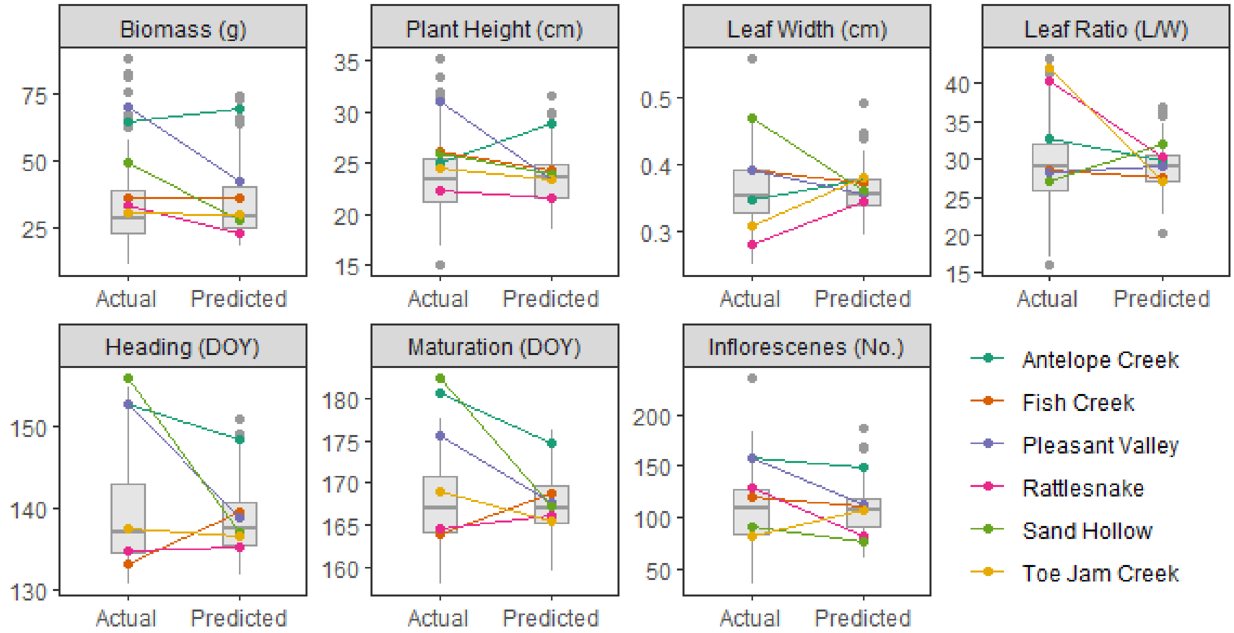


Figure 5. Actual trait values (averages of measurements in three common gardens) compared to predicted values at source locations (calculated via a transfer function) for wildland populations and germplasms of squirreltail (*Elymus elymoides* and *E. multisetus*) from the intermountain western USA. The transfer function was built from principal components of traits using data from wildland populations only (all *E. elymoides*) and was subsequently applied to germplasms (see Appendix S1). Boxplots show distributions for all populations, overlain by colored points indicating germplasms (gray points are wildland populations outliers), with lines connecting actual and predicted germplasm trait values.

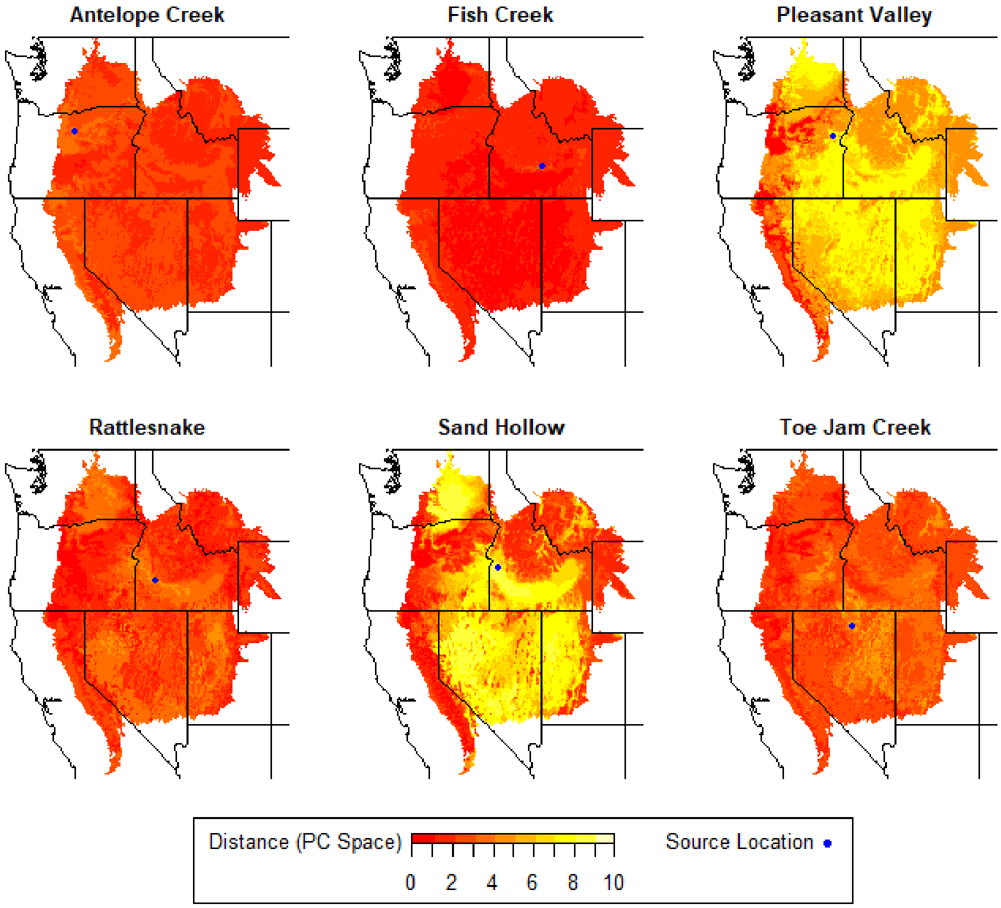


Figure 6. Maps depicting, for six germplasms of squirreltail (*Elymus elymoides* and *E. multisetus*), the degree to which modeled climate suitability differs when based on predicted trait values at source locations (see Fig. S1) versus actual trait values of these germplasms measured in common gardens (see Fig. S2). Mapped values were generated using a transfer function that quantifies relationships between principal components (PCs) of trait variation and climate variables in focal ecoregions of the intermountain western USA. PCs and their associated transfer function were developed using data from wildland populations only (all *E. elymoides*) and subsequently applied to germplasms (see Appendix S1). Units are Euclidean distances across 18 significant PC axes, with larger values indicating greater absolute difference between modeled climate suitability for predicted versus actual traits.

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

Science partners:
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USDA Forest Service, Pacific Northwest Research Station: Holly Prendeville and Brad St. Clair
The Understory Initiative, Oregon: Kathryn Prive
Oregon State University: Matt Orr and Ron Reuter
USDI Geological Survey, Flagstaff Campus: Rob Massatti
USDA Agricultural Research Service: Steve Larson and Blair Waldron

Introduction – Land managers face numerous challenges when maintaining and restoring healthy ecosystems that are resilient to climate change. One challenge is determining and procuring the appropriate plant material to restore an area. In the western United States, plant species span a wide range of climates from arid desert to temperate rainforest to alpine areas. Climatic extremes can lead to natural selection on populations leading to improved survival and reproduction in local environments, i.e. local adaptation. To ensure success in restoration activities and healthy ecosystems, federal agencies have directives to use genetically appropriate materials that are locally adapted. Seed transfer zones have been developed to guide the movement of appropriate plant materials in restoration and reforestation. Seed transfer zones separate areas by plant performance and/or climatic conditions important to plant growth, survival, and reproduction. Provisional seed zones combine minimum winter temperature with aridity (mean annual temperature/mean annual precipitation) to delineate areas of similar climate. Empirical seed zones are delineated for a particular species and incorporate climatic data related to genetically differentiated traits important to survival and reproduction. Empirical seed zones have been developed for over 20 species in the western United States. However, the efficacy of seed transfer zones in predicting the climatic match of seed sources to restoration sites has not been tested in non-tree species.

Focal plant – Bluebunch wheatgrass (*Pseudoroegneria spicata*) is an ecologically important restoration species that provides structure to plant communities and forage for wildlife. Bluebunch wheatgrass is a cool-season, long-lived perennial bunchgrass native to the western United States. This grass thrives in a variety of habitats that range in mean annual temperature (3-11°C), annual precipitation (21-187 cm), and elevation (230-2460 m). Populations of bluebunch wheatgrass differ in several traits important for adaptation to precipitation and temperature (St.Clair et al. 2013). Seed zones for bluebunch wheatgrass demarcate areas with similar climate and populations with climate-associated genetic variation. To examine if populations are locally or regionally adapted requires comparing performance of local and non-local populations in a reciprocal manner. We are using a reciprocal transplant experiment to investigate the efficacy of bluebunch wheatgrass seed zones. Results from this experiment will determine if seed zones for bluebunch wheatgrass are delineated appropriately or if they need modification. We investigate the effectiveness of empirical seed zones for bluebunch wheatgrass by comparing establishment, survival, and reproduction of populations from local seed zones to non-local seed zones.

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

Methods – We hypothesize that in the long-term, populations from local seed zones will better establish, survive, and reproduce. To test this hypothesis, we established a reciprocal transplant study at 16 sites located in two broad regions (i.e. transects) (Figure 1). The two broad regions include (1) a transect through hot, dry climates of the lower Snake River Plain to the cool, relatively wet climates of the higher elevations of the Great Basin Ranges to the cold, dry climates of the upper Snake River Plain, and (2) a transect from hot, dry climates of the Columbia Plateau to cool, wet climates of the Blue Mountains to the cold, dry climates east of the Blue Mountains. Within each transect, we reciprocally planted native populations from eight seed zones into eight sites that represent the climate of each seed zone (Figure 1). In addition, we planted two propagated lines at all sites and one propagated line at sites at the two extremes of the seed zones.

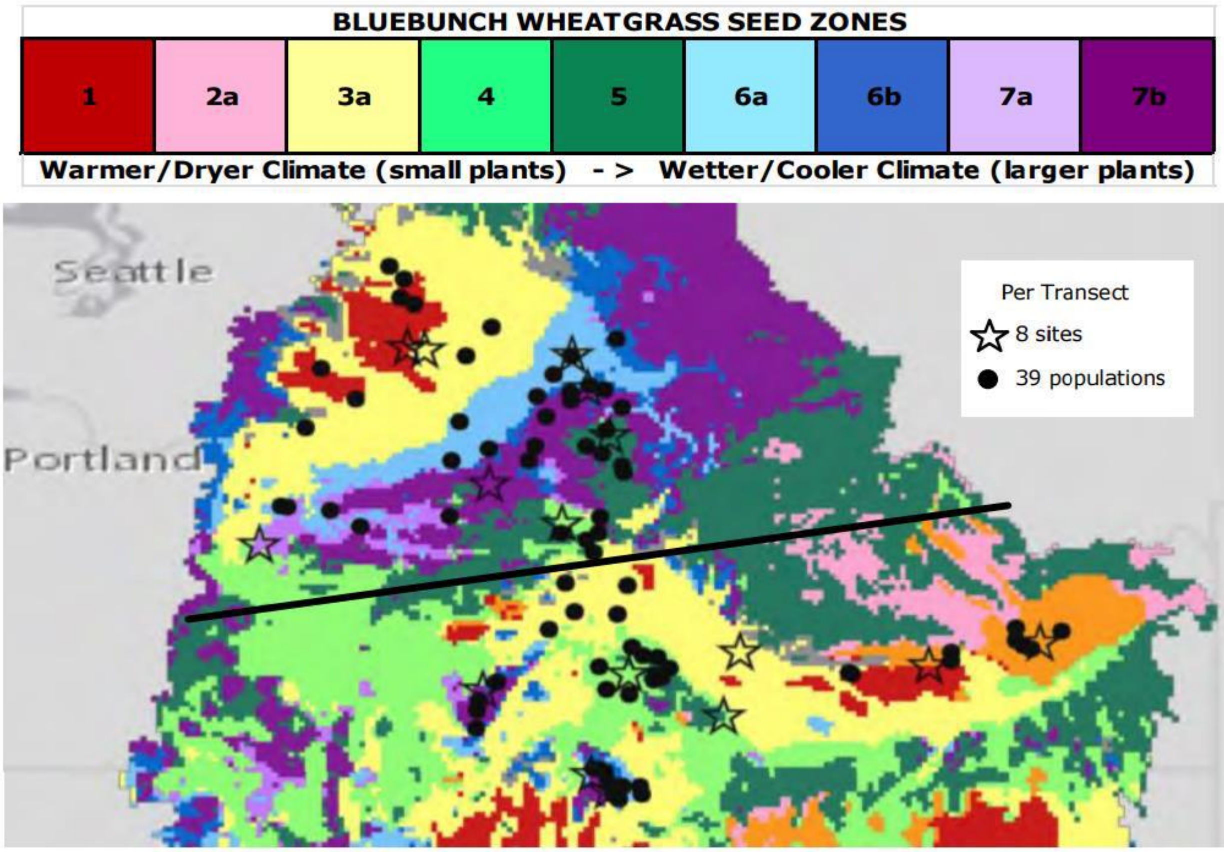

Figure 1. Map of bluebunch wheatgrass populations (black circles) used in eight common gardens (stars) in each transect (delineated) in the northwest US.

Seed was collected from 78 populations throughout the two broad regions in 2013. The RMRS Moscow lab produced containerized planting stock for the study in 2014. Federal, state and private collaborators provided land for common garden sites. The 16 common gardens were identified, prepared and established in 2014. Several common gardens were fenced to protect plants from herbivory. Each common garden was planted with 39 populations and two propagated lines (Anatone and Goldar) for a total of 820 plants surrounded by two rows of buffer plants. A few common garden sites had an additional treatment that included: (1) a seed zone from the other transect, or (2) an extra propagated line (Wahluke) for a total of 1000 plants per common garden.

The experimental design at each common garden is a split-plot design with populations planted by seed zone into subplots and all seed zones present within a plot. Each site includes four replicate plots. Each subplot has 25 plants: five replicates of five populations or all one propagated line. However, only four populations were available from the hottest, driest seed zone within each transect and had additional replicates to reach 25 plants per subplot. Spacing is 0.6 m x 0.8 m between plants. Each site was visited in spring and summer of 2015, 2016, 2017, 2018, and 2019 to record various traits including: leaf length, width and roll; survival; reproductive phenology; herbivory; root crown diameter; and number of reproductive stalks. In 2015 and 2016 reproductive stalks were collected from a subset of individuals per population at each site to estimate seed production. In the summer 2017 after reproductive stalk production, biomass was harvested from a subset of individuals per populations at each site. Weather data loggers were installed at plant height and at 2 m at each site to record local temperature for comparison with regional weather stations and climate interpolation models. Common gardens are managed to control weeds to ensure establishment and to reduce the effect of competing vegetation to allow better evaluation of differences in plant growth, survival, and reproduction associated with local climates.

Site visits to the gardens were also made from 2020-2022 to maintain them in as weed free state as possible. Additional data on plant size, survival and reproduction were taken in most years and at most gardens. Several sites have been retired due to low survival rates or the ending of agreements with local land owners. Currently, 12 sites are still active across the study (6 on each transect).

Preliminary results and discussion – Across 16 common garden sites survival was high (>80%) through the first growing season. One site was completely lost with the majority of plants dying a month after transplant due to an extreme weather event. This site was re-planted, but subsequently lost due to repeated vandalism. Of the 15 sites that remained through 2017, plant survival declined over time to 54% on average. Plants varied in survival, leaf morphology, reproductive phenology and reproduction among common garden sites and among seed sources.

Preliminary analyses of data collected in 2017 indicated that populations that were local to a common garden site sometimes but not always performed better (in terms of being larger, having more reproductive stalks, and having higher survival) compared to non-local populations. In these analyses, local populations were defined as either (1) populations from the same seed transfer zone as the common garden site where they were planted, or (2) populations from a source environment within one standard deviation of the garden location in multidimensional climate space (“derived local”). Performance of local populations varied depending on the trait being measured (size, reproduction, or survival) and how "local" was defined, but on average, local populations performed best in approximately one third of the cases (Table 1). Reproduction showed the clearest pattern of local adaptation, with plants from the derived local environment having the highest reproduction at a garden site, and plants from different environments having less reproduction the farther away in climatic space they were sourced from (Table 1). Size and survival tended to be higher among plants from cooler/wetter areas and lower among plants from warmer/drier areas, indicating an adaptive pattern that was not strictly related to local adaptation.

Table 1. Summary table showing the proportion of gardens where the relative performance of local populations was better, the same as, or worse than the average non-local population for size, reproduction, and survival in 2017. Green colors represent higher percentages and red colors represent lower percentages. The "Average Local Best?" column indicates whether the average relative performance of all local populations across the study is greater than the average performance of all non-local populations, and the "Average Significant" column indicates whether this difference is significant.

		Local Best	Local Same	Local Not Best	Average Local Best?	Average Significant?
Local	**Size**	46.7%	26.7%	26.7%	yes	no
	Reproduction	40.0%	26.7%	33.3%	yes	no
	Survival	33.3%	40.0%	26.7%	yes	no
Derived Local	**Size**	28.6%	50.0%	21.4%	yes	no
	Reproduction	50.0%	28.6%	21.4%	yes	yes
	Survival	21.4%	50.0%	28.6%	no	no

Additional analyses have been implemented to examine performance across multiple years starting with 2015 (the first year following planting) through 2019 for sites and years where data were collected. These analyses highlight variation in trait expression and patterns of local adaptation over time. For example, reproductive output was low in 2015 as most plants had not yet matured, then increased for many but not all populations in subsequent years (Fig. 2). Over time, reproductive output became more variable across populations and tended to be highest among populations closer to zero in the derived climate space, i.e. populations from source locations where climates more closely resembled the climates of the garden sites during the years since planting (Fig. 2). These results suggest that reproductive success of bluebunch wheatgrass at planting sites is likely to be greater if the climate of origin is more similar to the climate experienced at the planting site, although it may take multiple years for this pattern to emerge, and other factors also influence reproductive success.

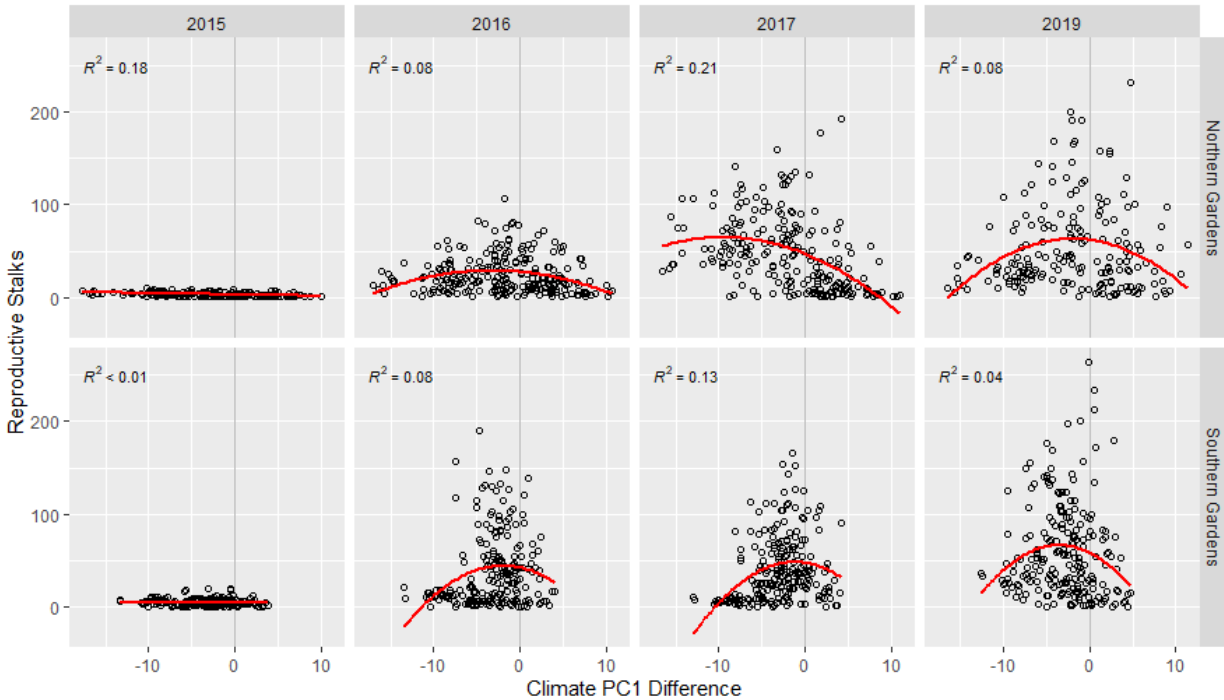

Figure 2. Transfer distance functions across multiple years for *Psuedoroegneria spicata* Northern and Southern common garden transects for reproduction. PC 1 difference axis indicates expected trait values of a source population at a restoration site given the difference between the climate at the restoration site and the climate at the source location. Negative values on the PC 1 difference axis represent source locations that are cooler and wetter than garden sites, and positive values represent source locations that are warmer and wetter than garden sites.

Management Applications – Since bluebunch wheatgrass is an ecologically important restoration species, it is essential to have effective seed-transfer zones to improve restoration success. This study is examining the efficacy of seed zones for bluebunch wheatgrass to ensure successful establishment and allow for long-term adaptation by maintaining genetic diversity. The results of this study will help land managers to determine sources of bluebunch wheatgrass populations for post-fire restoration of an area. Furthermore, this study will explore the consequences of changing climates for adaptation by substituting space for time to evaluate various populations in different climates. Results from this portion of the study will aid land managers in maintaining and restoring areas considering future climate changes. Long-term productivity and adaptation will be modeled to allow evaluation of trade-offs between different management options for current and future climates. Plant material movement guidelines and associated seed zones can be adjusted based on results from this study and management objectives.

References- St. Clair JB, Kilkenny FF, Johnson RC, Shaw NL, Weaver, G. 2013. Genetic variation in adaptive traits and seed transfer zones for Pseudoroegneria spicata (bluebunch wheatgrass) in the northwestern United States. Evolutionary Applications, 6: 933-948.

Project publications:

Massatti R, Prendeville HR, Larson S, Richardson BA, Waldron B, Kilkenny FF. 2018. Population history provides foundational knowledge for utilizing and developing native plant restoration materials. Evolutionary Applications, 11: 2025-2039.

Cooke B, Richardson B, Kilkenny F, St. Clair B, Finch D, Prendeville H. 2019. Science You Can Use (SYCU) - Getting climate-smart with seeds: How a new software tool helps prepare landscapes for expected future conditions. Science You Can Use Bulletin, Issue 35. Fort Collins, CO: Rocky Mountain Research Station. 11 p.

Prive K, Orr MR, Kilkenny FF, Reuter RJ, Prendeville, HR. 2021. Phenological Variation in Bluebunch Wheatgrass (*Pseudoroegneria spicata*): Implications for Seed Sourcing, Harvest, and Restoration. Land, 10: 1064.

9. Science Delivery – Great Basin Native Plant Project

Cooperators: Corey Gucker Coordinator, Writer, Great Basin Fire Science Exchange; Francis Kilkenny, Research Biologist, USFS Rocky Mountain Research Station

(*This report was submitted as a final report on a sunsetting agreement. A new agreement has been established to continue science delivery work*)

Purpose. The purpose of this agreement is to document the cooperation between the parties to support synthesis and dissemination of research and applied science products and knowledge of the Great Basin Native Plant's (GBNPP) focus on native Great Basin plant species.

Original Work Plan. Collaborative research and science delivery with the GBNPP (Boise, ID) includes preparation and dissemination of synthesized literature reviews, which include research findings from the many projects funded by the GBNPP that focused on Great Basin native forb species.

Science integration and application of research findings is an integral function of the 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 exists in journal article, theses, reports, and other media. Providing syntheses of these results in an organized, user-friendly format to seed collectors, seed growers, nurserymen, landowners, restoration contractors, and land managers is essential to increasing the supply and use of appropriate native forbs in restoration, which in turn supports successful land restoration or rehabilitation.

Corey Gucker is a part-time researcher, writer, and consultant supporting ecological research, science writing, and science delivery for non-profits, universities, and government agencies. Her skills and expertise will help the GBNPP in the production and delivery of science related to ecosystem restoration in the Great Basin. Collaboration between Gucker and GBNPP will support the GBNPP's science delivery mission and Gucker's goal of supporting crossover in science-management relationships.

Development and printing of fliers, cards, and example reports to be presented and disseminated at in-person meetings and conferences.

2019 Deliverables. To support the collaborative research and science delivery of the GBNPP (Boise, ID), a considerable amount of time and funds in 2019 were devoted to finalizing, printing, and disseminating the project's 2016 and 2017 annual reports, highlighting current and on-going partnership research. This is a critical first step in sharing and transferring research and practitioner knowledge gained over the last several years. These reports summarize and consolidate the information on native forb material development, cultural practices for seed production, and restoration ecology and technology that was funded and supported by the GBNPP.

2020 Deliverables. Time and funds in 2020 were devoted to initial steps in the search for a web developer to support a redesign of the GBNPP website. This included discussing options for the website platform and brainstorming ways to automate content entries and update organization that would cut down on time devoted to website maintenance.

In 2020, eleven reviews that synthesized the biology, ecology, and restoration use of specific Great Basin forb species were finalized and posted online. Although researching, writing, and editing of these chapters was funded through another Bureau of Land Management (BLM)-U.S. Forest Service, Rocky Mountain Research Station (USFS RMRS) funding source, funds from this agreement supported development of a consistent, user-friendly layout for print and online reports. This required working with and learning from a locally based firm to help with development and use of an interactive pdf template for easy online and hard-copy navigation.

In 2020, a number of conferences and meetings were attended. At these events, a project poster was presented and information and resources were distributed about the Western Forbs: Biology, Ecology, and Use in Restoration online book. This online book is a collaborative effort of the BLM, USFS-RMRS, GBNPP, Great Basin Fire Science Exchange (GBFSE), and the Plant Conservation Network.

- Restoring Resilient Communities in Changing Landscapes: Society for Ecological Restoration Conference in Spokane, WA; 2018 October 15-17
- Joint Fire Science Program's (JFSP) Fire Science Exchange Network Meeting in Reston, VA; 2019 March 12-14
- Restoration of Sagebrush Ecosystems in Boise, ID; 2019 March 18-22
- Congressional and Forest Service Leadership meetings in Boise, ID and Reno, NV; 2019 August

2021 Deliverables. Most of the FY2021 project focus was on updating the GBNPP logo and building a new GBNPP website. The new website was developed using the Word Press platform. It includes a redesign of the main menu options as well as a search feature for GBNPP documents. All content from the old website was migrated to the new site, but the content had to be manually updated for consistent display and population of the website search feature. In 2021, nearly all GBNPP annual reports and journal articles published between 2012 and 2019 were manually updated.

Presented project poster and disseminated advertising materials about the Western Forbs project at the following conferences and meetings:

- Sage-Grouse Conservation (SageCon) Virtual Summit; 2020 December 8-9
- USGS Sagebrush and Fire Research Information Transfer Webinars; 2020 December 1-2, 9-10
- Invasive Annual Grass Virtual Workshop; 2020 December 14
- Big Sagebrush Restoration – Society for Range Management Virtual Symposium; 2021 February 18

2022 Deliverables. Time and funds in 2022 were devoted to manual checks and updates of all remaining publications and reports (with publication dates through 2021) available on the website. These publications and reports are those featuring work and projects funded by the GBNPP and they now have consistent citation formatting and updated links. We updated the collaborator webpage to feature past and current agency cooperators, this is a change from the content displayed on the original website which featured the individuals associated with each agency and required a lot more updating. We drafted a web form that will allow cooperators to upload project progress in a way that also satisfies BLM and USFS agreement reporting, reducing duplicated efforts for all cooperators. We developed and have nearly finalized a new more modern GBNPP logo.

Presented project poster and disseminated advertising materials about the Western Forbs project (with 33 species reviews finalized and posted) at the following conferences and meetings:

- Sage-Grouse Conservation (SageCon) Virtual Summit; 2021 November 3-4
- Institute for Applied Ecology Workshop; 2022 January 12-13
- Native Seed in Restoration Workshop; 2022 March 8
- International Association of Wildland Fire; 2022 May 23-27

10. Ongoing Cooperator Projects

- Western Forbs: Biology, Ecology, and Use in Restoration

  Purpose: Synthesize knowledge on native forbs, including distribution, ecology, nursery and cultivation practices, and seeing and planting requirements

  Cooperators: *Great Basin Fire Science Exchange*: Corey Gucker; *USDA Forest Service, Rocky Mountain Research Station:* Nancy Shaw

- Effects of plant species diversity and soil biochar amendments on reestablishment and performance of native sage steppe species

  Purpose: Study the effects of seed-mix diversity and design, as well as biochar additions, on soil properties and microbiota in post-fire seedings

  Cooperators: *Boise State University:* Marie-Anne de Graaff and Luci Wilson; *USDA Forest Service, Rocky Mountain Research Station:* Francis Kilkenny and Jessica Irwin

- Plant-Pollinator Interaction Provenance Trials

  Purpose: Determine how various seed sources respond to variation in precipitation and how this impacts their interactions with pollinators

  Cooperators: *Northern Arizona University:* Kevin Grady

- Precipitation effects on native species establishment in post-fire restoration

  Purpose: Study the effects of drought and extreme rainfall events on post-fire seeding success

  Cooperators: *USDA Agricultural Research Service:* Beth Newingham

- Research related to the management and use of native plant materials for restoration

  Purpose: Support Seeds of Success collections; assess functional trait variation in great basin forb species and how it might change in stressful environments and affect plant community succession and assembly; determine whether genetic differences between *Penstemon pachyphyllus* seed sources exhibit outbreeding depression in mixed-source production fields

  Cooperators: *Chicago Botanic Garden:* Kayri Havens, Andrea Kramer and Jacob Zeldin

- Irrigation Requirements for Seed Production of Five Native Penstemon Species in the Intermountain West, USA

  Purpose: Develop and test cultural practices for native forbs, in this case determining optimal irrigation practices for *Penstemon* species

  Cooperators: Oregon State University, Malheur Experiment Station: Clint Shock and Erik Feibert, *USDA Forest Service, Rocky Mountain Research Station:* Nancy Shaw and Francis Kilkenny

11. Federal Fiscal Year 2022 Publications and Tools Resulting from Current or Past GBNPP-Funded Projects

Publications

Calendar year 2021:

Jain TB, Abrahamson I, Anderson N, Hood S, Hanberry B, Kilkenny F, McKinney S, Ott J, Urza A, Chambers J, Battaglia M, Varner M, O'Brien JJ. 2021. Effectiveness of fuel treatments at the landscape scale: State of understanding and key research gaps. PROJECT ID: 19-S-01-2. Boise, ID: Joint Fire Sciences Program. 65 p. https://www.fs.usda.gov/research/treesearch/63869

Leger EA, Agneray AC, Baughman OW, Brummer EC, Erickson, TE, Hufford KM, Kettenring KM. 2021. Integrating evolutionary potential and ecological function into agricultural seed production to meet demands for the decade of restoration. Restoration Ecology e13543. https://doi.org/10.1111/rec.13543

Prive K, Orr MR, Kilkenny FF, Reuter RJ, Prendeville HR. 2021. Phenological variation in bluebunch wheatgrass (Pseudoroegneria spicata): Implications for seed Sourcing, harvest, and restoration. Land 10:1064. https://doi.org/10.3390/land10101064

Calendar year 2022:

Agneray AC, Forister ML, Parchman TL, Leger EA. 2022. Does a history of co-occurrence predict plant performance, community productivity, or invasion resistance? bioRxiv 2022.09.20.508783; https://doi.org/10.1101/2022.09.20.508783 **This article is a preprint and has not been certified by peer review*

Barga SC, Kilkenny FF, Jensen S, Kulpa SM, Agneray AC, Leger EA. 2022. Not all seed transfer zones are created equal: Using fire history to identify seed needs in the Cold Deserts of the Western US. bioRxiv 2022.08.15.503985; https://doi.org/10.1101/2022.08.15.503985 **This article is a preprint and has not been certified by peer review*

Gucker CL, Shaw NL 2022. Lemon scurfpea (*Psoralidium lanceolatum* [Pursh] Rydb.). In: Gucker CL, Shaw NL eds. Western forbs: Biology, ecology, and use in restoration. Reno, NV: Great Basin Fire Science Exchange.15 p. http://greatbasinfirescience.org/western-forbs-restoration

Innes P, Gossweiler A, Jensen S, Tilley D, St. John L, Jones T, Kitchen S, Hulke BS. 2022. Assessment of biogeographic variation in traits of Lewis flax (*Linum lewisii*) for use in restoration and agriculture. AoB Plants. 14(2): 1-14. https://doi.org/10.1093/aobpla/plac005

Jensen S, Christensen WF, Roundy B, Anderson VJ, Kitchen SG, Allphin, L. 2022. Temporal and spatial factors influence native forb emergence more than sowing depth. Rangeland Ecology and Management. 83: 41-49. https://doi.org/10.1016/j.rama.2022.03.003

Ott JE, Kilkenny FF, Summers DD, Thompson TW, Petersen SL. 2022. Post-fire succession of seeding treatments in relation to reference communities in the Great Basin. Applied Vegetation Science 25:e12633. https://doi.org/10.1111/avsc.12633

Ott JE, Kilkenny FF, Summers DD, Thompson TW, Petersen SL. 2022. Influence of seeding treatments on vegetation succession following wildfire. U.S. Department of Agriculture, U.S. Forest Service, Rocky Mountain Research Station. https://www.fs.usda.gov/rmrs/science-spotlights/influence-seeding-treatments-vegetation-succession-following-wildfire

Richardson BA, Kilkenny FF, Milano E, Islam-Faridi N, Missatti R. 2022. Forb genetic research provides a basis for restoration. U.S. Department of Agriculture, U.S. Forest Service, Rocky Mountain Research Station. https://www.fs.usda.gov/rmrs/science-spotlights/forb-genetic-research-provides-basis-restoration

Richardson BA, Kilkenny FF, St. Clair JB. 2022. Web-based tools for sourcing seed adapted to future climates. Science Spotlight. U.S. Department of Agriculture, U.S. Forest Service, Rocky Mountain Research Station. https://www.fs.usda.gov/rmrs/science-spotlights/web-based-tools-sourcing-seed-adapted-future-climates

Richardson BA, Massatti R, Islam-Faridi N, Johnson S, Kilkenny FF. 2022. Assessing population genomic structure and polyploidy: a crucial step for native plant restoration. Restoration Ecology e13740. https://doi.org/10.1111/rec.13740

Shaw NL, Kilkenny FF, Gucker C, Halford A, MontBlanc E. 2022. The rundown on native western forbs. U.S. Department of Agriculture, U.S. Forest Service, Rocky Mountain Research Station. https://www.fs.usda.gov/rmrs/science-spotlights/rundown-native-western-forbs

St. Clair JB, Richardson BA, Stevenson-Molnar N, Howe GT, Bower AD, Erickson VJ, Ward B, Bachelet D, Kilkenny FF. Wang T. 2022. Seedlot Selection Tool and Climate-Smart Restoration Tool: Web-based tools for sourcing seed adapted to future climates. Ecosphere 13:e4089. https://doi.org/10.1002/ecs2.4089

Online Tools Maintained by Great Basin Native Plant Project and Cooperators

- Western Wildland Environmental Threat Assessment Center (WWETAC) Seed Zone Mapper
- Climate Smart Restoration Tool
- Great Basin Native Plant Project Website – Undergoing significant revamp, current site is out of date

Appendix. Native species, varieties/sources and environments tested/synthesized

Project/ Sub-Project[1]	Species over life of project	Current species	Species added in FY22	Species completed in FY2022	Varieties/ sources over life of project	Current varieties/ sources	Varieties/ sources added in FY22	Sites/ environments
Empirical Studies								
1. Workhorse Native Forb Adaptative Genetics and Plant Materials Development for Postfire Restoration of Critical Wildlife Habitat	**9**	**9**	**2**		**500**	**500**	**85**	**11**
A. *Seed and tissue collection*[2]	9	2	2		N/R[3]	N/R	N/R	
B. *Common garden array*	6	3	1		N/R	N/R	N/R	
C. *Seed germination*	3	1		2	N/R	N/R	N/R	
D. *Population genomics*	9	8	1	1	N/R	N/R	N/R	
2. Vegetation Succession in Post-Fire Seeding Treatments	**12**	**12**			**16**	**16**		**2**
3. Testing the Efficacy of Seed Zones for Re-establishment and Adaptation of Bluebunch Wheatgrass (*Pseudoroegneria spicata*)	**1**	**1**			**79**	**79**		**15**
4. Adaptive genetic variation and seed transfer guidelines for bottlebrush squirreltail (*Elymus elymoides*)	**1**			**1**	**116**			**3**
5. Effects of plant species diversity and soil biochar amendments on reestablishment and performance of native sage steppe species	**12**	**12**			**6**	**6**		**1**
6. Plant-Pollinator Interaction Provenance Trials	**10**			**10**	**60**			**2**
7. Research related to the management and use of native plant materials for restoration (part of this funding is used to support SOS, only non-SOS work is reported here)	**4**	**4**			**30**	**30**		**2**
8. Irrigation Requirements for Seed Production of Five Native Penstemon Species in the Intermountain West	**5**			**5**	**5**			**1**
Empirical Total	**54**	**38**	**2**	**16**	**812**	**631**	**85**	**37**
Information Syntheses								
Western Forbs: Biology, Ecology, and Use in Restoration	**41**	**2**	**2**	**7**	**N/R**	**N/R**	**N/R**	**N/A[4]**
Overall Species Total[5]	**95**	**40**	**4**	**23**				
Non-Overlapping Species Total[6]	**74**	**30**	**4**	**21**				

1: Only projects that were ongoing in FY22 and that test or synthesize information on specific species are listed here.
2: Number for sub-projects are marked in gray, only full project numbers are counted in the totals.
3: N/R = not reported here.
4: N/A = not applicable.
5: Overall species totals include species that overlap between projects; high priority species are the subject of multiple projects.
6: Species totals with overlapping duplicate species removed.