Supporting the development and use of native plant materials for restoration on the Colorado Plateau (Fiscal Year 2019 Report)

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Introduction

A primary focus of the Bureau of Land Management's (BLM's) Colorado Plateau Native Plant Program (CPNPP) is to identify and develop appropriate native plant materials (NPMs) for current and future restoration projects. Multiple efforts have characterized the myriad challenges inherent in providing appropriate seed resources to enable effective, widespread restoration and have identified a broad suite of research activities to provide the information necessary to overcome those challenges (e.g., Plant Conservation Alliance 2015; Breed et al. 2018; Winkler et al. 2018). Many of the most complex information needs relate to identifying the appropriate sources of plant species that can successfully establish in dryland environments, like the Colorado Plateau, where low and highly variable precipitation is standard. Providing this information requires synergistic research efforts in which results from earlier investigations inform the design of subsequent investigations. The U.S. Geological Survey Southwest Biological Science Center's (SBSC's) research activities in FY19 followed an FY19 Statement of Work to support a research framework that is continually adapting based on the needs of the restoration community and results from previous investigations; the long-term research framework is outlined in the 2019-2023 5-Year Research Strategy (hereafter referred to as the 5-year plan). This research framework provides support for the National Seed Strategy for Rehabilitation and Restoration (Plant Conservation Alliance, 2015), Department of Interior Secretarial Order #3347 (*Conservation Stewardship and Outdoor Recreation*), and Department of Interior Leadership Priority #1 (*Create a conservation stewardship legacy second only to Teddy Roosevelt*).

Research activities in FY19 centered on landscape genetics, collecting seeds in preparation for experimental common gardens, and planning and trials in support of experimental drought gardens. These activities were supported by three biological technicians, one of which was jointly funded by the Ecological Society of America for six pay periods. Most of the field-related activities, including plant trait measurement, seed/tissue collecting, and GRID (Germination for Restoration Information and Decision-making) experimental treatments at the Canyonlands Research Center near Moab, UT were assigned to these technicians. Contrary to the drought conditions the pervaded the Colorado Plateau in FY18, plentiful spring precipitation resulted in easily-collected plant tissue and seed collections. However, the cool and wet spring delayed the phenology of early blooming species, which caused difficulties for timing seed collecting. Furthermore, seed collecting for late blooming species was difficult because of lower than average monsoon precipitation. While Dr. Rob Massatti was the only scientist supported by the SBSC-CPNPP agreement in FY19, other scientists, including Drs. John Bradford, Seth Munson, Mike Duniway, Sasha Reed, and Daniel Winkler, spent a considerable amount of time providing expert guidance and support for individual projects. Work activities performed in support of each 5-year plan goal are discussed in turn.

Resolving patterns and drivers of genetic diversity, structure, and adaptation using landscape genetic approaches

Genetic diversity is recognized as an important component of healthy ecosystem functioning (Hughes et al., 2008) and a unit of conservation concern (Hoban et al., 2013), but the consideration of diversity is often not incorporated into the development and use of NPMs for restoration purposes. However, it is highly likely that consideration of genetic diversity would increase the success of restoration outcomes (e.g., Broadhurst et al., 2008). For example, NPMs with too little genetic diversity may reduce success due to inbreeding depression, while NPMs that are too genetically different from a local population may reduce restoration success due to outbreeding depression (Hufford et al., 2012). Numerous historical and contemporary processes affect a plant's genetic structure and variation. The application of molecular genetic techniques is valuable for assessing these processes, which in turn can inform the development and deployment of NPMs, a species' genetic diversity and differentiation, taxonomic issues, and adaptation to environmental gradients. Genetic analyses are especially informative when applied to species for which there is little prior knowledge, for example because they generate data that can help structure field-based experimental frameworks, thereby ensuring that experiments will provide the informative results. For most of the important Colorado Plateau restoration species, knowledge on adaptive differentiation, genetic diversity, and spatial variation in standing genetic diversity is lacking (Wood et al., 2015).

FY19 Results and Discussion

During 2019 field work, SBSC collected leaf tissues for CPNPP priority species at environmentally stratified sites across the Colorado Plateau. Data collection at some sites and for some species was hindered by lower than average monsoonal precipitation. **Given these conditions, biological technicians visited 124 sites and made 213 collections for 21 species. These efforts resulted in 1,928 total tissues (Fig. 1).** Leaf tissue samples are being stored at SBSC in Flagstaff, Arizona. In addition, commercial germplasm sources for priority species were obtained and grown at Northern Arizona University's (NAU's) research greenhouses to include in analyses, and herbarium loans from regional herbaria were requested and sampled so that genetic variation can be represented across species' distributions.

Data have been (or are being) produced for eight species (see Table 1) and analyzed using the U.S. Geological Survey high performance computing cluster. Progress on genetic projects, which include tissue collection, laboratory work and genetic sequencing, and data processing and analysis, is essentially on time (Table 1). Many activities scheduled to begin in FY20 have already been initiated, as well as tissue sampling for the FY21 candidate species (e.g., *Bouteloua gracilis, Hesperostipa comata, Astragalus lonchocarpus, Cleome serrulata, Phacelia crenulata, Plantago patagonica,* and *Heterotheca villosa*). **Seed transfer zones have been published for all species initiated in FY17 (e.g., *Pleuraphis jamesii, Sphaeralcea parvifolia,* and *Sporobolus cryptandrus*)** (Massatti 2019a; Massatti 2019b); however, an ongoing project involving *Sporobolus cryptandrus* and *Sphaeralcea parvifolia* necessitates that these species are not marked as complete in FY19. **This project will result in a peer-reviewed publication in an applied journal that will broadly discuss the management implications of species' life history characteristics with respect to seed transfer guidance and native plant materials development.** Specifically, *Sphaeralcea parvifolia* is representative of outcrossing species (i.e., species in which cross pollination freely occurs), while *Sporobolus cryptandrus* exemplifies species that are selfing (i.e., species that nearly always self-fertilize). These life history strategies have important repercussions for how seed transfer guidelines should be created and used, and this manuscript will be submitted for review in FY20.

Analyses, manuscripts, and data releases are essentially complete for *Pleuraphis jamesii* (Massatti and Knowles 2020; Massatti 2020; Winkler and Massatti, *In revision*; Massatti and Winkler 2020). Massatti and Knowles (2020) document the historical factors that shaped the grass's patterns of genetic variation and adaptation; these data underlie the seed transfer zones reported in Massatti (2019a). Relevant to plant materials development, *Pleuraphis jamesii* shows a stronger signature of selection to environmental gradients associated with latitude compared to gradients associated with elevation, contrary to patterns reported in other regional species (Massatti et al. 2018a; Shryock et al. 2017). Important to note, **seed transfer zones reported in Massatti (2019a) reflect both patterns of inferred adaptation (e.g., the species' larger inferred response to latitudinal environmental gradients compared to elevational environmental gradients) AND patterns of genetic differentiation that may affect restoration outcomes if not properly accounted for** (see more below). These are the first seed transfer zones available that provide the synthesis of these types of data. Winkler and Massatti (*In revision*) report on a subset of the *Pleuraphis jamesii* data that support hybridization between *Pleuraphis jamesii* and *Pleuraphis mutica* both within naturally occurring, overlapping occurrences and in the *Pleuraphis jamesii* 'Viva' native plant restoration material. These results have **important implications for how 'Viva' is used in restoration treatments across the Intermountain West, as it will disintegrate the genetic integrity of *Pleuraphis jamesii* when used within the core range of that species**.

Another research project supported by Dr. Massatti in FY19 involved patterns of genetic differentiation across the western United States. Massatti et al. (2020) summarize available genetic and climate data from across the Intermountain West to support modifications to the way climate-informed seed transfer zones (i.e., CSTZs) are used to assist regional seed transfer guidance and native plant materials development. In summary, due to the topographic and environmental complexity of the West, genetic differentiation and climatic variability increase from any user-defined reference point. The climate results are important for practitioners to understand when considering how available materials match the climate at a restoration site or how to develop new materials because **they demonstrate that geographically close sites may have more similar environmental conditions, regardless of CSTZ or ecoregion boundaries, than sites within the same CSTZ and ecoregion but separated by a large geographic distance**. Furthermore, the genetic results clearly show that genetic variability rapidly increases with distance, such that by about 200 kilometers (~125 miles) from a reference point there is a higher probability that individuals of the same species belong to different genetic groups. These inferences can be used to understand the risk involved when using native plant materials at a restoration site where the species already exists. **Across the West, some ecoregionally-constrained CSTZs are so large that even if seed transfer is constrained by CSTZs and ecoregions, restoration outcomes may be affected by the genetic consequences of mixing genetically differentiated individuals**. Moreover, these results shed light on another problem of CSTZs – due to their generalized nature, they inherently do not protect species' natural patterns of genetic variation. Genetic diversity within native species is an important resource, especially if managers and practitioners plan to develop NPMs in an agronomic framework to meet large-scale restoration goals. This project will be completed in FY20 with the publication of the manuscript; data and scripts to repeat analyses or tailor to different geographic regions will be published as a data release available on ScienceBase and at https://www.usgs.gov/sbsc/native-plants (Massatti and Shriver 2020).

To support the development of species-specific seed transfer guidelines that take into account both inferred patterns of adaptation and patterns of genetic differentiation, Dr. Massatti and colleagues have developed methods to extrapolate species' genetic patterns across landscapes. These methods test multiple geographic and environmental factors and determine which ones explain a species' geographic patterns of neutral genetic variation best. Next, the methods utilize empirical genetic data to assign a probability to every geographic location regarding the genetic identity of individuals of that species. Uncertainty is built into this framework due to the lack of complete sampling across the landscape. These methods were used in the development of the seed transfer zones released in 2019 (Massatti 2019a; Massatti 2019b). A publication is currently being drafted to report these methods – after publication, programs and data will be available as a data release available on ScienceBase and at https://www.usgs.gov/sbsc/native-plants. In addition, Dr. Massatti is providing expertise to support the application of this method to bluebunch wheatgrass (*Pseudoroegneria spicata*) so that patterns of genetic variability (as reported in Massatti et al. 2018b) can be added as a constraint to seed transfer decisions mapped using the Climate Smart Restoration Tool (https://climaterestorationtool.org/csrt/). This is primarily an effort of the Great Basin Native Plant Project, but it may directly support CPNPP activities if, for example, CPNPP would like to include restoration species of interest in the Climate Smart Restoration Tool.

Note that the schedule in Table 1 reflects the 5-year plan, in which focus will shift away from landscape genomics toward other genetically-oriented restoration and production questions from FY21-FY23. Data will be released according to the schedule in Table 1 and will include molecular data and genetically-informed maps of seed transfer zones. All data will be made publicly available as official data releases that have gone through internal review at the U.S. Geological Survey to ensure that they meet the Fundamental Science Practices guidelines. In FY20, SBSC technicians will finish collecting leaf tissues for two priority species decided upon by SBSC researchers and the CPNPP Coordinator and continue to work according to the schedule in Table 1.

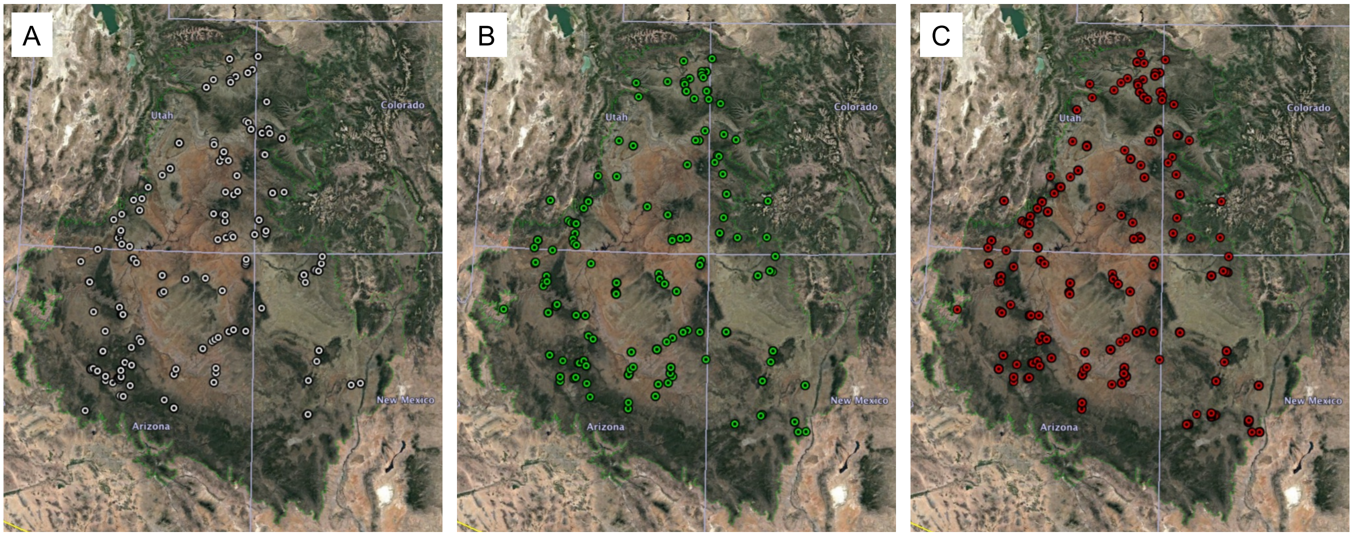

Figure 1. Colorado Plateau collection sites for seeds (A), tissues for genetic analyses (B), and tissues for trait analyses (C) during 2019.

Determining adaptive phenotypic variation in natural populations using common gardens and plant traits

The ability of land managers to achieve restoration goals is often hindered by a lack of scientifically sound information regarding how to use plant materials across a heterogeneous landscape. To mitigate this knowledge gap, SBSC proposed to establish common gardens at environmentally stratified sites on the Colorado Plateau. Including multiple sources of a species in a common environment (and replicated across environments) enables researchers to tease apart local adaptation (genotype-by-environment interactions), phenotypic plasticity, and the ability of successive generations to respond to novel environmental conditions (Hufford and Mazer 2003, de Villemereuil et al. 2016). Therefore, common garden experiments allow restoration ecologists to identify seed sources of plants locally adapted to specific climate variables, which can be common across the Intermountain West (Baughman et al. 2019). In addition, common gardens offer exceptional educational, training, and information-sharing opportunities, as they are locations where scientists, growers, and managers can visit together to look at plants and their responses to known conditions.

In addition to common gardens, SBSC researchers will assess plant trait variability across the Colorado Plateau. Understanding variation in plant traits within and among species can help researchers understand how they are able to persist in their current environments, how they may respond to climate variability and land management actions, and how they affect ecological services valued by society. Determining the structural and physiological characteristics of plant populations that allow them to survive under a set of environmental conditions can allow growers to select for these traits in new seed lines and plant materials development. Measuring plant traits of wild populations is also important when collecting seeds for restoration or evolutionary experiments (Li et al. 1998, Cornelissen et al. 2003, Swenson and Enquist 2007, Makkonen et al. 2012, Frenne et al. 2013). Traits can explain differential performance of populations in experimental and/or common garden environments by serving as a baseline for population phenotypes (Primack et al. 1989, Oleksyn et al. 1998, Vogel et al. 2005, Martin et al. 2007, Vitasse et al. 2009, Hancock et al. 2013, de Villemereuil et al. 2016). Knowledge of which combination of plant traits lead to enhanced performance in a specific environment can inform which species are likely to be successful without having to carry out grow-outs of all of them. Furthermore, linking the traits of

Table 1. Species for which molecular data are being gathered and analyzed and the timeframe for the release of data and reports. Due to field seasons being near the end of fiscal years, the majority of lab work and DNA sequencing occurs in the fiscal year following the year in which work for a species is initiated. According to the 5-year plan, the goal is to release reports and data within one year after DNA sequencing is completed. Green cells = work complete; yellow cells = work in progress; red cells = work not yet initiated.

Species	FY17	FY18	FY19	FY20	FY21	FY22
Pleuraphis jamesii (James' galleta grass)	Tissue collection	Laboratory work; DNA sequencing	Data analysis; report writing, data release			
Sporobolus cryptandrus (Sand dropseed)	Tissue collection	Laboratory work; DNA sequencing	Data analysis; report writing, data release			
Sphaeralcea parvifolia (Small-leaf globemallow)	Tissue collection	Laboratory work; DNA sequencing	Data analysis; report writing, data release			
Achnatherum hymenoides (Indian ricegrass)		Tissue collection	Laboratory work; DNA sequencing	Data analysis; report writing, data release		
Cleome lutea (Yellow spiderflower)		Tissue collection	Laboratory work; DNA sequencing	Data analysis; report writing, data release		
Machaeranthera canescens (Hoary tansyaster)		Tissue collection	Laboratory work; DNA sequencing	Data analysis; report writing, data release		
Heliomeris multiflora (Showy goldeneye)			Tissue collection	Laboratory work; DNA sequencing	Data analysis; report writing, data release	
Elymus elymoides (Squirreltail)			Tissue collection	Laboratory work; DNA sequencing	Data analysis; report writing, data release	
Priority species 3				Tissue collection	Laboratory work; DNA sequencing	Data analysis; report writing, data release
Priority species 4				Tissue collection	Laboratory work; DNA sequencing	Data analysis; report writing, data release

seed sources and plant materials to ecological services, such as soil erosion control or wildlife habitat, can allow for land managers to meet intended goals to bolster the health of a managed ecosystem.

FY19 Results and Discussion

During 2019 field work, SBSC collected plant trait data at environmentally-stratified sites across the Colorado Plateau. Due to the dry conditions present across the region in 2018, field work in 2019 focused on filling in tissue gaps for specific geographic locations and species. **Growing conditions in 2019 supported this sampling plan – 3,280 tissues to generate plant trait data were collected for 19 species across 147 sampling locations (Fig. 1)**. Tissue samples are being stored at SBSC in Moab, UT, and raw data are being generated by a biological technician. This work is supported by laboratory space made available by Dr. Reed. Furthermore, Dr. Winkler is leading the data analysis and preparation of a manuscript that details patterns in specific leaf area and isotope ratios. **The services provided by SBSC researchers that are not funded by CPNPP is a prime example of how CPNPP funds are extended as a result of the partnership with the U.S. Geological Survey.** In FY20, SBSC technicians will continue to collect the trait data for the genetics species initiated in FY19 and FY20. The data generated from these activities will be available as data releases as manuscripts are published; data will be available from the ScienceBase catalog and from https://www.usgs.gov/sbsc/native-plants. A manuscript detailing trait patterns in the FY17 and FY18 genetics species (see Table 1) will be submitted for review in FY20.

Work in FY19 to support common gardens centered on collecting seeds for priority species that can be used to establish gardens in FY20. **In total, 214 seed collections were made for 16 species at 116 sampling locations (Fig. 1).** Seed collections generally contain approximately 2000 seeds and are being cleaned and stored at SBSC in Flagstaff. Funding was not available to establish common gardens in FY19; however, SBSC researchers are hopeful that at least one common garden can be established in FY20 with available funding – planning has commenced for the establishment of a garden in the Uinta Basin, UT. For example, species selection is underway and will be followed by stratification and sowing at the NAU research greenhouses. Plugs will grow for two to three months before hardening off, transport to Vernal, and outplanting (target August 2020). In addition, biological technicians will continue to collect seed for CPNPP priority species during the 2020 field season to support the further development of common gardens.

Other common garden opportunities were supported in FY19 that may directly benefit CPNPP at no direct cost (see details in Massatti et al. 2019). Common gardens associated with NAU containing several CPNPP-funded seed accessions were established in FY19. These gardens are still in early stages and data are not yet available. The New Mexico BLM-funded effort to establish a common garden near Santa Fe, New Mexico succeeded in FY19. This garden includes two CPNPP priority species: *Heterotheca villosa* and *Sporobolus cryptandrus*. Similar to the NAU gardens, the BLM garden is in the early stages of establishment and data are not yet available. However, analyses will be performed by a graduate student, under the supervision of Dr. Rachel Mitchell at NAU and Dr. Winkler, again displaying how CPNPP benefits, at no cost, from the connections within and among researchers at SBSC and NAU. SBSC researchers will continue to support the NAU and New Mexico BLM common gardens in FY20.

Quantifying seed survival and establishment in the context of growing aridity using the GRID experimental framework

Although restoring native plant communities is a key management need for the Colorado Plateau (Copeland et al. 2019), restoration success is often hampered by a lack of understanding of the basic processes that facilitate or impede native plant regeneration (Call and Roundy 1991). The establishment of plants from seed is highly sensitive to environmental variability and is expected to be dramatically influenced by changing conditions in coming decades. However, our understanding of the drivers and consequences of plant regeneration are surprisingly rudimentary compared to other demographic processes, particularly in drylands. Increased aridity and enhanced weather variability may dramatically impact regeneration in drylands, although the potential consequences (positive or negative) for regeneration have received less attention than mortality or growth. Regeneration of many long-lived dryland plants is notoriously episodic, responding to a relatively rare combination of soil moisture and temperature conditions (Brown and Wu 2005, Coop and Givnish 2008, Kolb and Robberecht 1996, Petrie, et al. 2016, Puhlick, et al. 2012, Savage, et al. 2013, Schlaepfer, et al. 2014). While the details of the conditions that facilitate regeneration remain unclear for many species and locations, the recognized importance of adequate soil moisture underscores the potential negative impacts of rising aridity in coming decades (Feddema, et al. 2013, Petrie, et al. 2017, Schlaepfer, et al. 2015). Indeed, regeneration failures have already been observed, and are expected to continue, across western North America (Allen, et al. 2010, Breshears, et al. 2009, Stevens-Rumann, et al. 2017, Williams, et al. 2013). In the context of both increasing environmental stress and the rising prevalence of disturbances, the long-term persistence of many dryland ecosystems, and the maintenance of the ecosystem services that they provide, may depend on regeneration of the dominant species that characterize these communities. SBSC researchers aim to address plant establishment questions for priority restoration species using the Germination for Restoration Information and Decision-making (GRID) experimental framework.

FY19 Results and Discussion

SBSC researchers and the CPNPP coordinator decided in June 2019 that available FY19 funding would be used to prioritize the establishment of an experimental garden in or around Flagstaff, Arizona and a fall GRID trial at The Nature Conservancy Cayonlands Research Center (CRC) south of Moab, UT. After assessing the benefits and drawbacks of a number of sites surrounding Flagstaff, SBSC researchers decided to pursue a site adjacent to the U.S. Geological Survey campus owned by the City of Flagstaff. The primary benefit of this site is that it accentuates the environmental differences compared to the sister garden at the CRC; having different environments represented at the two gardens is critical so that researchers can better understand the factors controlling plants' responses to watering treatments. In addition, the proximity of the Flagstaff garden to SBSC offices will save time and resources, especially given that watering treatments may need to be implemented 3-5x per week. Dr. Massatti has navigated the licensing process for the site with the City of Flagstaff, hired a contractor to build the infrastructure, and developed the plot layout that best suits the site (Fig. 2). This infrastructure will be available to use in 2020, which coincides with the SBSC research schedule (Table 2).

A GRID trial at the CRC commenced in August 2019 with *Sporobolus cryptandrus* seed collected by SBSC technicians and two cultivars (Nueces and Dolores) obtained from South Texas Natives and Uncompahgre Partnership, respectively. Seeds were cold stratified for one month prior to sowing in plots, which was found to be sufficient for germination after generating *Sporobolus cryptandrus* plugs for the New Mexico BLM common garden (work completed by NAU graduate student). Watering treatments were designed to mimic the range of precipitation conditions seed sources naturally receive (as determined by analyzing climatological data from their geographic sources), and a technician applied the range of watering treatments to plots on a regular schedule. Despite accounting for these details, germination did not occur within plots, even after high summer temperatures cooled. Likely, while watering treatments may have mimicked natural growing conditions, they were not similar to the conditions that promote seed germination. This highlights the challenges not only of executing a naturally relevant experimental design, but also those of achieving successful restorations treatments across this region (e.g., the need for appropriate periods of continuous moisture that support seed germination, in addition to seedling establishment). The watering treatment protocols will be modified in 2020 to ensure a period of moisture availability that supports germination before imposing watering treatments representative of the species' source populations. The ultimate goal of this study is to determine if some seed sources (for example, those from more arid locations) are able to better survive the establishment phase than others, especially under the drier conditions expected to by prevalent across the Colorado Plateau in the coming decades. These results can immediately inform native plant materials development by helping seed developers understand which seed sources for a species may better be able to cope with more arid environmental conditions.

Additional activities

Beyond the activities that closely align with the goals detailed in the 5-year plan, SBSC researchers participated in an array of additional activities that supported CPNPP. A large accomplishment initiated in FY18 and completed in early FY19 was the development of the 5-year plan that will guide SBSC research activities during the period of performance for the new U.S. Geological Survey – BLM Interagency Agreement (L18PG00152). The research strategy includes the following goals: 1) Provide scientific support to CPNPP; 2) Resolve patterns and drivers of genetic diversity, structure, and adaptation; 3) Determine adaptive phenotypic variation in natural populations; 4) Quantify seed survival and establishment in the context of growing aridity; 5) Investigate the impact of seed increase on the genetic identity of restoration materials; and 6) Investigate the long-term impacts of restoration materials on the genetic identity of plants in their natural communities. In addition to the 5-year plan, Dr. Massatti and colleagues reported on fieldwork accomplishments (e.g., yearly reports for state BLM offices and Navajo Nation on collecting activities), composed internal and public versions of the End of Year 18 report (Massatti et al. 2019), developed a Final Report for the previous U.S. Geological Survey – BLM IAA (L13PG00306), created a Cooperator Report (Massatti 2019b) providing details on the seed transfer zone data release (Massatti 2019a), provided an FY20 Statement Of Work, and developed an FY19 Statement of Work update. All of these products, outside of the publicly available data releases and Cooperator Reports, were given to the CPNPP coordinator upon completion. In addition, Dr. Massatti spent time providing guidance to technicians and researchers working on the Colorado Plateau, coordinating research efforts (genetics, common gardens, GRID experiments with relevant outside activities), and ensuring that communications across research groups were maintained such that efforts are not duplicated and that research efforts are synergistic whenever possible.

A common venue for disseminating research and interacting with other Colorado Plateau researchers was at scientific and stakeholder meetings. Dr. Massatti presented information on the genetic considerations for restoration at the 2019 Biennial Conference for Science and Management (9/12/19), the Society for Ecological Restoration – Southwest Chapter (11/9/19), and at the Intermountain Plant Conference (11/6/19). He also presented about the historical factors influencing *Pleuraphis jamesii* at the Botany Conference in Tucson, Arizona (7/29/19). Beyond giving talks, Dr. Massatti co-organized two symposia at the Biennial Conference, one directly related to CPNPP activities (“Restoration and conservation across Colorado Plateau drylands: concerted activities of the Colorado Plateau Native Plant Program and partners”) and the other to provide a forum for managers and scientists to learn techniques to co-produce science (“Producing science that makes a difference: perspectives from managers and scientists”). Finally, Dr. Massatti participated in Southwest Seed Partnership steering and research committee meetings to support cross-programmatic efforts in developing seed transfer guidance and new native plant materials.

A variety of miscellaneous activities were also supported by Dr. Massatti in FY19. At the request of the CPNPP coordinator, geospatial shapefiles were developed for the ten priority restoration species reported in Doherty et al. (2017). These shapefiles are now publicly available on the Western Wildland Environmental Threat Assessment Center’s website (https://www.fs.fed.us/wwetac/threat-map/TRMSeedZoneData.php) alongside other regional seed transfer zones. Dr. Massatti also developed a public-facing webpage on the SBSC website (https://www.usgs.gov/sbsc/native-plants) that describes SBSC activities with respect to CPNPP. This website will serve as a point where all data releases, papers, and programs (e.g., the Climate Partitioning Tool and Seed Selection Tool resulting from Doherty et al. 2017) that have been assessed in accordance with the Fundamental Science Practices can be easily accessed. Information is being continually gathered for the Plant Materials Project, whose goal is to provide knowledge about where regional plant materials are lacking for priority restoration species. The initial stage of this project is due to wrap up in FY20 so that results can be extended into future climates.

Finally, Dr. Massatti supported the maintenance and use of CPNPP seed collections in freezers located at the U.S. Geological Survey campus in Flagstaff, Arizona. Seed collections were both newly cataloged (e.g., collections that were generated by Seeds of Success collecting crews) as well as distributed to researchers. These types of activities will continue in FY20 in support of the CPNPP mission.

Conclusion

As a result of FY19 work, progress has been made to inform restoration efforts across the Colorado Plateau. In particular, genetic studies provide a wide range of information pertinent to native plant materials development and their use in restoration projects, and they will continue to be a central focus of CPNPP-related research by SBSC over the next four years (FY20-FY23). With a well-designed research plan, the data gathered from initial genetic studies will inform subsequent experiments such that restoration-related outcomes are maximized. As a result of the U.S. Geological Survey – BLM partnership, restoration efforts across the Colorado Plateau and plant materials development for regional use are more informed, and there is strong momentum for continuing to provide knowledge that will improve restoration outcomes.

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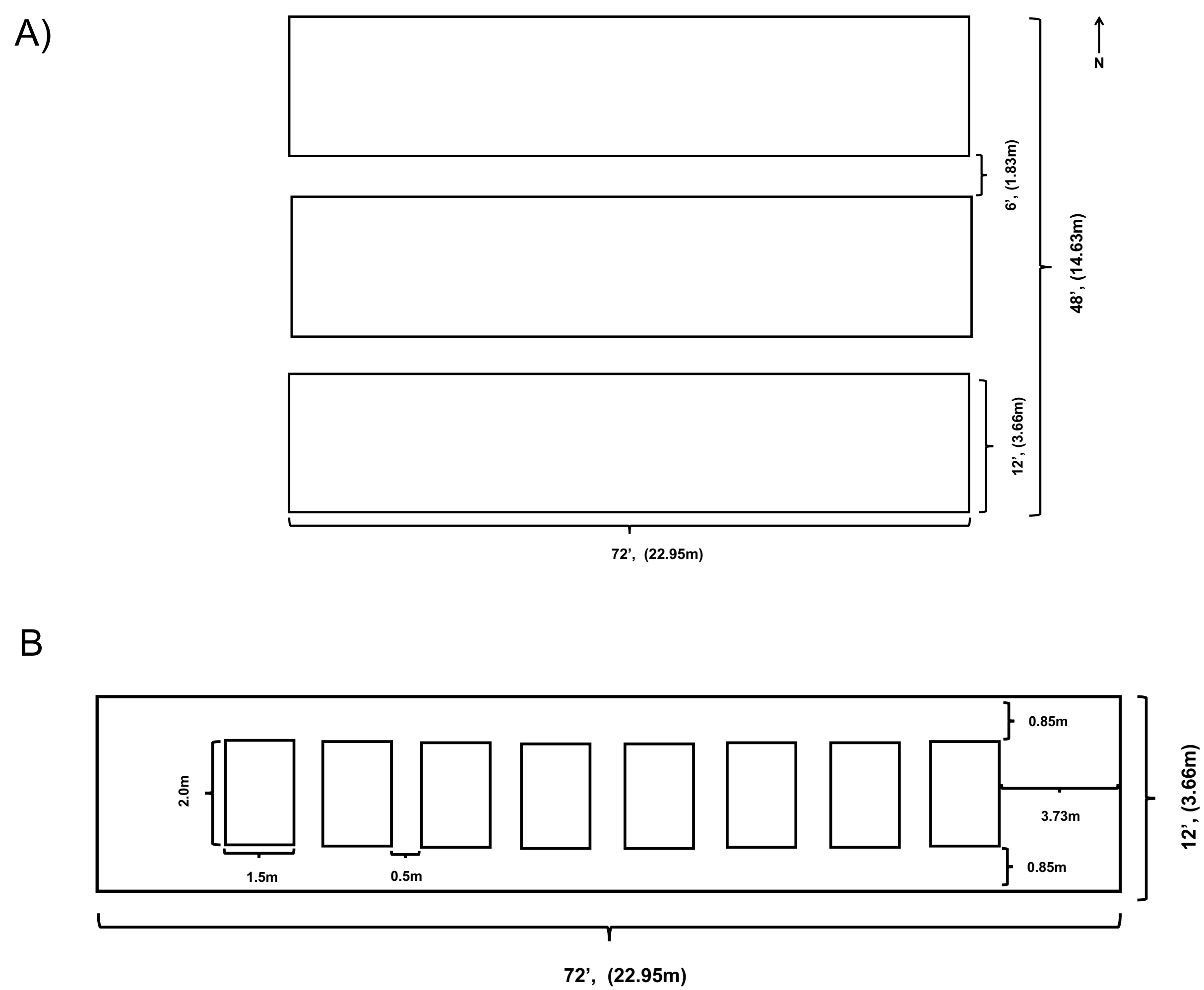

Figure 2. Plot design for the Flagstaff GRID experimental garden. Plots will be dispersed across three parallel hoop houses (A). Within each hoop house, plots will be uniformly spaced with buffers on either end to mitigate precipitation influences from uncovered areas (B).

Table 2. Experimental schedule for GRID garden in Flagstaff, AZ. The garden treatments in Moab, UT will commence earlier than those in Flagstaff – exact start dates will be determined by calculating similar growing degree days between the sites. S = setup (e.g., installing probes, sowing seeds); H = harvest (e.g., excavating all plants and collecting root measurements); P = preparation (e.g., counting seeds, determining plot layout).

Species Week:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Sphaeralcea parvifolia	S							H																
Cleome lutea								P	S							H								
Sporobolus cryptandrus																P	S							H

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