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RESEARCH ARTICLE

What Seeds to Plant in the Great Basin? Comparing Traits Prioritized in Native Plant Cultivars and Releases with Those That Promote Survival in the Field

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ABSTRACT: Restoration in the Great Basin is typically a large-scale enterprise, with aerial, drill, and broadcast seeding of perennial species common after wildfires. Arid conditions and invasive plants are significant barriers to overcome, but relatively simple changes to seeds used for restoration may improve success. Here we summarize: 1) the composition of seed mixes used in recent postfire seedings in Nevada, 2) traits that were valued when cultivars and other native seed materials were named and released, and 3) traits that have been demonstrated to increase native perennial grass performance in invaded systems. A review of 420 seeding treatments on public shrublands in Nevada between 2006 and 2009 indicated that native perennial grasses and native shrubs were most frequently included in these projects, followed by exotic and native forbs, and lastly, exotic perennial grasses. Native perennial grasses made up the bulk of seeds used in these treatments, with multiple species of grasses (average of 3.4 species) typically seeded per treatment, while the richness of other functional groups in seed mixes was closer to 1 species per treatment. Traits prioritized in cultivars and native seed material releases included, in order of frequency: forage quality and yield, seed yield, seedling vigor, ability to establish and persist, and drought tolerance, with many other traits mentioned with less frequency. Traits that had consistent support for improving native perennial grass performance in the field were related to early phenology, small size, and higher root allocation. Further tests to determine which traits improve shrub and forb establishment under field conditions could further refine seed source selection, and help maintain diversity in Great Basin systems.

Index terms: adaptation, native seeds, phenology, postfire seeding, restoration, roots

INTRODUCTION

The shrublands of the Great Basin are a unique expanse of open lands in the continental United States, comprised of millions of hectares of nearly continuous and relatively intact native vegetation, compared to converted and highly altered systems like the Great Plains and eastern deciduous forests. However, there is widespread and increasingly rapid loss of these communities due to past and present disturbances such as intensive grazing, exotic plant invasion, and increased frequency of wildfires (Stewart and Hull 1949; Pellant et al. 2004; Davies et al. 2011; Chambers et al. 2013). Maintaining desirable plant communities in the face of these disturbances often requires large-scale efforts that use immense quantities of seeds. Implementing successful restoration in the Great Basin is challenging, especially in the driest and more resource-limited areas (Davies et al. 2011; Hardegree et al. 2011; Arkle et al. 2014). While restoration success may be improved through continued research on plant establishment needs and restoration methods, the seed sources used in restoration are a fundamental consideration for any restoration project (e.g., McKay et al. 2005).

In the Great Basin, an extensive amount of seeding takes place after wildfire, with the aim of preventing conversion to exotic, annual-dominated systems (Davies et al. 2011). Because of the large scale of many of these efforts, hand-collections of wild seeds cannot meet demand for most nonwoody species, especially during years with many fires (Tischew et al. 2011). This places importance on the agronomic suitability of seeds used in large-scale seedings. Plants that are amenable to being grown and harvested efficiently in an agricultural setting are more likely to be cost-effective options for practitioners. In addition, many efforts exist to increase the diversity and availability of native seeds that can be increased for restoration (e.g., Tischew et al. 2011; Shaw et al. 2012).

In addition to agronomic considerations, there are other important factors involved in acquiring seeds for restoration. Restoration is an opportunity to maintain genetic diversity in native systems, and, to achieve this, selected materials should ideally be native species with contemporary ranges that overlap the sites needing restoration. As local adaptation is common in plants (Joshi et al. 2001; Leimu and Fischer 2008), seeded species should originate from areas with similar environmental conditions, following empirical seed zones (e.g., Johnson et al. 2012; Johnson et al. 2013) or generalized seed zones (e.g. Bower et al. 2014) when possible to increase the chances that seeds will perform well under abiotic conditions present at the site. Additionally, there should be evidence, or a well-founded expectation, that seeds will perform well at the site, given likely environmental conditions, which may include altered soils, the presence of invasive weeds (e.g., Leger 2008), different types of grazing systems, or repeated fire.

Balancing all of these considerations – agronomic suitability, site appropriateness, and restoration performance – is important for selecting plant material of the highest quality and usefulness. Our goal here is to provide information about three aspects of the current state of wildland seedings in the Great Basin. First, we summarize information on the frequency and amount of seeds used in recent seedings, focusing on postfire rehabilitation projects, a major source of seeding in the Great Basin, which took place on public US Bureau of Land Management (BLM) lands in Nevada over a four-year period. Secondly, we present information on traits highlighted in descriptions of most of the commercially available grass, forb, and shrub cultivars and other native plant releases commonly used as seed materials in the Great Basin, gathering data from plant release documents and plant brochures. Finally, we summarize information from a series of field and greenhouse experiments conducted in our lab that were designed to discern which phenological and morphological traits increase perennial native grass performance in disturbed Great Basin systems, and discuss the fit between these results and current restoration practice.

METHODS

Large-Scale Seeding in Nevada

We queried the Land Treatment Digital Library (Pilliod and Welty 2013) for seeding projects (aerial, broadcast, and drill) conducted by the BLM in Nevada between 2006 and 2009. Data were available for 420 individual aerial and ground-seeding treatments associated with 164 projects. Most projects involved more than one treatment, as different seed mixes or application methods were used to seed different areas within the same project (average of 11 treatments per project, ranging from 1 to 95). Most treatments were reported from the Elko office (212 treatments), followed by Ely (77), Winnemucca (41), Battle Mountain (33), Jarbidge (20), other offices combined that included some out of state offices on cross-state projects (19), and Carson City (18).

We assessed the frequency of use of seeded species in these treatments, separating species into three different functional groups: grasses, forbs, and shrubs. We further differentiated between native and nonnative species, and tabulated the number of species in each group seeded into each treatment. We defined "native" as species indigenous to the Great Basin, even if the particular collection was outside Nevada state boundaries. Most classifications were straightforward, but we chose to include forage kochia (*Bassia prostrata* (L.) Schrad.), a subshrub, in the forb category, as it has a forb-like growth form under dry conditions. Additionally, two species of blue flax, (*Linum perenne* L. and *L. lewisii* Pursh) were combined due to frequent mislabeling of the *L. perenne* as *L. lewisii* (Pendleton et al. 2008), and included in the native forb category. Finally, Snake River wheatgrass (*Elymus wawawaiensis* J. Carlson & Barkworth) was included in our tabulations as a native grass, though its native range does not include Nevada. Data were included from treatments that were verified as implemented (84%), planned but unverified as implemented (16%), or planned but not implemented (<1%). Seeding rates in total pure live seed, or PLS, lbs/acre were not available for every project, but we compiled species-specific seeding rates for 808 species in 88 projects. From this, we extrapolated likely seeding rates for the other projects using the median seeding rate for each species. Two records were excluded because unrealistic seeding rates appeared to be typos. Most records did not include the name of the cultivar or release planted, which was true for both native and exotic species. While native shrubs are typically wild-collected, the opposite is typically true for native grass and forb species. Grasses and forbs reported without names may represent wild-collected seeds, but this is unlikely to be the case for all but a few species that are difficult to cultivate (e.g., *Hesperostipa comata* (Trin. & Rupr.) Barkworth) and some of the smallest projects.

Traits Prioritized in Cultivar and Release Selection

Using the Natural Resources Conservation Service Plant Materials Program's list of Conservation Plants as a starting point, we identified any cultivar or named release (hereafter, "release") of nonriparian species that are native to any part of Nevada, as well as species native to North America that appeared in our Land Treatment Digital Library query of seeded species. We searched both the academic literature and the World Wide Web to find a Notice of Release or Notice of Naming, as well as any agency-published brochures, for each release. In the absence of these materials, other published documents discussing release traits were used, such as Plant Guides, conference proceedings, and internal agency reports. These published materials were examined and any trait or quality that was mentioned as important or noteworthy in the development and/or selection of each release was recorded. Some releases were cultivars that were bred, selected, or developed with certain traits in mind. Other releases were wild collections, chosen from among other accessions because they possessed particular desirable traits or were from particular regions, but without breeding or selection thereafter. Any traits mentioned during either of these processes were recorded.

We consolidated related traits into categories. For example, traits such as good establishment, high persistence, high survival, and longevity were grouped into "establishment and persistence." Traits such as site adaptability, wide adapted range, and targeted areas of adaptation were grouped into a "large/useful adapted range" category. Traits such as early phenology, late phenology, and uniform phenology were grouped into"specific/uniform phenology." Traits such as awn mass, improved seed retention, and indeterminate disarticulation were grouped into a "seed harvestability" category. Finally, traits such as high forage production or quality, increased leafiness, high biomass yield, high palatability, high nutrient content, and retention of senesced leaves were grouped as "forage yield/quality." In cases where more than one trait within our categories appeared for a single release (e.g., "high biomass" and "leafiness"), they were counted once, to not overwhelm our survey with results from particularly well-described releases.

Traits Important for Survival in Invaded and Disturbed Systems

Focusing on studies from our lab using three experimental techniques, we summarized the traits associated with increased performance or survival in disturbed and invaded Great Basin systems. In studies that compared traits between populations experiencing invasion and nearby, putatively ancestral populations, we summarized information on traits that were more common in invaded populations. We report information only from traits measured on plants grown in common environments, rather than field-measured traits, to increase the likelihood that traits had a genetic basis. When multiple populations show increased frequencies of the same traits in invaded areas, this provides some indication of the potentially adaptive nature of such shifts, although it does not provide direct evidence that these traits are adaptive. Secondly, we summarized information from a study looking at traits associated with survival in a Great Basin restoration site, again focusing on traits measured in a common environment. Finally, we present information on traits that were correlated with increased performance in either greenhouse competition studies or field plantings into Great Basin field sites.

RESULTS

Large-Scale Seeding in Nevada

Native perennial grasses were the most frequently seeded functional group by a slight margin, occurring in 54% of projects, and were a high proportion of the volume seeded, consisting of 63% of total PLS lbs. seeded (Figure 1). The frequency of use of other functional groups ranged from 50% (native shrubs) to 25% (exotic perennial grasses), and all other functional groups made up a smaller percent of PLS lbs.

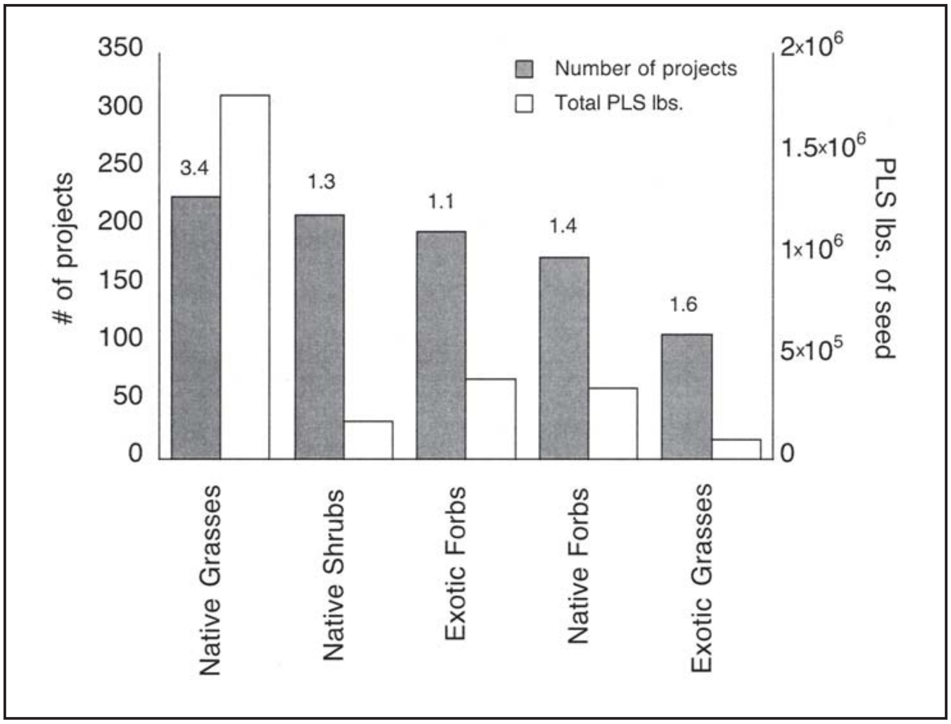

Figure 1. The number of treatments that seeded at least one member of each functional group, out of 420 aerial or ground seeding treatments associated with 164 projects in Nevada from 2006 to 2009, with the average number of species seeded per treatment indicated above each column, and the total number of pure live seed (PLS) pounds seeded of each category.

seeded (Figure 1). In treatments where native perennial grasses were seeded, more than one species was included in the mix on average, while the average richness of all other groups was closer to one (Figure 1). Sandberg's bluegrass (*Poa secunda* J. Presl), Indian ricegrass (*Achnatherum hymenoides* (Roem. & Schult.) Barkworth), and bottlebrush squirreltail (*Elymus elymoides* (Raf.) Swezey) were the most frequently seeded perennial grass species in treatments that seeded this functional group, present in 69%, 49%, and 34% of treatments, respectively. Indian ricegrass, bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) Á. Löve), and Snake River wheatgrass had the highest PLS lbs. seeded (Figure 2). In the 174 treatments that seeded native forbs, western yarrow (*Achilea millefolium* L. var. *occidentalis* DC.) and blue flax were most commonly seeded (present in 51% and 35% of treatments, respectively), followed by globemallow (Munro's and scarlet, *Sphaeralcea munroana* (Douglas) Spach and *Sphaeralcea coccinea* (Nutt.) Rydb., respectively), which was seeded in 12% of treatments. Of the 210 treatments that seeded native shrubs, Wyoming big sagebrush (*Artemisia tridentata* Nutt. ssp. *wyomingensis* Beetle & Young) was most commonly seeded (42% of treatments), followed by basin big sagebrush (*Artemisia tridentata* Nutt. ssp. *tridentata*) in 31% of treatments, antelope bitterbrush (*Purshia tridentata* (Pursh) DC.) in 16% of treatments, and fourwing saltbush (*Atriplex canescens* (Pursh) Nutt.) in 15% of treatments.

Traits Prioritized in Cultivar and Release Selection

Published materials that mentioned important traits were located for 90 releases of 33 species of native plants, with more for perennial grasses (66 releases of 18 species) than for forbs (14 releases of 11 species) and shrubs (10 releases of 4 species), collected between 1932 and 2005, and released between 1945 and 2011. From more than 350 references to traits, those pertaining to forage yield and quality were the most valued across all functional groups (Figure 3; 52% of releases; see also Appendix), with seed yield (43% of releases), seedling vigor (which was not

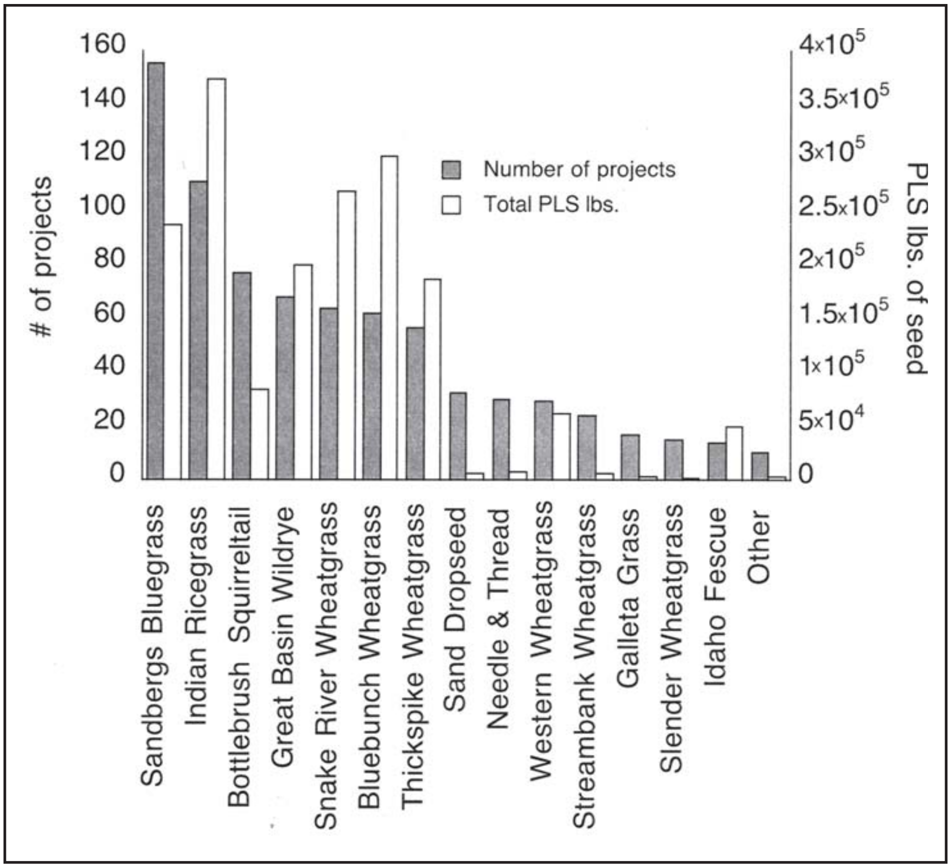

Figure 2. The number of treatments that seeded each perennial grass species, and the number of PLS pounds seeded, out of 420 aerial or ground seeding treatments associated with 164 projects in Nevada from 2006 to 2009.

defined, but presumably relates to size, growth rates, and perhaps greenness of seedlings, in 40% of releases), establishment and persistence (37% of releases), and drought tolerance (31% of releases) also being commonly valued traits. These traits were also among the most valued within each functional group. For forbs, forage yield/quality (50% of forb releases), establishment and persistence (43%), large/useful adapted range (43%), and seed yield (36%) were the most commonly valued traits. For grasses, forage yield/quality (47% of grass releases), seedling vigor (42%), seed yield (41%), establishment and persistence (33%), drought/semiarid tolerance (32%), and high/fast germinability (32%) were most commonly valued. In shrubs, high forage yield quality (60% of shrub releases), seed yield (40%), establishment and persistence (30%), large/useful adapted range (30%), seedling vigor (30%), and cold tolerance (30%) were most commonly valued. Traits that were only valued in one functional group included high/fast germinability, seed mass, and growth on contaminated soil (in 32%, 8%, and 3% of grass releases, respectively), and beauty (in 21% of forbs).

Traits Important for Survival in Invaded and Disturbed Systems

Traits were compiled from seven studies conducted in our lab (four greenhouse studies, three field studies) focusing on six species of native grasses (Table 1). Some traits were commonly associated with increased survival or performance in invaded systems, while others were more species- or site-specific. For example, multiple lines of evidence indicated that phenological traits such as fall green-up timing for adult plants, flowering time, and timing of seed emergence affect plant performance in invaded systems (Table 1). Early fall green-up was consistently observed when comparing five species of perennial grasses grown in invaded systems with nearby uninvaded systems (Leger 2008; Goergen et al. 2011), a characteristic linked with increased performance in the presence of competition from cheatgrass (*Bromus tectorum* L.) for one species (Leger 2008). Earlier flowering times in plants from invaded systems were observed in four of these same five species (Goergen et al. 2011), and plants grown from seeds that survived in a restoration seeding also showed earlier flowering times (Kulpa and Leger 2013). While no shifts in emergence timing were observed in invaded populations, or in seeds that survived in restoration, increased survival of earlier-emerging seeds was observed in a common garden field study (Kulpa and Leger 2013).

Other traits with consistent support for improving performance in invaded systems included smaller plant and seed size, and increased root allocation. Big squirreltail (*Elymus multisetus* M.E. Jones) plants grown from seeds collected in invaded systems were smaller than plants grown from seeds collected in nearby uninvaded systems and produced smaller seeds when grown in a common environment (Rowe and Leger 2011). Additionally, these small plants were more tolerant of cheatgrass competition than were larger plants (Rowe and Leger 2011). Smaller bottlebrush squirreltail plants were more likely to survive than larger plants in a restoration seeding, and these plants also made smaller seeds when grown in a common environment. Smaller plants tend to have higher root allocations than larger plants, and this was observed in big squirreltail plants from invaded areas (Rowe and Leger 2011). Higher root allocation was also correlated with increased tolerance to competition in this greenhouse study (Rowe and Leger 2011). Higher root allocation was also observed in bottlebrush squirreltail plants that survived during restoration (Ferguson 2012). In two field plantings in Northern Nevada, increased root allocation had mixed results on seedling survival, with a negative relationship between root allocation and survival at one site and a positive one at another (Atwater et al., in press).

Other root traits, such as root diameter, root length, and root branching had effects that were more variable. For example, big

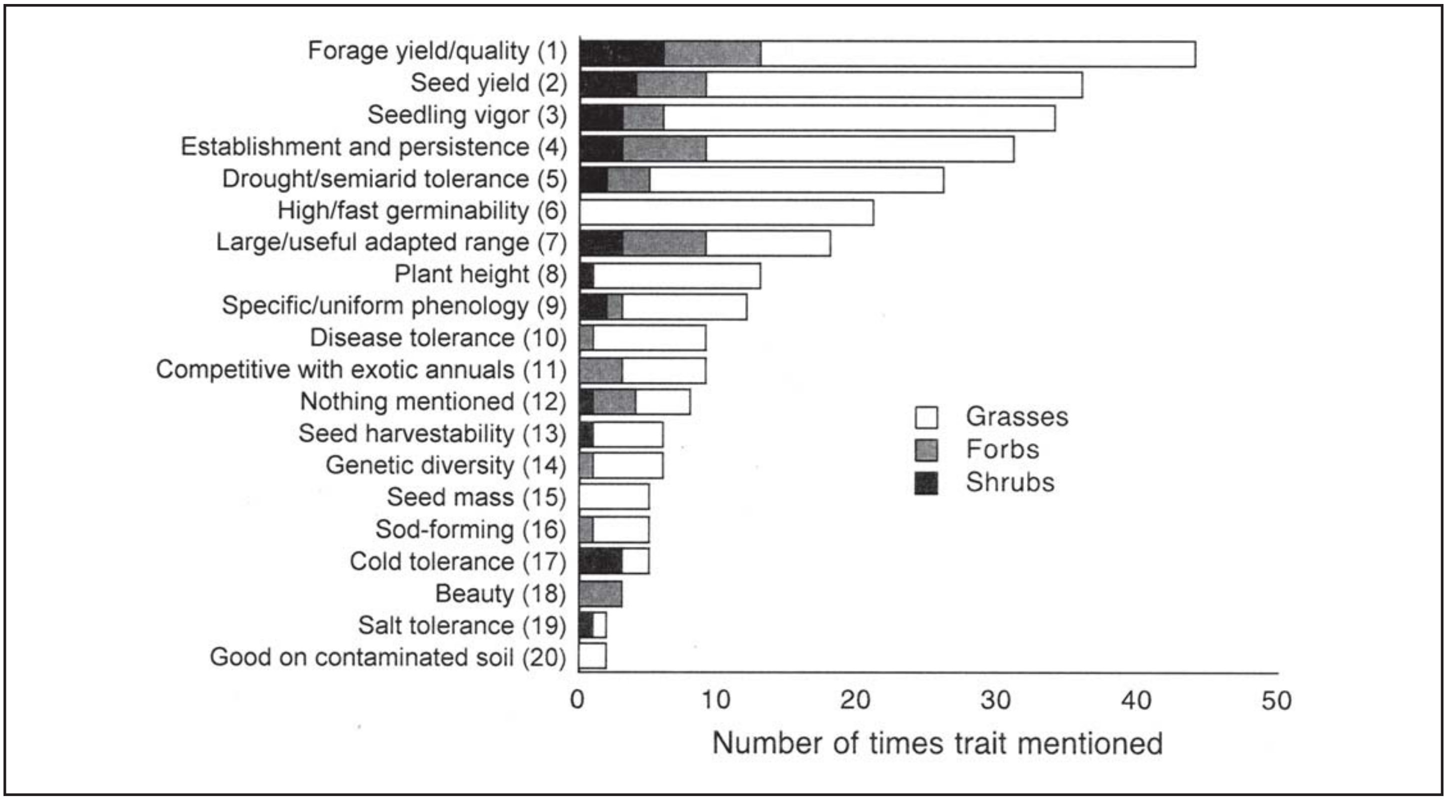

Figure 3. The number of times each trait was discussed as important for development or selection in a plant release, brochure, or other publication, for 90 cultivars and named releases of 33 species of native grasses, forbs and shrubs either native to the Great Basin or seeded in Nevada from 2006 to 2009. Details on traits selected for particular releases are presented in Appendix.

squirreltail plants from invaded areas had smaller root diameters and increased allocation to fine roots, which were directly linked with increased tolerance to cheatgrass competition in one study (Rowe and Leger 2011). These same traits, however, were of mixed importance in a field-survival study with bottlebrush squirreltail, where higher specific root length (the ratio of root length to root weight; higher values are associated with finer roots) was associated with decreased survival in one field site, and increased survival at another (Atwater et al., in press). Increased root forks were associated with increased cheatgrass tolerance in big squirreltail (Rowe and Leger 2011), and increased root tips were correlated with increased field survival of Sandberg's bluegrass in an invaded field site (Leger and Goergen, unpubl. data), but root tips had mixed results in a field study with bottlebrush squirreltail, where overall root length had positive effects on survival in two sites (Atwater et al., in press).

DISCUSSION

Maintaining diverse native plant communities in the Great Basin under continuing disturbances such as invasion, changing climate and fire regimes, and shifts in grazing pressure is a challenge for land managers, and many efforts are focused on making this process proceed more effectively (Johnson et al. 2010; Hardegree et al. 2011; Shaw et al. 2012). Here, we presented information on the nature of seeds used in recent large-scale, often postfire, seedings on BLM lands in Nevada, the suites of traits most commonly selected in many grass, shrub, and forb cultivars and releases, and the traits associated with increased native perennial grass performance in invaded systems. Relative to a larger-scale and longer-term assessment of seeds used in postfire seedings on BLM lands in four western states (including Nevada) between 1990 and 2003 (Knutson et al. 2014), the seeds used in large-scale restoration in Nevada between 2006 and 2009 had a much larger emphasis on native, rather than introduced, plants. For example, exotic perennial grasses were seeded in 48% of aerial and 82% of drill seeded sites in the Knutson et al. (2014) study, whereas they were seeded in only 25% of treatments reported here (Figure 1), likely reflecting a change in practice over time.

Native perennial grasses were frequently seeded and made up a large portion of the total pure live seed (PLS) pounds seeded in the projects surveyed here. Though not always documented, these seeds were almost certainly named releases and cultivars, which are the primary seed sources available for large-scale projects. These releases have been developed over many years (Appendix) and are often selected for multiple purposes, including maximizing forage quality and yield, seed production, and increasing the ease of cultivation and increase, which may fit some management priorities, but not others (Johnson et al. 2010). Other frequently mentioned traits, such as seedling vigor and drought tolerance, are presumably aimed to increase establishment on rangelands. Empirical research associating specific traits with increased performance under invaded conditions has been done on only a subset of native perennial species in a limited area, but our research indicates that a different suite of traits are adaptive when growing in competition with *B. tectorum* or in invaded areas, including early phenology, small size, and high root allocation. Whether these are generalizable traits for other species, functional groups, or areas remains unknown, and additional research should strive to directly describe traits that increase performance in restoration field conditions, so this information can be part of seed source selection decisions.

When commonly available releases do not match management priorities or needs, sources other than named releases may increase overall project success. Because we see restoration as an opportunity to maintain diversity in wild plant populations, we agree with others (Johnson et al. 2010) who advocate the use of increases from wild populations within ecoregions or seed zones (Bower et al. 2014). Ideally, sites for these collections would be populations that have been proven to establish well in field conditions similar to those present at the restoration site. Alternately, utilizing populations that have been selected for their abundance of particularly valuable traits, like early phenology or high allocation to roots, may be beneficial when seeding in areas with invasive annuals. When screening populations for desirable traits is not possible, simply collecting and increasing seeds from invaded or disturbed populations may be beneficial if those populations have undergone natural selection for increased tolerance to annual competition (e.g., Leger 2008; Goergen et al. 2011).

Grasses have many properties that are valuable for restoration, as they produce abundant seed in cultivation, are easy to harvest with existing technology, grow quickly, decrease erosion, suppress weeds, and produce forage for livestock and wildlife. The same characteristics that help grasses suppress weeds may also decrease shrub establishment, and shrub performance can be lower in the presence of grasses (e.g., Hild et al. 2006; Porensky et al. 2014). As

Table 1. Summary of results of studies that a) compared traits of plants growing in invaded and uninvaded communities, b) compared traits of surviving seedlings with those seeded in an original restoration seed mix, or c) directly correlated traits with competitive ability in greenhouse studies or survival in the field. "–" indicates untested variables; SRL = specific root length, the ratio of root length to root weight; and R:S is the root to shoot ratio.

Trait	a) More prevalent in invaded communities	b) More prevalent in survivors of restoration	c) Associated with increased performance
Early fall green-up (adults)	Yes [1, 2]	–	Yes [1]
Early flowering	Yes [3]	Yes [6]	–
Early seedling emergence	No [4]	No [6]	Yes [6]
Smaller plants	Yes [4]	Yes [6]	Yes [4]
Smaller seeds	Yes [4]	Yes [6]	–
Increased root allocation (R:S or root fraction)	Yes [4]	Yes [5]	Yes [4], Mixed [7]
Smaller root diameter, or higher SRL	Yes [4]	No [5]	Yes [4], Mixed [7]
Allocation to fine roots	Yes [4]	No [5]	Yes [4]
Increased root forks or tips	No [4]	–	Yes [4, 8], Mixed [7]
Root length	No [4]	No [5]	Yes [7]

[1] *Elymus multisetus*, Leger 2008; [2] *Achnatherum hymenoides, A. thurberianum, Elymus multisetus, Hesperostipa comata* and *Poa secunda*, Goergen et al. 2011; [3] All species listed in footnote 2 except *P. secunda*, Goergen et al. 2011; [4] *Elymus multisetus*, Rowe and Leger 2011; [5] *Elymus elymoides*, Ferguson 2012; [6] *Elymus elymoides*, Kulpa and Leger 2013; [7] *Elymus elymoides*, Atwater et al. in press; [8] *Poa secunda*, Leger and Goergen, unpubl. data.

many of the drier sites in the Great Basin are naturally dominated by shrubs rather than grasses, heavy grass seeding, which may provide desirable short-term restoration outcomes, may not be as beneficial for longer-term vegetation trajectories. Further studies that investigate ways to establish shrubs in disturbed systems, potentially manipulating the arrangement of seeds in space (seeding in alternate row or drill passes), seeding in sequence over time, or transplanting seedlings instead of seeds (e.g., McAdoo et al. 2013), may elucidate ways to increase shrub establishment in these systems. Forbs may benefit from such treatment as well.

The scale of seeding and restoration in this region has forced an agronomic approach to seed generation, but such an approach does not necessarily require a reduction in diversity, either at the functional group, species, or population level. For example, while forb diversity was quite low in the seedings we surveyed, likely reflecting seed availability and cost, these obstacles are diminishing. The amount and diversity of forb seed available for increase in the Great Basin has been on a steady upward trajectory, with many more forbs available now than in 2009, the last year for which these data were available (Shaw et al. 2012). Increasing wild-collected populations of grasses, shrubs, and forbs on a regional scale would increase the diversity of genotypes represented in this region, an attractive proposition, as genetic diversity is the foundation for the continued, long-term adaption of populations to ever-changing conditions (Kingsolver et al. 2001). An abundance of evidence supports the importance of maintaining diversity in natural systems, with cascading effects of plant diversity on ecosystem function, community structure, and diversity of other species guilds (Crutsinger et al. 2006; Hughes et al. 2008; Hooper et al. 2012). Downsides of this approach are primarily the cost of these efforts, but any increases in costs could well be offset by increased performance of such regional collections, and this approach has additional benefits such as conserving native plant diversity and stimulating local seed industries.

In conclusion, we see opportunities for embracing new seed sources for restoration and other seeding projects in the Great Basin, especially for native grasses in regions or vegetative conditions that are not well served by available releases, and for native forbs, in general. While barriers such as climate variability, aridity, exotic weeds, and fire pressures are challenging to overcome, improvements to restoration through changes in seed source selection are relatively attainable. Direct testing of traits that increase establishment across different types of soils, climates, and invasion status, for additional grasses, forbs, and shrubs, may allow us to more accurately find the best seed sources for specific growing conditions, allowing for increased success of restoration projects in the Great Basin.

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Elizabeth Leger is an Associate Professor in the Department of Natural Resources and Environmental Sciences at the University of Nevada, Reno (UNR). Her research interests include native plant restoration and the study of Great Basin plant communities. She also co-directs UNR's new Museum of Natural History, which offers opportunities for students of all ages to explore the plants and animals of the Great Basin.

Owen Baughman received his MS degree in the Department of Natural Resources and Environmental Sciences at the University of Nevada, Reno. Often at large in some basin or range, his professional interests are to facilitate effective management and conservation of the rich ecosystems of the Intermountain West through a healthy union of science and management. The diversity of plants and the complexity of their ecology in the Great Basin are topics that will keep him intrigued and challenged for decades.

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Appendix. Species and cultivars of grasses, shrubs, and forbs assessed for traits noted during release or description in a brochure or other publication, with collection year and release year noted when this information was available.

Species	Release	Functional Group [1]	Collection Year	Release Year	Publication Type: Release Notice	Publication Type: Brochure	Publication Type: Other Publication	Traits [2]	Lead Organization [3]	Authors
Achillea millefolium	Eagle	F	1988	2011	x			1, 4, 5, 7, 10	USDA FS RMRS	S.M. Lambert, S.B. Monsen, N. Shaw
Achillea millefolium	Yakima	F	2000	2004	x			1, 4, 13	USDA ARS	B.L. Waldron, K.B. Jensen, R.D. Harrison, A.J. Palazzo, T.J. Cary
Achnatherum hymenoides	Ribstone	G	1993	2003			x	14	USDA ARS FRRL, Logan, UT	T.A. Jones, D.C. Nielson, S.A. Young, A. Phan
Achnatherum hymenoides	Rimrock	G	1960	1996		x		14	USDA NRCS PMC, Bridger, MT	
Achnatherum hymenoides	Star Lake	G	1988	2004	x			6	USDA ARS	T.A. Jones, D.C. Nielson, S.L. Caicco, G.A. Fenchel, S.A. Young
Achnatherum hymenoides	White River	G	1955	2010	x			2, 3, 6	USDA ARS FRRL, Logan, UT	T.A. Jones, S.R. Winslow, S.D. Parr, K.L. Memmott
Achnatherum hymenoides	Nezpar	G	1935	1980	x			1, 3, 4, 6, 8	USDA NRCS PMC, Aberdeen, ID	D.T. Booth, C.G. Howard, C.E. Mowry
Achnatherum hymenoides	Paloma	G		1974		x		1, 2, 3, 4, 5	USDA NRCS PMC, Los Lunas, NM	
Achnatherum occidentale	LK621e	G	1997	2006			x	12	USDA NRCS PMC, Lockeford, CA	
Atriplex canescens	Marana	S	1961	1979		x		4, 5	USDA NRCS PMC, Lockeford, CA	
Atriplex canescens	Rincon	S	1957	1984	x			1, 7, 8, 9, 15	USDA NRCS PMC, Meeker, CO	E.D. McArthur, S.E. Stranathan, G.L. Noller
Atriplex canescens	Santa Rita	S	1962	1987	x	x		1, 2	USDA NRCS PMC, Tuscon, AZ	B.D. Munda, S.M. Lambert
Atriplex canescens	Snake River Plains	S	1976	2001			x	4, 7, 15	USDA NRCS PMC, Aberdeen, ID	L. St. John, P. Blaker

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Appendix. (*Continued*)

					Publication Type					
Species	**Release**	**Functional Group** [1]	**Collection Year**	**Release Year**	**Release Notice**	**Brochure**	**Other Publication**	**Traits** [2]	**Lead Organization** [3]	**Authors**
Atriplex canescens	Wytana	S	1960	1979		x		1, 2, 3, 4, 5, 20	USDA NRCS PMC, Bridger, MT	
Atriplex lentiformis	Casa	S	1964	1979		x		1	USDA NRCS PMC, Lockeford, CA	
Bouteloua gracilis	Bad River	G	1988	1996	x			1, 3, 4, 6, 8	USDA NRCS PMC, Bismarck, ND	N.K. Jensen, D.A. Tober, M.J. Knudson
Bouteloua gracilis	Hatchita	G	1957	< 1982		x		5	USDA NRCS PMC, Los Lunas, NM	
Bromus marginatus	Bromar	G	1933	1946			x	1, 2, 3, 8, 9, 11	USDA NRCS PMC, Pullman, WA	A.G. Law, J.L. Schwendiman
Bromus marginatus	Garnet	G		1999	x			1, 2, 4, 11	USDA NRCS PMC, Meeker, CO	G.L. Noller, J. Scheetz, M. Majerus, D. Ogle, L. Hoizworth
Dalea ornata	Majestic	F	2005	2011	x			1, 7, 9	USDA ARS FRRL, Logan, UT	D.A. Johnson, B.S. Bushman, K. Bhattarai, K.J. Connors
Dalea ornata	Spectrum	F	2005	2011	x			1, 7	USDA ARS FRRL, Logan, UT	D.A. Johnson, B.S. Bushman, K. Bhattarai, K.J. Connors
Distichlis spicata	LK517f	G	1982	2005		x		1, 11	USDA NRCS PMC, Lockeford, CA	
Elymus lanceolatus	Schwendimar	G	1934	1994	x			6, 15	USDA NRCS PMC, Pullman, WA	
Elymus elymoides	Antelope Creek	G	2003	2008	x			7	USDA ARS FRRL, Logan, UT	T.A. Jones, M.C. Parsons, S.R. Larson, I.W. Mott
Elymus elymoides	Fish Creek	G	1995	2003	x			3, 6, 8, 9, 14, 17	USDA ARS FRRL, Logan, UT	T.A. Monaco, S.L. Caicco, D.G. Ogle, S.A. Young
Elymus elymoides	Pleasant Valley	G	2002	2009	x			7	USDA ARS FRRL, Logan, UT	T.A. Jones, M.C. Parsons, S.R. Larson, I.W. Mott
Elymus elymoides	Pueblo	G	1976	2005	x	x		1, 2, 3, 4, 7, 8	USDA NRCS PMC, Meeker, CO	

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Appendix. (***Continued***)

Species	Release	Functional Group [1]	Collection Year	Release Year	Publication Type: Release Notice	Publication Type: Brochure	Publication Type: Other Publication	Traits [2]	Lead Organization [3]	Authors
Elymus elymoides	Sand Hollow	G	1984	1998	x			2, 9, 10, 17	USDA ARS FRRL, Logan, UT	T.A. Jones, D.C. Nielson, D.G. Ogle, D.A. Johnson, S.A. Young
Elymus elymoides	Sodar	G		1954		x		12	USDA NRCS PMC, Aberdeen, ID	
Elymus elymoides	Toe Jam	G		2004	x			2, 9, 14, 17	USDA ARS FRRL, Logan, UT	T.A. Jones, D.C. Nielson, S.R Larson, D.A. Johnson, T.A. Monaco, S.L. Caicco, D.G. Ogle, S.A. Young, J.R. Carlson
Elymus elymoides	Tusas	G		2001			x	2, 3, 9	USDA NRCS PMC, Los Lunas, NM	
Elymus elymoides	Wapiti	G	1981	2005	x	x		1, 2, 3, 4, 7, 8	USDA NRCS PMC, Meeker, CO	M.F. Jones, S. Parr, M. Rosales
Elymus glaucus	Arlington	G	1979	1995	x			4, 6, 11	USDA NRCS PMC, Pullman, WA	
Elymus glaucus	Elkton	G	1979	1997	x			1, 2, 3, 6, 9	USDA NRCS PMC, Corvalis, OR	
Elymus glaucus	Mariposa	G	1982	1990		x		1, 2, 3, 5, 11	USDA NRCS PMC, Lockeford, CA	
Elymus glaucus	Union Flat	G	1997	2008	x	x		1, 2, 6	USDA NRCS PMC, Pullman, WA	M. Stannard
Elymus glaucus	White Pass	G	1994	2007	x			1, 6, 7, 11	USDA NRCS PMC, Pullman, WA	
Elymus lanceolatus	Bannock	G	1934	2003	x	x		1, 5, 6, 8, 10	USDA NRCS PMC, Aberdeen, ID	L. St. John, P. Blaker
Elymus lanceolatus	Critana	G	1960	1971		x		2, 3, 5, 6, 16	USDA NRCS PMC, Bridger, MT	S.R. Winslow, R. Hybner

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Appendix. (*Continued*)

Species	Release	Functional Group [1]	Collection Year	Release Year	Publication Type: Release Notice	Publication Type: Brochure	Publication Type: Other Publication	Traits [2]	Lead Organization [3]	Authors
Elymus trachycaulus	Copperhead	G	1998	<2007	x	x		1, 4, 6, 19	USDA NRCS PMC, Bridger, MT	M.E. Majerus, S. Majerus
Elymus trachycaulus	FirstStrike	G		2006		x		1, 3, 4, 5	USDA ARS FRRL, Logan, UT	K.B. Jensen, A.J. Palazzo, B.L. Waldron, B.S Bushman
Elymus trachycaulus	Primar	G	1933	1946	x			12	USDA NRCS PMC, Pullman, WA	
Elymus trachycaulus	Pryor	G		1988	x	x		1, 2, 3, 4, 5, 20	USDA NRCS PMC, Bridger, MT	
Elymus trachycaulus	San Luis	G	1975	1984	x	x		4, 6	USDA NRCS PMC, Meeker, CO	
Elymus wawawaiensis	Discovery	G	1980-86	2008	x			1, 2, 3, 4, 5	USDA ARS FRRL, Logan, UT	T.A. Jones
Elymus wawawaiensis	Secar	G		1980			x	5	USDA NRCS PMC, Pullman, WA	
Festuca idahoensis	Joseph	G		1983			x	1, 2, 6, 17	Idaho AES, Moscow, ID	R.D. Ensign, V.G. Hickey, T.J. Bakken
Festuca idahoensis	Nezpurs	G		1983			x	6, 17	Idaho AES, Moscow, ID	R.D. Ensign, V.G. Hickey, T.J. Bakken
Hedysarum boreale	Timp	F		1994	x	x		2, 3, 4, 7	USDA NRCS PMC, Meeker, CO	M.A. Rosales
Krascheninnikovia lanata	N. Cold Desert	S	1974-77	2001			x	15	USDA NRCS PMC, Aberdeen, ID	L. St. John, P. Blaker
Krascheninnikovia lanata	Open Range	S	1985	2002	x	x		1, 2, 3, 7, 9	USDA NRCS PMC, Bridger, MT	M.E. Majerus, L.K. Holzworth
Leymus cinereus	Continental	G		2009	x			2, 3, 4, 6, 8	USDA ARS FRRL, Logan, UT	T.A.Winslow, M.A. Rosales
Leymus cinereus	Magnar	G		1979			x	1, 3, 5	USDA NRCS PMC, Pullman, WA	

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Appendix. (***Continued***)

Species	Release	Functional Group [1]	Collection Year	Release Year	Publication Type: Release Notice	Publication Type: Brochure	Publication Type: Other Publication	Traits [2]	Lead Organization [3]	Authors
Leymus cinereus	Trailhead	G		1991			x	1, 4, 5	USDA NRCS PMC, Bridger, MT	
Leymus cinereus	Washoe	G		2002			x	3, 8	USDA NRCS PMC, Bridger, MT	
Linum lewisii	Maple Grove	F	1988	2003		x		2, 3, 4, 5, 11	USDA NRCS PMC, Aberdeen, ID	
Linum perenne	Appar	F	1955	1980	x	x		2, 3, 10, 18	USDA NRCS PMC, Aberdeen, ID	
Muhlenbergia asperifolia	Moapa	G	<2005	2007	x	x		7, 13	USDA NRCS PMC, Tuscon, AZ	E.R. Garner, M.E. Hershdorfer
Muhlenbergia asperifolia	Westwater	G	1993	2006	x			4	USDA NRCS PMC, Tuscon, AZ	E.R. Garner, M.E. Hershdorfer
Pascopyrum smithii	Arriba	G	1957	1973	x	x		1, 2, 3, 6	USDA NRCS PMC, Los Lunas, NM	
Pascopyrum smithii	Barton	G	1947	1970	x	x		1, 2, 11, 16	USDA NRCS PMC, Manhattan, KS	
Pascopyrum smithii	Recovery	G	1972	2009	x	x		1, 2, 3, 4, 5	USDA ARS FRRL, Logan, UT	B.L. Waldron, K.B. Jensen, A.J. Palazzo, T.J. Cary, J.G. Robins, M.D. Peel, D.G. Ogle, L. St. John
Pascopyrum smithii	Rodan	G		<1988		x		1, 4, 5, 11, 15	USDA NRCS PMC, Mismarck, ND	
Pascopyrum smithii	Rosana	G	1959	1972	x	x		1, 2, 3, 4, 5, 6, 1	USDA NRCS PMC, Bridger, MT	S.R Winslow
Penstemon eatonii	Richfield	F	1974	1995			x	2, 4, 7, 18	USDA NRCS PMC, Aberdeen, ID	L. St. John, P. Blaker
Penstemon palmeri	Cedar	F	1939	1985			x	1, 4, 7, 10	USDA ARS FRRL, Logan, UT	

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Appendix. (*Continued*)

Species	Release	Functional Group [1]	Collection Year	Release Year	Publication Type: Release Notice	Publication Type: Brochure	Publication Type: Other Publication	Traits [2]	Lead Organization [3]	Authors
Penstemon strictus	Bandera	F		1973			x	12	USDA NRCS PMC, Los Lunas, NM	
Penstemon venustus	Alpine	F		1994			x	12	USDA NRCS PMC, Aberdeen, ID	
Penstemon venustus	Clearwater	F	<1981	1995			x	12, 18	USDA NRCS PMC, Aberdeen, ID	L. St. John, P. Blaker
Pleuraphis jamesii	Viva	G		1979			x	1, 2, 3	USDA NRCS PMC, Los Lunas, NM	
Poa secunda	Canbar	G		1979			x	10	USDA NRCS PMC, Pullman, WA	
Poa secunda	Hanford	G					x	5	L&H Seeds, Inc., Connell, WA	
Poa secunda	High Plains	G	1980	2000	x	x		3, 4, 5, 6, 9, 13	USDA NRCS PMC, Bridger, MT	M.E. Majerus, L.K. Holzworth
Poa secunda	Mt. Home	G	1997	2011	x			3, 5, 6, 10	USDA FS RMRS Fort Collins, CO	S.M. Lambert, S.B. Monsen, N. Shaw
Poa secunda	Opportunity	G		2008			x	8, 9, 19	USDA NRCS PMC, Bridger, MT	
Poa secunda	Reliable	G		2004			x	4, 5, 7, 13	USDA ARS FRRL, Logan, UT	
Poa secunda	Service	G	1978	1989		x		1, 15	Alaska PMC, Palmer, AK	P. Hunt, S. Wright
Poa secunda	Sherman	G	1932-35	1945			x	8	USDA NRCS PMC, Pullman, WA	
Pseudoroegneria spicata	Anatone	G	1934-38	2003	x			3, 5, 6, 10	USDA FS RMRS Provo, UT	S.B. Monsen, S.G. Kitchen, K. Memmott, N. Shaw, M. Pellant, S. Young, D. Ogle, L. St. John

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Appendix. (*Continued*)

Species	Release	Functional Group[1]	Collection Year	Release Year	Publication Type: Release Notice	Publication Type: Brochure	Publication Type: Other Publication	Traits[2]	Lead Organization[3]	Authors
Pseudoroegneria spicata	P-7	G	many	2002		x		2, 7, 13	USDA ARS FRRL, Logan, UT	T.A. Jones, S.R. Larson, D.C. Nielson, S.A. Young, N.J. Chatterton, A.J. Palazzo
Pseudoroegneria spicata	Whitmar	G		1945		x		1, 2, 3, 14	USDA NRCS PMC, Pullman, WA	
Purshia tridentata	Lassen	S	<1954	1984	x	x		1, 2, 3, 14	USDA NRCS PMC, Lockeford, CA	
Purshia tridentata	Maybell	S		1997		x		12	USDA NRCS PMC, Meeker, CO	G.L. Noller, M. Walsh
Sphaeralcea coccinea	ARS-2936	F	1987	1993	x			1, 16	USDA ARS FRRL, Logan, UT	M.D. Rumbaugh, B.M. Pendery, H.F. Mayland, G.E. Shewmaker
Sphaeralcea munroana	ARS-2892	F	1986	1993	x			1, 2, 5	USDA ARS FRRL, Logan, UT	M.D. Rumbaugh, B.M. Pendery
Sporobolus airoides	Salado	G	1958	1982	x			1, 2, 3, 4, 5, 9	USDA NRCS PMC, Los Lunas, NM	
Sporobolus airoides	Saltalk	G		1981		x		12	USDA NRCS PMC, Knox City, TX	
Sporobolus airoides	Vegas	G		2006	x	x		13	USDA NRCS PMC, Tuscon, AZ	

[1] Forb (F), grass(G), shrub (S).

[2] Refer to Figure 3 for associated traits.

[3] United States Department of Agriculture (USDA) Forest Service (FS) Rocky Mountain Research Station (RMRS), Natural Resources Conservation Service Plant Materials Center (NRCS PMC), Agricultural Research Service Forage and Range Research Laboratory (ARS FRRL), Agricultural Experiment Station (AES).