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Establishment and 10 Year Persistence of Plant Materials at Curlew National Grassland in Southern Idaho

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ABSTRACT

In 2010, 58 plant material accessions of 35 species of native and introduced grasses, forbs and shrubs were planted in a replicated study at the Curlew National Grassland (CNG) in Oneida County, in southern Idaho. Introduced bunchgrasses, Russian wildrye (*Psathrostachys juncea* (Fisch.) Nevski), Siberian wheatgrass (*Agropyron fragile* (Roth) P. Candargy), and meadow brome (*Bromus biebersteinii* Roem. & Schult.) exhibited excellent establishment. Early successional native grass species including bottlebrush squirreltail (*Elymus elymoides* (Raf.) Swezey) and slender wheatgrass (*E. trachycaulus* (Link) Gould ex Shinners) also had exceptional establishment. Other native grasses such as bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) Á. Löve) western wheatgrass (*Pascopyrum smithii*) (Rydb.) Á. Löve) and thickspike wheatgrass (*Elymus lanceolatus* (Scribn. & J.G. Sm.) Gould) had fair to good establishment densities, while native and introduced forbs and legumes generally had poor establishment. The locally collected Bonneville big sagebrush (*A. tridentata* ssp. x *bonnevillensis*) had the highest rated stand establishment of all evaluated shrub entries. After 10 years, many introduced grasses maintained high plant densities. Plant density of early successional species like bottlebrush squirreltail and slender wheatgrass had declined significantly, while late-seral grasses, especially those with rhizomatous growth, increased. Our results show several accessions of all plant groups to be well-suited to conditions at CNG and other semi-arid sites of the sagebrush steppe. Long-term data also suggest that including a diversity of species of multiple seral stages in restoration seed mixes could be beneficial to occupying available niches in space and time and lead to desirable restoration results.

INTRODUCTION

Over the last 70 years, numerous plant materials have been released for restoration and wildlife habitat improvement in the cold desert shrub ecosystem of western North America. However, relatively few formal studies have tracked long-term persistence on a release-by-release basis. Government facilities such as the USDA-NRCS Aberdeen Plant Materials Center (IDPMC) (Aberdeen, ID) and ARS Forage and Range Research Laboratory (FRRL) (Logan, UT), as well as commercial entities have been developing plant varieties for use in the Intermountain West since the 1940s and 50s (Norris, 1989; Alderson and Sharp, 1994). These products are widely used by land management agencies such as USDA-Forest Service, USDI-Bureau of Land Management and private landowners and conservation groups. Most of these plant releases have undergone various levels of performance testing and comparative trait evaluations during the development process (USDA NRCS, 2010), which can imply suitability and adaptation to certain site conditions, but long-term (greater than 3-5 year) comparisons are limited.

Since the 1930s, vast amounts of the Intermountain Region landscape have been converted to near monocultures of the introduced forage and reclamation species, crested wheatgrass (Pilliod et al., 2017), which was planted in post-wildfire seed mixtures to control soil erosion and to enhance livestock forage

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production. There is currently a desire by many managers and restorationists to transition these crested wheatgrass stands back to a native species dominated community. Long-term plant survival studies are needed to ascertain which plant materials can persist beyond the initial establishment years and increase and compete with crested wheatgrass and other non-native species.

Manipulation of successional stages may be a means of more effectively capturing a disturbed site and creating a desired plant community. Early-seral plants have evolved to reestablish on a site following disturbance. Plant communities naturally respond with an initial colonization by early successional plant species (Koniak and Everett, 1982; Bradshaw, 2000; Ott et al., 2003). Over time, longer-lived, late-seral species reestablish from surviving root systems, soil seed banks, or from seed dispersal from adjacent locations driving the site towards a more mature community. Many native early successional species occupy a similar niche to many of the region's exotic grass invaders such as cheatgrass (*Bromus tectorum* L.) and medusahead (*Taeniatherum caput-medusae* (L.) Nevski) and should be better equipped to resist potential invasive species than mid or late seral species (Emery, 2007; Leger et al., 2013; Uselman et al., 2015). Inclusion of species that fill all available niches (including space and time) could help to increase resilience and ecosystem services of the site (Chambers et al., 2007; Anderson and Johnson, 2020). However, early, and mid-seral species are frequently overlooked by restoration practitioners (Jones and Johnson, 1998; Ogle et al., 2011; Shaw et al., 2005).

Figure 1. Curlew National Grassland located in the cold-desert, sagebrush steppe of North America. The dominant shrub is Bonneville big sagebrush with an understory of perennial bunchgrasses. Photo by Derek Tilley.

The USDA Curlew National Grassland (CNG) located in Southeastern Idaho comprises 19,000 ha (47,000 ac) of public land and is home to numerous species of wildlife including blacktail deer, pronghorn, and sage-grouse. In the late 19th and early 20th centuries, the area was occupied by pioneers and homesteaders; however, droughts during the late 1920's and early 1930's resulted in crop failure and severe soil erosion. The Federal Government subsequently purchased several thousand ha of homesteaded land between 1934 and 1942. Currently the Curlew National Grassland is administered by the Forest Service, Caribou-Targhee National Forest (CTNF) and is managed to promote and demonstrate grassland agriculture and sustained-yield management of forage, and wildlife in the sagebrush steppe ecosystem (USDA FS, 2021).

In November 2010, IDPMC installed a multi-species planting in a fenced exclosure located on the CNG approximately 48 km (30 mi) south of American Falls, Idaho in cooperation with the Caribou-Targhee National Forest (CTNF) (Figure 1). The trial contained 58 accessions of 35 species of native and introduced grasses, forbs and shrubs representing various seral stages and presumed to be adapted for use in MLRA 13 Eastern Idaho Plateau. The goal of this trial was to evaluate the adaptability of new conservation releases in mid-elevation shrub steppe ecosystems and compare their establishment and longevity against traditionally recommended released plant materials. The planting was also designed to serve as a display nursery for CTNF and other conservation practitioners to view plant species and releases in a natural setting.

MATERIALS AND METHODS

Study Site

The study site was a fenced exclosure in the Curlew National Grassland in Oneida County, Idaho located at 42.219706, -112.757656 near the Idaho-Utah border at an elevation of 1,580 m (5,200 ft) (Figure 2). The site is described as a mountain big sagebrush/bluebunch wheatgrass (*Artemisia tridentata* ssp. *vaseyana/ Pseudoeroegneria spicata*) plant community (USDA-NRCS, 2020a; USDA-NRCS, 2020b); however, local Forest Service botanists classify the dominant sagebrush in the area as Bonneville sagebrush (*A. tridentata* ssp. x *bonnevillensis*) (Lehman, 2012). For several decades, however, it has been dominated by crested wheatgrass and bulbous bluegrass (*Poa bulbosa*) that had been planted for livestock forage. Climatic conditions are semi-arid with mean annual precipitation ranging from 356 to 610 mm (14 to 24 in). Site characteristics are listed in Table 1.

Figure 2. Location of the test site located on the Curlew National Grassland in southeastern Idaho. Images courtesy of Google Earth.

Table 1. Site Characteristics (USDA-NRCS, 2020)	
Soil type	Arbone-Hondoho-Cedarhill complex
Soil texture	Silt loam
Mean annual precipitation	355 to 600 mm (14 to 24 in)
Elevation	1,580 m (5,200 ft)
Aspect	Southeast
Slope	3-5%
Plant Community	*Artemisia tridentata* ssp. x *bonnevillensis* / *Pseudoeroegneria spicata*)

Weather

There are no weather stations located in close proximity to the Curlew site or in nearby locations with similar elevation and conditions. The closest weather station is the Bull Canyon weather station located 18 km (11 mi) north of the Curlew study site at an elevation of 1,956 m (6,418 ft). During the establishment year, 2011, Bull Canyon recorded 580 mm (22.7 in) of precipitation (Figure 3). The Curlew study site, being lower in elevation, probably received less precipitation than Bull Canyon, but the Curlew test site likely received normal to above normal precipitation for the year (University of Utah, 2020). Precipitation was below average throughout the Intermountain West in 2012, wherein the Bull Canyon station recorded below average precipitation with a cumulative total of 295 mm (11.6 in). Water year 2013 was somewhat better for precipitation in the region with a cumulative total of 363 mm (14.3 in) through September 4, 2013 at the Bull Canyon station (Figure 4). During 2014 the Bull Canyon station reported 513 mm (20.2 in) of precipitation, much of that coming from an abnormally wet August in which the region received nearly 100 mm (4.0 in) of rain. Mean precipitation of subsequent years through 2020 ranged between 381 and 635 mm (15.0 and 25.0 in) annually.

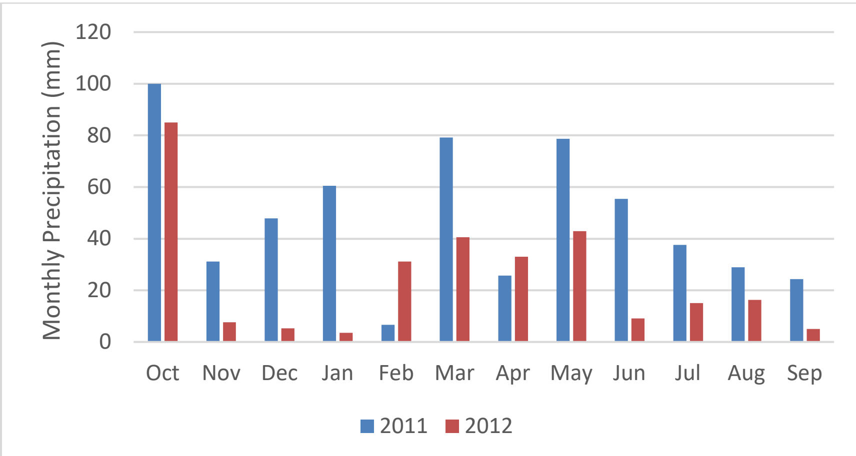

Figure 3. Monthly precipitation (mm) at the nearby Bull Canyon weather station during Water Years 2011-2012.

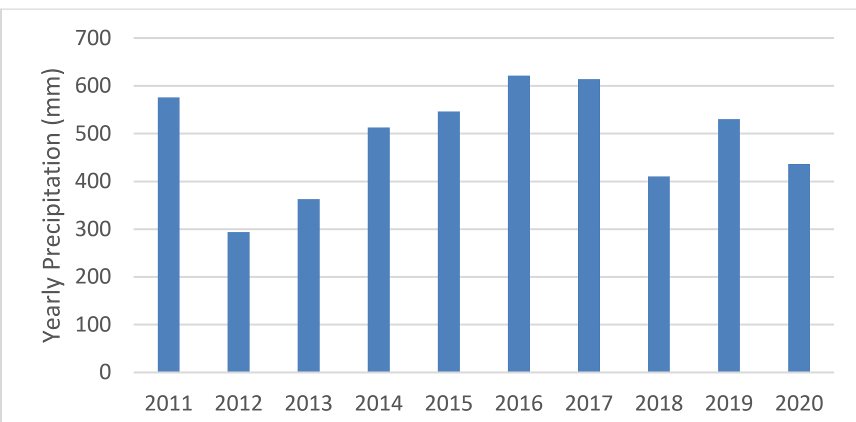

Figure 4. Total yearly precipitation (mm) at Bull Canyon weather station from 2011-2020.

The study area was burned by wildfire in 2006. In the fall of 2009, the study site was plowed and packed, followed by applications of 1.2 l/ha (16 oz/ac) 2, 4-D and 4.7 l/ha (64 oz/ac) glyphosate on June 18, 2010 and July 29, 2010. The trial was planted on November 17, 2010 using a modified Tye® grain drill with a width of 2 m (80 in) comprised of 8 rows at 25 cm (10 in) spacing. The experiment was designed as a randomized complete block with 3 replicates. Species were selected for the trial based on their potential adaptation to the test location and their presumed value for restoration and wildlife habitat improvement in the cold desert steppe ecosystem. In total, we planted 33 accessions of 11 native grasses, 14 species of forbs, 9 of which were native, 4 native shrubs, and 7 accessions of 4 introduced forage grasses (Table 2). We attempted to include a mixture of early and late seral species when plant materials were available.

Each plot is one drill width wide 2.0 m (80 in) and 6.1 m (20 ft) long. Seeding depths were adjusted for each species according to recommendations from Ogle et al. (2010), and species were seeded at a target rate based on NRCS Idaho practice standards. NRCS bases seed rates on a two-tiered system wherein a seed rate of 450-500 pure live seeds (PLS) per m^2 is recommended for small-seeded species (species with >227,000 seeds/kg) and 250-300 PLS/m^2 is targeted for large-seeded species (species with <227,000/kg). Pure live seed values were determined by seed lab results or best estimates when lab results were not available. All seed was mixed with rice hulls as an inert carrier to improve seed flow and drill calibration according to St. John et al. (2005). The plots were mowed to a height of approximately 10 cm on September 29, 2011 to prevent weedy species from setting seed. No further weed control measures were taken for the duration of the trial. No supplemental irrigation or fertilizer was applied at any time.

Plant densities of the planted species were measured using a frequency grid based on that described by Vogel and Masters (2001). The grid measured approximately 100 x 100 cm, having four 25-cm columns (to incorporate 1 drill row per column) and 5 rows, totaling 20 cells (Figure 5). The first grid was laid on the rows approximately one grid length (1 m) into the plot. Counts were made of the cells that contained at least one plant. The grid was then flipped repeatedly into the plot and densities recorded 4 more times for a total of 5. Total area for one grid is approximately 1m^2; total area evaluated was therefore approximately 5m^2. A conservative estimate of plant density (plants/m^2) is the total number of cells containing at least one plant divided by five. It is important to note that because cells with plants were counted and not the number of plants per cell, the best possible score is 100 hits per 5 frames which converts to 20 plants/m^2. Actual plant density may be higher than the numbers indicated below. (To convert from plants/m^2 to plants/ft^2, divide data by 10.76).

Figure 5. We used a 1m² density grid of 4X5 cells to estimate plant density of grasses, forbs and shrubs. Photo by Derek Tilley.

Plant density at initial establishment was measured on July 11, 2011. Subsequent yearly plant density data were also collected in June of 2012, 2013, 2014 and 2020.

Analysis

Plant density means are presented in the following groupings: all species, native grasses; introduced grasses, all forbs, and all shrubs. Early establishment (year 1 through 4) are presented first, followed by final plant density after 10 years. Final density data were analyzed using the Statistix 10 Analytical software (Tallahassee, FL). Data were log transformed to meet assumptions of normality and subjected to an analysis of variance with a significance level of $p<0.05$. Means were separated using a Least Significant Difference (LSD) all pairwise comparison. Early establishment means are not analyzed statistically, but standard error bars are included to offer an indication of variance.

Table 2. Plant Materials species and releases included in the 2010 CNG planting.				
Release Name	Common Name	Scientific Name	Family	Release Year
Covar	Sheep fescue	*Festuca ovina* L.	Poaceae	1977[a]
Durar	Hard fescue	*F. brevipila* Tracey	Poaceae	1963[a]
9076499	Idaho fescue	*F. idahoensis* Elmer	Poaceae	NA
Arriba	Western wheatgrass	Pascopyrum smithii (Rydb.) Á. Löve	Poaceae	1973[a]
Recovery	Western wheatgrass	*P. smithii*	Poaceae	2009[b]
Rosana	Western wheatgrass	*P. smithii*	Poaceae	1972[a]
Bannock	Thickspike wheatgrass	*Elymus lanceolatus* (Scribn. & J.G. Sm.) Gould	Poaceae	1995[c]
Sodar	Thickspike wheatgrass	*E. lanceolatus*	Poaceae	1954[a]
Critana	Thickspike wheatgrass	*E. lanceolatus*	Poaceae	1971[a]
High Plains	Sandberg bluegrass	*Poa secunda* J. Presl	Poaceae	2000[c]
Mountain Home	Sandberg bluegrass	*P. secunda*	Poaceae	2011[d]
Opportunity	Nevada bluegrass	*P. secunda*	Poaceae	2007[c]
Reliable	Sandberg Bluegrass	*P. secunda*	Poaceae	2004[b]
Sherman	Big bluegrass	*P. secunda*	Poaceae	1945[a]
Anatone	Bluebunch wheatgrass	*Pseudoroegneria spicata* (Pursh) Á. Löve	Poaceae	2004[c]
Goldar	Bluebunch wheatgrass	*P. spicata*	Poaceae	1989[a]
P-7	Bluebunch wheatgrass	*P. spicata*	Poaceae	2001[b]
P-33	Bluebunch wheatgrass	*P. spicata*	Poaceae	NA
Discovery	Snake River wheatgrass	*Elymus wawawaiensis* J. Carlson & Barkworth	Poaceae	2007[b]
Secar	Snake River wheatgrass	*E. wawawaiensis*	Poaceae	1980[a]
Fish Creek	Bottlebrush squirreltail	*Elymus elymoides* (Raf.) Swezey	Poaceae	2003[b]
Toe Jam Creek	Bottlebrush squirreltail	*Elymus elymoides*	Poaceae	2003[b]
9019219	Bottlebrush squirreltail	*E. elymoides*	Poaceae	NA
9092275	Bottlebrush squirreltail	*E. elymoides*	Poaceae	NA
Wapiti	Bottlebrush squirreltail	*E. elymoides*	Poaceae	2005[c]
Sand Hollow	Big squirreltail	*Elymus multisetus*	Poaceae	1996[b]
Pryor	Slender wheatgrass	*Elymus trachycaulus* (Link) Gould ex Shinners	Poaceae	1988[a]
First Strike	Slender wheatgrass	*E. trachycaulus*	Poaceae	2006[b]
Cucharas	Green needlegrass	*Nassella viridula* (Trin.) Barkworth	Poaceae	2003[b]
Trailhead	Basin wildrye	Leymus cinereus (Scribn. & Merr.) Á. Löve	Poaceae	1991[a]
Washoe	Basin wildrye	*L. cinereus*	Poaceae	2002[c]
Continental	Basin wildrye	*L. cinereus*	Poaceae	2008[b]
Magnar	Basin wildrye	*L. cinereus*	Poaceae	1979[a]
Bozoisky	Russian wildrye	*Psathrostachys* juncea (Fisch.) Nevski	Poaceae	1984[a]
Bozoisky II	Russian wildrye	P. juncea	Poaceae	2006[b]
Mustang	Altai wildrye	*Leymus angustus (Trin.) Pilg.*	Poaceae	2004[b]
Vavilov	Siberian wheatgrass	*Agropyron fragile* (Roth) P. Candargy	Poaceae	1994[c]
Vavilov II	Siberian wheatgrass	*A. fragile*	Poaceae	2008[b]
Cache	Meadow brome	*Bromus biebersteinii* Roem. & Schult. [excluded]	Poaceae	2004[b]
Regar	Meadow brome	*B. biebersteinii*	Poaceae	1966[a]
Antelope	White prairie clover	*Dalea candida* Michx. ex Willd.	Fabaceae	2000[c]

Appar	Blue flax	*Linum perenne* L.	Linaceae	1980[c]
Delar	Small burnet	*Sanguisorba minor* Scop.	Rosaceae	1981[c]
Don	Falcata alfalfa	*Medicago sativa* L. ssp. *falcata* (L.) Arcang.	Fabaceae	2009[g]
VNS[e]	Douglas' dusty Maiden	*Chaenactis douglasii* (Hook.) Hook. & Arn.	Asteraceae	NA
Great Northern	Western yarrow	*Achillea* L. *millefolium* var. *occidentalis* DC.	Asteraceae	2004[c]
Lutana	Cicer milkvetch	*Astragalus cicer* L.	Fabaceae	1971[c]
Maple Grove	Lewis flax	*Linum lewisii* Pursh	Linaceae	2004[c]
NBR-1	Basalt milkvetch	*Astragalus filipes* Torr. ex A. Gray	Fabaceae	2008[h]
VNS	Silverleaf phacelia	*Phacelia hastata* Douglas ex Lehm.	Hydrophyllaceae	NA
Richfield	Firecracker penstemon	*Penstemon eatonii* A. Gray	Scrophulariaceae	1994[c]
VNS	Sainfoin	*Onobrychis viciifolia* Scop.	Fabaceae	NA
Stillwater	Prairie coneflower	*Ratibida columnifera* (Nutt.) Wooton & Standl.	Asteraceae	2004[c]
Timp	Northern sweetvetch	*Hedysarum boreale* Nutt.	Fabaceae	1994[c]
Northern Cold Desert	Winterfat	*Krascheninnikovia lanata* (Pursh) A. Meeuse & Smit	Chenopodiaceae	2001[f]
VNS	Bonneville big sagebrush	*Artemisia tridentata* Nutt. ssp. X *bonnevillensis* H. Garrison, L. Schultz, & E.D. McArthur	Asteraceae	NA
Wytana	Fourwing saltbush	*Atriplex canescens* (Pursh) Nutt.	Chenopodiaceae	1976[c]
Snake River Plains	Fourwing saltbush	*A. canescens*	Chenopodiaceae	2001[i]

[a] Alderson and Sharp, 1994; [b] Staub et al., 2016; [c] DePue and Englert, 2015; [d] Lambert et al., 2011; [e] VNS=Variety Not Stated. Plant under investigation but not formally released; [f] Ogle et al., 2003; [g] Peel et al., 2009; [h] Jonson et al., 2008; [i] Majerus, 2003.

RESULTS AND DISCUSSION

Establishment (Year 1-4)

Native grasses

The highest-ranking native grasses of the establishment year were Fish Creek bottlebrush squirreltail (11.6 plants/m²) and Pryor slender wheatgrass (11.5 plants/m²), both of which are short-lived perennials commonly recommended as a nurse crop with longer lived species in a seed mixture (Figure 6). Other species to establish well in the first year included Covar sheep fescue and Anatone bluebunch wheatgrass with 8.5 and 7.6 plants/m²; however, most native grasses established poorly with densities under 5.0 plants/m² (Figure 7).

Despite drought conditions in 2012, plant densities of most of the native grasses did not generally show dramatic decreases. However, Pryor and First Strike slender wheatgrass decreased from 11.6 and 6.3 plants/m² respectively in the first year to 2.0 plants/m² in 2012. Squirreltail accessions, also known to be short lived perennials, did not change in density to the same degree as slender wheatgrass. Bluebunch wheatgrass densities stayed essentially the same as 2011, with the exception of Anatone which increased in density from 7.6 to 9.5 plants/m². The rhizomatous grass species, western wheatgrass, thickspike wheatgrass, and streambank wheatgrass, all increased in density from 2011 to 2012.

Several native grasses continued to maintain fair densities into 2013. Fish Creek bottlebrush squirreltail continued to persist and had the highest plant density for native species (9.8 plants/m²) followed by Rosana western wheatgrass and Anatone bluebunch wheatgrass with 8.7 and 6.9 plants/m² respectively. Short-lived perennials such as slender wheatgrass decreased steadily in density giving way to longer lived species as would be expected. Rhizomatous perennials such as western wheatgrass and thickspike wheatgrass likewise increased in density as plants spread vegetatively.

Figure 6. Fish Creek bottlebrush squirreltail had excellent establishment densities during the first 4 yr of the trial. Photo by Derek Tilley.

Fish creek bottlebrush squirreltail had the highest plant density of the native grasses in 2014 with 10.4 plants/m², significantly greater than all other entries with the exception of the introduced grass, Bozoisky II Russian wildrye. Other native species accessions in the top ten densities included Discovery Snake River wheatgrass (6.1 plants/m²), Sodar streambank wheatgrass (5.8 plants/m²), Toe Jam Creek bottlebrush squirreltail (5.6 plants/m²), and Rosana western wheatgrass (3.9 plants/m²). Almost all entries in the trial decreased in density from 2013 to 2014. Exceptions include two bottlebrush squirreltail accessions (Fish Creek and Toe Jam Creek), Discovery Snake River wheatgrass, and two sod-forming grasses (Sodar Streambank wheatgrass and Critana thickspike wheatgrass), which are expected to spread via rhizomes.

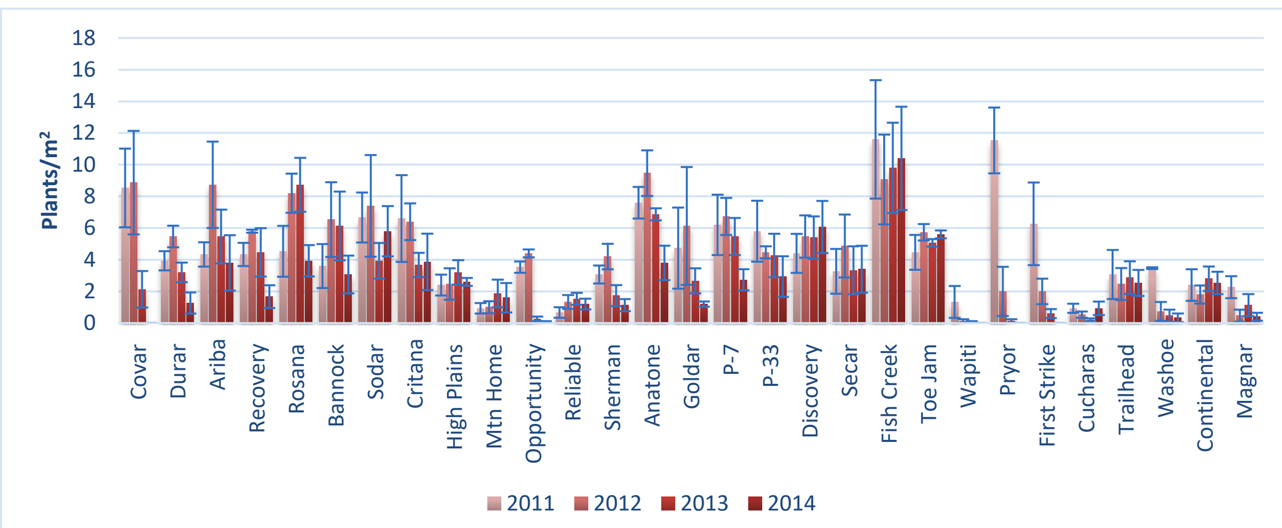

Figure 7. Plant density (plants/m^2) of native grass entries from 2011 to 2014. Error bars represent ±1 standard error.

Introduced grasses

Introduced grasses all had excellent establishment (Figure 8). The lowest plant density recorded was 6.7 plants/m² from Bozoisky Russian wildrye, while Cache meadow brome had the highest density with 13.0 plants/m².

Bozoisky and Bozoisky II Russian wildrye plant density changed little from 2011 to 2012. Vavilov however, decreased in density approximately 50% from 9.6 to 4.2 plants/m², while its successor, Vavilov II showed no decline. Mustang altai wildrye also decreased significantly going from 6.8 to 2.5 plants/m² in the second year. Cache and Regar meadow brome both decreased under drought stress although Cache maintained a good stand with 10.7 plants/m².

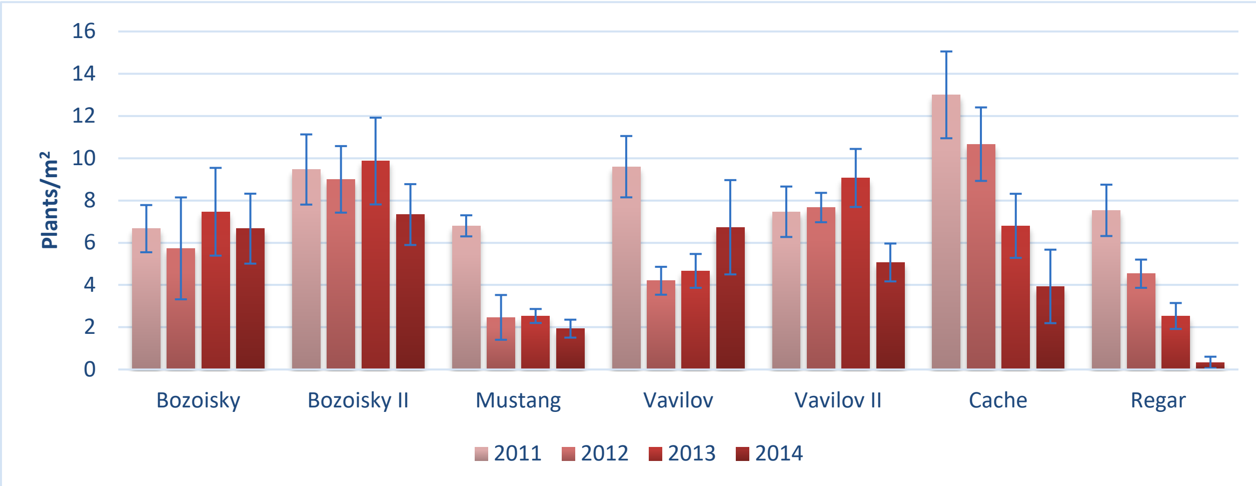

Figure 8. Plant density (plants/m^2) of introduced grass entries from 2011 to 2014. Error bars represent ±1 standard error.

Most introduced grasses decreased slightly in 2013 but seem to be well-established. Both Russian wildrye accessions, however, increased slightly in plant density from 2012 to 2013. This species is known to take time for establishment and increases over the first few years are expected (Ogle et al., 2011).

Meadow brome plant density continued to decline into 2014, with Regar meadow brome barely maintaining a presence with a mean density of 0.3 plants/m² while Cache plant density dropped to 3.9 plants/m². By 2014, Siberian wheatgrass entries Vavilov and Vavilov II had similar densities of 6.7 and 5.1 plants/m² respectively, and both Russian wildrye entries maintained plant densities greater than 6 plants/m².

Forbs and Legumes

Forb establishment was relatively high for several entries (Figure 9). Introduced forage forbs and legumes like Delar small burnet, Don falcata alfalfa, and sainfoin were all in the top 6 for establishment density with 8.1, 7.6 and 5.9 plants/m² respectively. Some conservation forb species also did very well. Maple Grove Lewis flax and Appar blue flax, for example, established with 8.1 and 7.0 plants/m² respectively, and the native legume, Timp northern sweetvetch, likewise had high establishment with 7.6 plants/m².

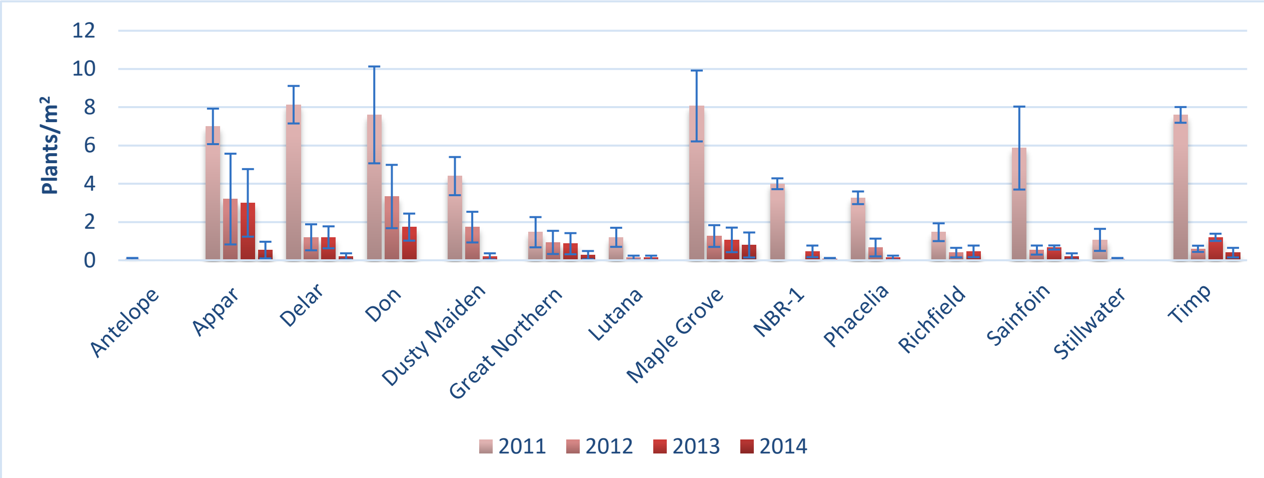

Figure 9. Plant density (plants/m^2) of forb and legume entries from 2011 to 2014. Error bars represent ±1 standard error.

Plant density for the forb entries declined significantly from 2011 to 2012 with many accessions nearly disappearing from the plots. Don falcata alfalfa and Appar blue flax (both introduced species) maintained the best stands with 3.3 and 3.2 plants/m^2 respectively. In 2013, forbs continued to show low plant density as a whole. Appar blue flax had the best density with 3.0 plants/m^2 in 2013, but most entries averaged fewer than 1 plant/m^2.

Forb density in 2014 continued to be low compared to the other plant groups. Maple Grove Lewis flax had the highest plant density with 0.8 plants/m^2. Six other accessions were observed with at least one plant in the evaluated frames: Appar blue flax, Timp northern sweetvetch, Great Northern yarrow, Delar small burnet, sainfoin and NBR-1 basalt milkvetch. Antelope prairie clover, Douglas' dustymaiden, Don alfalfa, Lutana vetch, phacelia, Richfield firecracker penstemon, and Stillwater prairie coneflower recorded 0 plants/m^2 in 2014.

Shrubs

Bonneville sagebrush established in much greater plant density than any other shrub species (1.5 plants/m^2) (Figure 10). It is possible that some of this is the result of residual seed persisting in the seed bank post-site treatment, or it could indicate superior performance due to being locally collected and adapted compared to the other tested species. Other entries had low establishment densities ranging from 0.1 to 0.5 plants/m^2.

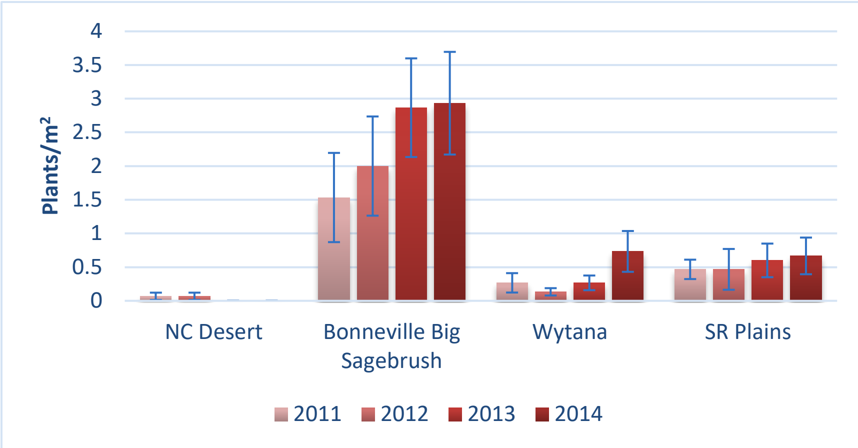

Figure 10. Plant density (plants/m^2) of shrub entries from 2011 to 2014. Error bars represent ±1 standard error.

In 2012, Bonneville big sagebrush and Snake River Plains fourwing saltbush had fair stands with 2.0 and 0.7 plants/m^2 respectively. Northern Cold Desert winterfat and Wytana fourwing saltbush continued to struggle. By 2013, Northern Cold Desert winterfat was absent from the plots. In 2014, Bonneville big sagebrush still had far greater plant density than all other shrubs with an average density of 2.9 plants/m^2, nearly 5 times the density of the next best shrub accession. However, Wytana and Snake River Plains fourwing saltbush showed slight gains in plant density in 2014.

Long-Term (10-year) Persistence

Native Grasses

Among the native grass accessions, the highest mean density in 2020 was observed among western wheatgrass accessions (Figure 11). Western wheatgrass is a strongly rhizomatous species, and the increase in density was likely due to underground spreading and the establishment of new ramets. Rosana, Recovery and Arriba plots had 15.3, 10.4 and 9.7 plants/m^2 respectively. Plant density of Rosana was statistically significant compared to all other entries ($p<0.01$). Recovery and Arriba were significantly greater than all other entries except for Anatone bluebunch wheatgrass. Bluebunch wheatgrass and its close analog, Snake River wheatgrass, formed a second group of relatively high plant density. Anatone, P-33 and P-7 bluebunch wheatgrasses had 6.5, 3.0, and 3.1 plants/m^2, while Discovery and Secar Snake River wheatgrass accessions had 4 and 2 plants/m^2 respectively. Covar and Durar fescues also had fair density with 2.1 and 4.0 plants/m^2. Another rhizomatous species, thickspike wheatgrass, had relatively consistent density across accessions at around 2.0 plants/m^2. Basin wildrye accessions ranged in density from 0.5 to 1.9 plants/m^2.

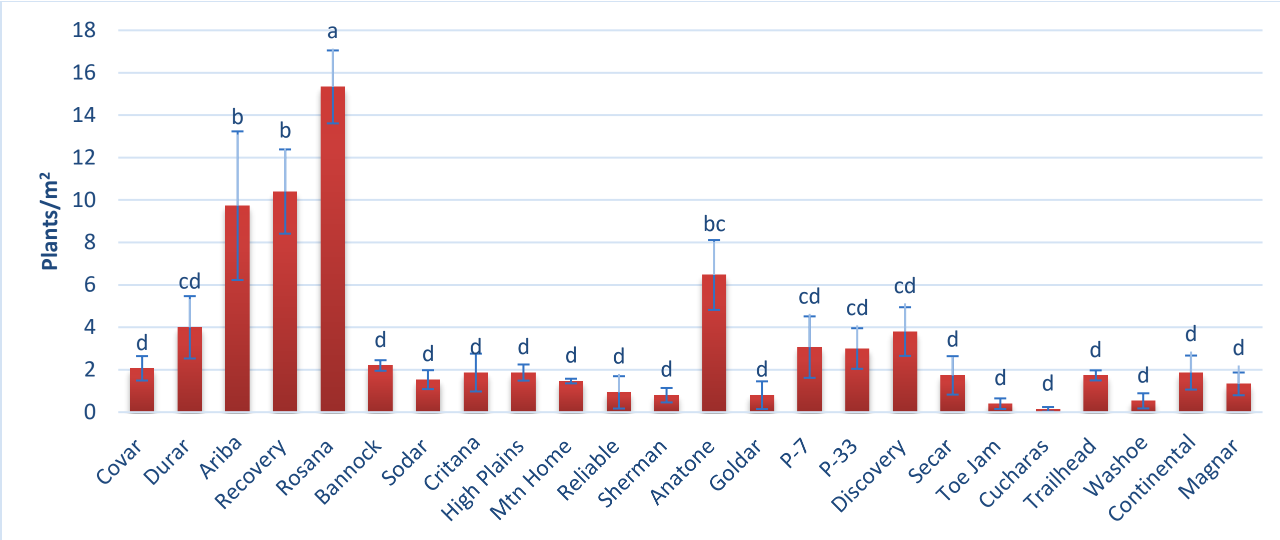

Figure 11. Long-term plant density (plants/m²) of native grasses in 2020. Error bars represent ±1 standard error. Bars with different letters represent significant difference at P≤0.05.

Introduced Grasses

In 2020, introduced grass density ranged from 0.7 to 3.7 plants/m^2 (Figure 12). Cache meadow brome had the highest density of all entries (3.7 plants/m^2) and appeared to be somewhat better suited to local conditions than its counterpart, Regar; however, mean density was not significantly different (p=0.21). Some of the meadow brome plants observed may have been ramets produced via rhizome spread, but that could not be determined positively. Both Siberian wheatgrass accessions, Vavilov and Vavilov II, had nearly equal density of 2.9 plants/m^2. Bozoisky II Russian wildrye had greater than 2 times as many plants/m^2 than its predecessor Bozoisky, but differences were not determined to be statistically significant. Mustang altai wildrye had the lowest density among the introduced grasses with 0.7 plants/m^2.

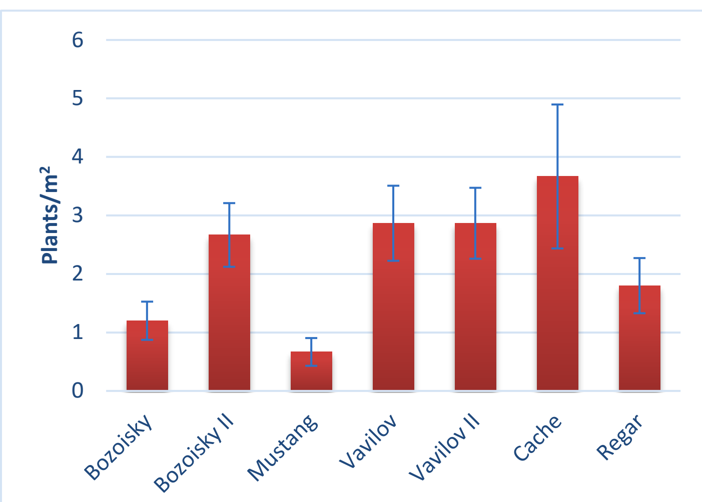

Figure 12. Mean Density (plants/m²) of introduced grasses in 2020. Error bars represent ±1 standard error. No statistical significance was detected between means; therefore, no means separation indicators are provided.

Forbs and Legumes

Forb and legume densities in 2020 were highly variable between the replicated plots of a given species, and no statistical differences between species could be found (p=0.51). Forb plant density was generally low with a few notable exceptions (Figure 13). Maple Grove Lewis flax and Stillwater prairie coneflower had the highest plant density in 2020, both with 4.7 and 4.0 plants/m^2 respectively, more than 2.5 times more plants/m^2 than the next best entry. Stillwater prairie coneflower was a fairly new release at the time of planting and had not been tested extensively in the Intermountain Region (DePue and Englert, 2015), and this study indicates it may be a good choice for plantings in the Northern Basin and Range in sites receiving 250-760 mm annual precipitation. The legumes Don falcata alfalfa and Timp sweetvetch, had fair persistence with approximately 1.5 and 1.4 plant/m^2 respectively. Other species with minimal stands persisting into 2020 included Appar blue flax, Delar small burnet, dusty maiden, NBR-1 basalt milkvetch and sainfoin. Richfield firecracker penstemon, Great Northern yarrow, Antelope prairie clover, phacelia, and Lutana cicer milkvetch were not detectable in 2020 and no density ratings are reported.

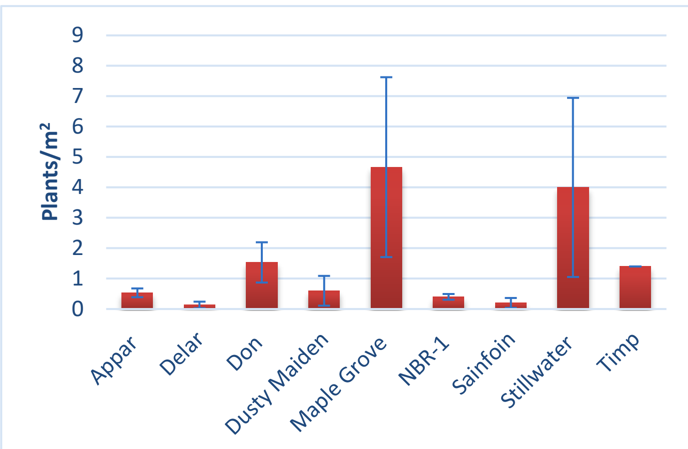

Figure 13. Mean density (plants/m²) of surviving forbs and legumes in 2020. Error bars represent ±1 standard error. No statistical significance was detected between means; therefore, no means separation indicators are provided.

Shrubs

Shrub density ranged from 0.1 to 1.5 plants/m^2 (Figure 14) 10 years after planting. Bonneville big sagebrush had significantly higher plant density than the other shrub entries (p=0.02) with 1.5 plants/m^2. However, it should be noted that many of the recorded plants were young, first-year seedlings. It is likely these seedlings resulted from previously seeded materials that had matured and set seed or from seed blown in from adjacent areas.

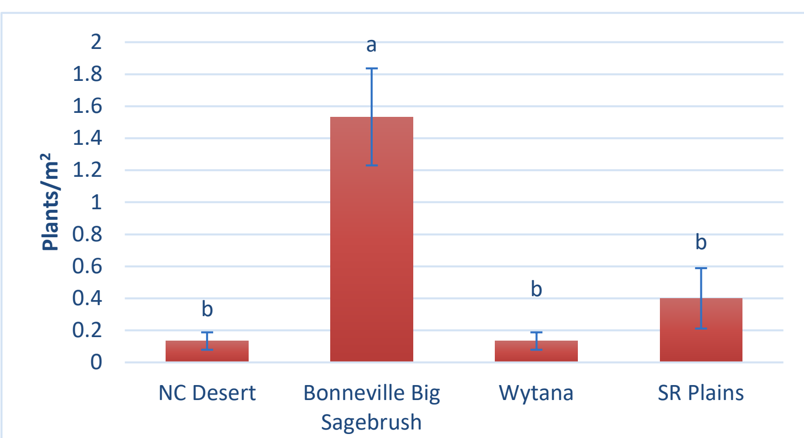

Figure 14. Mean density (plants/m²) of shrubs in 2020. Error bars represent ±1 standard error. Bars with different letters represent significant difference at P≤0.05.

CONCLUSION

Prior to this study, the site was mostly dominated by crested wheatgrass and bulbous bluegrass. Both species persisted despite plowing and chemical control efforts to prepare the site for planting. However, several plant materials in our study established in great enough numbers to add significant taxonomic heterogeneity to the site and increase species richness. A second year of chemical fallow may have provided better control of non-native perennials and led to better establishment of desired species, but longer fallow periods increase the risk of soil erosion, invasion of noxious weeds, and ultimately have the potential to increase the economic costs of site reclamation/restoration.

Seeded introduced grass entries showed excellent establishment and fair persistence over 10 years, but these should only be recommended for use in native ecosystems in cases of highly disturbed, critical area plantings. All introduced grasses in our trial decreased in density from 2014 to 2020. This is a positive result for those who wish to limit the persistence of introduced forage grasses and transition to more native-dominated communities in mid-elevation shrub steppe ecosystems in Idaho. However, this decreasing trend could also result in significant issues on sites where native species are limited or where subsequent seeding of natives is neglected or delayed resulting in an open niche for invasive species to occupy. Long-term monitoring of rangeland seedings to observe trends is needed to determine when additional treatments are necessary to prevent site and community degradation.

Based on plant density measurements, it was apparent that some species had naturally reseeded and perpetuated. Maple Grove Lewis flax decreased in density in 2011 from 8.1 plants/m^2 to 1.1 plant/m^2 in 2014, but then increased up to 4.7 plants/m^2 in 2020. Plant density of Stillwater prairie coneflower, a release originating from collections in Montana (DePue and Englert, 2015), was 0.00 and 0.01 plants/m^2 in 2013 and 2014 respectively; however, after 10 years it had not only established but had naturally reseeded, resulting in an average density of 4.0 plants/m^2. Likewise, although Bonneville big sagebrush plots had decreased in density between 2014 and 2020, seedlings were detected throughout the study site. The ability of these species to self-propagate reflects that they may be well-adapted to the site conditions of CNG.

The long duration of this study allowed us to observe clear successional changes over time. Many early seral entries such as bottlebrush squirreltail and slender wheatgrass showed excellent establishment and short-term persistence. For example, Fish Creek bottlebrush squirreltail and Pryor slender wheatgrass had the highest establishment density in 2011. These early-seral colonizers steadily decreased in presence over the 10 years, many to the point that they were undetected in the final evaluation. Conversely, late seral rhizomatous grasses like western wheatgrass and thickspike wheatgrass established, persisted and, in some cases, increased after 10 years. This concurs with results reported by Ott et al. (2019) regarding long-term vegetation recovery. Likewise, many forbs established well early in the study and decreased over time, while others maintained a very low presence until 10 years after seeding.

One key to a long-term, successful planting in the sagebrush steppe ecosystem may be to utilize a diversity of species encompassing a range of seral stages (Krueger-Mangold et al., 2006; Brown et al., 2008). Seed mixtures that include a component of early seral colonizing species and functional groups in addition to the traditional suite of late seral species reflecting the desired climax state, may effectively establish and persist, providing conservation benefits for all stages of the restoration process. Ideally, a seed mixture would contain species from a range of seral stages to occupy as many niches (in space and time) as possible. If seeded successfully, there would be few interspaces for exotics to occupy resulting in increased resilience of the site.

Several species and releases evaluated here showed fair to good adaptation to local site conditions. This information should be valuable to CNG and other regional managers in developing seed mixtures and planting plans for wildlife habitat rehabilitation and disturbed area restoration projects.

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