

REVEGETATION TRIALS IN THE PINEDALE ANTICLINE PROJECT AREA¹

S.R. Winslow², K.J. Clause, J.S. Jacobs, and R.M. Hybner

Abstract. Critical wildlife habitat supporting mule deer, antelope, and sage grouse in high elevation rangeland and sagebrush ecosystems of southwest Wyoming is threatened by energy development and residential sprawl, resulting in a declining forage base. Restoring disturbances with diverse plant communities is needed. Our objectives were to assess establishment and persistence of native grass, forb, and shrubs, and to test seed mixtures and seeding techniques. In October 2005, 72 entries of 50 native species were drill-seeded on a reclaimed well-pad site, in single-species plots in a randomized complete block design with four replications. Also, two seed mixtures were broadcast- and drill-seeded, and one seed mixture was hydroseeded on disturbed areas adjacent to the plots. In replicated plots, density of seeded species was recorded in each of the 3 years post-seeding, and biomass was clipped from grass plots in 2008. Density by species was counted in mixture plots. In replicated plots, ANOVA showed plant counts depended on seeded species. Of the grasses, densities of L-46 basin wildrye (72 plants/m²), ‘Sodar’ streambank wheatgrass (47 plants/m²), and ‘Critana’ thickspike wheatgrass (37 plants/m²) were greater than other grasses; ‘Appar’ blue flax (11 plants/m²), Richfield Eaton’s and Old Works fuzzytongue penstemon (5 plants/m²) were greater than other forbs; and ‘Wytana’ fourwing saltbush (7 plants/m²), Snake River Plains fourwing saltbush (4 plants/m²), and 9016134 Gardner’s saltbush (1.4 plants/m²) were greater than other shrubs. The most biomass was produced by L-46, Washoe, and ‘Trailhead’ basin wildryes, and Critana thickspike wheatgrass. Establishment of the broadcast-seeded Shell and Bridger mixtures were 140,923 and 78,309 plants/ha, respectively. Establishment of the drill-seeded Bridger and Shell mixtures were 45,865 and 34,706 plants/ha, respectively. The Shell mixture hydro-seeding was unsuccessful. Short-term results provide recommendations for native plant restoration. Relatively low establishment of forbs and shrubs indicate more work is needed to develop these plant materials and technologies.

Additional Key Words: Reclamation, native plants, wildlife habitat

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² Susan R. Winslow is the Agronomist at the NRCS Plant Materials Center in Bridger, MT 59014. Karen J. Clause is the NRCS Rangeland Management Specialist in Pinedale, WY 82941. James S. Jacobs is the NRCS Plant Materials Specialist in Bozeman, MT 59715. Roger M. Hybner is Manager of the Plant Materials Center in Bridger, MT.

Introduction

With national attention on issues associated with sagebrush systems and sensitive species such as sage-grouse, there is a need to prioritize vegetative restoration efforts in oil and gas development areas on both private and public lands in southwestern Wyoming (Holechek, 2006). The Shell Exploration and Production Company (hereby referred to as Shell), Sublette County Conservation District, Bureau of Land Management (BLM), Wyoming Game and Fish Department (WGFD), and USDA Natural Resources Conservation Service (NRCS) have teamed up to adopt appropriate reclamation techniques in association with oil and gas production activities taking place in the Pinedale Anticline and Jonah Gas Field regions located in Sublette County. Local resource professionals and land managers entered into discussions that led to the signing of a cooperative working agreement. Their common goal was to develop reclamation and rangeland restoration trials to determine the best native plants and establishment techniques for restoring, enhancing, and maintaining native rangeland and sagebrush ecosystem diversity, forage production, and wildlife habitat. The first project in the working agreement tests a wide variety of plant materials in a Field Evaluation Planting (FEP) in cooperation with Shell (fig. 1). Challenges to restoration of native plant species in the ecosystem include a short growing season, low and uncertain precipitation, high summer temperatures during drought periods, sandy soils with low organic matter and water-holding capacity, invasive plant species, and domestic and native ungulate herbivory (Newhall et al, 2004). Loss of soil structure and compaction associated with drill site disturbance may impede restoration under these site conditions.

Objectives

The major objectives coincide with objectives outlined in the Pinedale Resource Area Cooperative Working Agreement (PRACWA, 2005), and will: Test cultivars, varieties, and germplasms of grass, forb, and shrub species for adaptation to the Pinedale Resource Area. Emphasis is on plant species native to the Rocky Mountain Region that provide forage production, a diverse ecosystem, and habitat for sage-grouse, mule deer, antelope, and other wildlife species dependent upon sagebrush communities. Test seeding methods, mixtures, and rates for adaptation and desired ecological diversity in the Pinedale Resource Area. Distribute results to public and private land managers, as well as other interested individuals.

Site Description

The Shell project is located on a previously disturbed well-pad, approximately 48.3 km south of Pinedale, Wyoming (N ½ SW ¼ Section 10, T29N R107W). The site falls within the Cool Central Desertic Basins and Plateaus Major Land Resource Area (MLRA 34A) at an elevation of 2,193 m. Annual precipitation is approximately 250 mm, mainly in the form of snow. Peak growing season (60 to 70 days) precipitation is from May to June. The soils are mostly deep and well drained, and slope commonly ranges from 2 to 15%. Surface layers are 13 cm or more thick with sandy clay loam subsoils. The major soil series include Bluerim-Forelle complex and Bluerim-Cotha complex. Soil texture is sandy loam with 75.2% sand, 18.8% silt, and 6% clay. The results of soil laboratory tests on surface (0 to 13 cm) and subsurface (13 to 25 cm) characteristics include, respectively: pH 7.8-8.1, low excess carbonate, soluble salts (mmhos/cm) 0.34-0.46, sodium (ppm) 52-122, organic matter 0.7-1.0%, cation capacity 15.4-20.5; and parts-per-million of nitrate 11-17, phosphorus 4-6, potassium 123-177, magnesium 313-370, calcium 2427-3330, sulfur 16-38, zinc 0.4-0.5, iron 4.3-6.9, manganese 0.5-1.7, copper 1.2-1.5, boron 0.7-0.9, and sodium adsorption ratio 0.84-1.7.

It is a sandy ecological site, in a 250 to 356 mm precipitation zone in foothills and basins. The dominant vegetative cover type is classified as sagebrush steppe and the potential natural vegetation is estimated at 70% grass and grass-like plants, 10% forbs, and 20% woody plants. The key grass species are needle and thread, thickspike wheatgrass, Indian ricegrass, and bluebunch wheatgrass. The forbs include buckwheat, clover, milkvetch, fleabane, and biscuitroot. Shrub cover is dominated by big sagebrush. The total annual production (air-dry weight) ranges from 785 kg/ha in unfavorable years up to 1,682 kg/ha in favorable years (USDA, NRCS 2005).

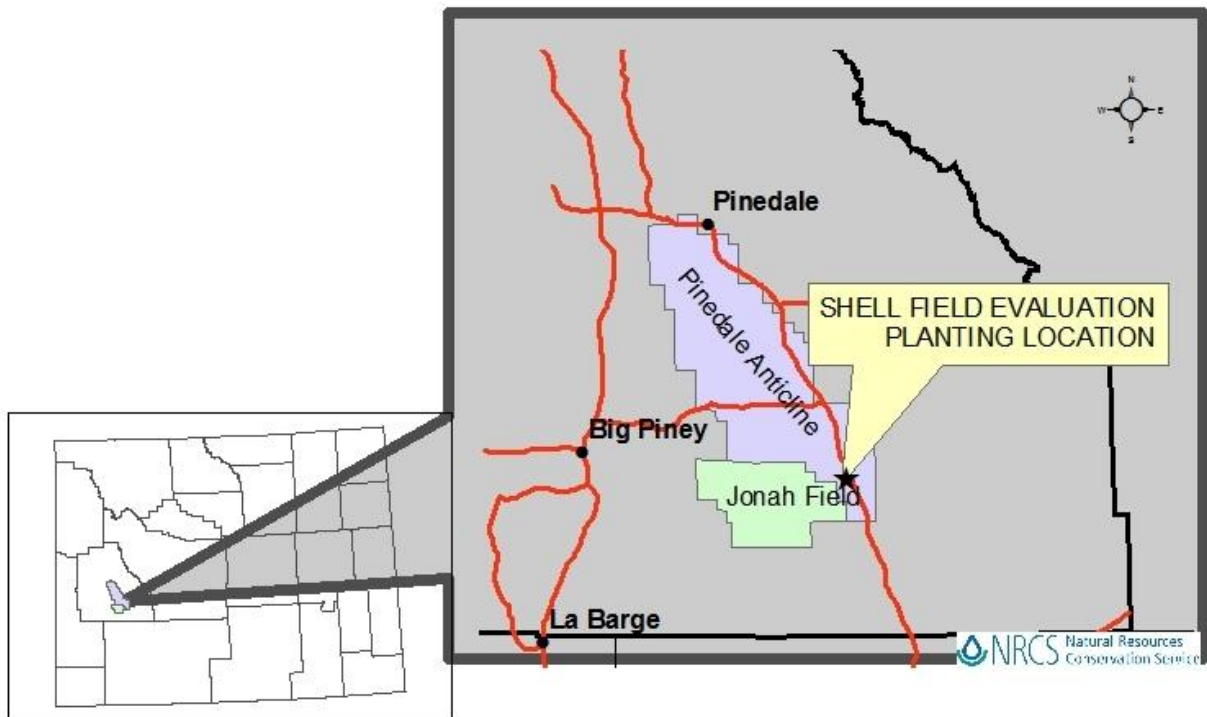


Figure 1. Locational map of the Shell FEP in Sublette County near Pinedale, Wyoming

Methods and Materials

The 1.8-ha site was disturbed in 2002 and an oil and gas well-pad was constructed. Approximately 15 cm of topsoil was stripped and stockpiled for 37 months and re-applied to the pad following development. The soil was ripped to mitigate heavy equipment compaction and restore infiltration, then firmed and smoothed. Seedbed conditions were moderately fluffy and less than ideal for precise seed placement.

Seeding Treatments

Establishment and growth of 15 grass, 22 forb, and 13 shrub species, mostly native to the Pinedale Resource Area, were tested in a randomized complete block study with four replications (appendix table 1). The scientific plant nomenclature is standardized by the USDA NRCS Plants Database (USDA, NRCS 2009). Plots were 1.2 m wide by 6 m long (7.4 m²), and the 72 entries were dormant-seeded in the fall of 2005 as monocultures using a Kincaid Precision Cone-seeder (fig. 2). Two seeding mixtures, Bridger and Shell (see tables 1 and 2 for species composition), were tested on adjacent plots. Each mixture was seeded with a Truax™ drill in 0.4-ha plots and an ATV-mounted broadcast seeder in 0.2-ha plots.



Figure 2. Seeding replicated (left) and drill plots (right), October 2005.

Following planting of the broadcast-seeded plots, the area was roughened with a wooden pallet pulled behind the ATV (fig. 3). In addition, the Shell mixture was hydroseeded to a 0.4-ha plot on a smooth slope in a one-step mulch application.



Figure 3. Seeding broadcast (left) and hydro-mulch plots (right), October 2005.

Evaluations

Plots were evaluated early July 2006 and early September 2007. In 2008, the forb replicated treatment was evaluated on June 27 and the remaining treatments were evaluated on July 29 and 30. Evaluation variables included a relative rating of plant vigor and stand establishment, height in centimeters, plant counts and/or biomass production, and photo points.

Table 1. The species composition and seeding rates of the Bridger Seed Mixture.

Common Name	Scientific Name	Seeds	Mix	PLS [†]	Seeding Rate [†]	Drill Rate [†]	Broadcast Rate [†]
		<i>g</i>	<i>%</i>	<i>%</i>	<i>kg/ha</i>	<i>seeds/m²</i>	<i>seeds/m²</i>
'Pryor' slender wheatgrass	<i>Elymus trachycaulus</i>	209	12.8	87.44	2.58	54	108
Critana thickspike wheatgrass	<i>Elymus lanceolatus</i>	319	12.8	~90.00	1.68	54	108
'Rosana' western wheatgrass	<i>Pascopyrum smithii</i>	205	12.8	87.90	2.90	54	108
High Plains Sandberg bluegrass	<i>Poa secunda (P. sandbergii)</i>	2,037	12.8	~80.00	0.28	54	108
'Rimrock' Indian ricegrass	<i>Achnatherum hymenoides</i>	341	12.8	98.83	1.57	54	108
'Trailhead' basin wildrye	<i>Leymus cinereus</i>	275	7.7	85.85	1.12	32	64
Great Northern western yarrow	<i>Achillea millefolium var. occidentalis</i>	9,912	5.1	~90.00	0.02	22	44
Stillwater prairie coneflower	<i>Ratibida columnifera</i>	1,322	5.1	93.16	0.17	22	44
Maple Grove prairie flax	<i>Linum lewisii</i>	612	5.1	90.25	0.35	22	44
Silverleaf phacelia	<i>Phacelia hastata</i>	1,000	5.1	91.57	0.21	22	44
Scarlet globemallow	<i>Sphaeralcea coccinea</i>	1,101	2.6	71.56	0.19	11	22
Wytana fourwing saltbush	<i>Atriplex aptera</i>	108	1.3	48.05	0.50	5	10
Open Range winterfat	<i>Krascheninnikovia lanata</i>	775	1.3	~90.00	0.07	5	10
Wyoming big sagebrush	<i>Artemisia tridentata ssp. wyomingensis</i>	5,286	1.3	13.38	0.01	5	10
Fringed sagewort	<i>Artemisia frigida</i>	10,022	1.3	85.71	0.006	5	10
Total: 15 species		-	99.9	-	11.21	421	842

[†] Pure Live Seed.

Table 2. The species composition and seeding rates of the Shell Seed Mixture.

Common Name	Scientific Name	Seeds	Mix	PLS [†]	Seeding Rate [†]	Drill Rate [†]	Broadcast Rate [†]
		<i>g</i>	<i>%</i>	<i>%</i>	<i>kg/ha</i>	<i>seeds/m²</i>	<i>seeds/m²</i>
Wyoming big sagebrush	<i>Artemisia tridentata</i> ssp. <i>wyomingensis</i>	5,507	41.50	5.269	0.60	309	618
Sandberg bluegrass	<i>Poa secunda</i> (<i>P. sandbergii</i>)	2,037	30.71	10.539	1.12	229	458
Fringed sagewort	<i>Artemisia frigida</i>	9,991	7.53	0.530	0.06	56	112
Rydberg's penstemon	<i>Penstemon rydbergii</i>	9,692	7.30	0.525	0.06	54	108
Indian ricegrass	<i>Achnatherum hymenoides</i>	311	4.68	10.541	1.12	35	70
Native yarrow	<i>Achillea millefolium</i>	6,101	4.60	0.529	0.06	34	68
Winterfat – bearded	<i>Krascheninnikovia lanata</i>	125	1.88	10.537	1.12	14	28
Fourwing saltbush	<i>Atriplex canescens</i>	115	0.86	5.268	0.60	6	12
Scarlet globemallow	<i>Sphaeralcea coccinea</i>	1,101	0.50	3.096	0.03	4	8
Silvery lupine	<i>Lupinus argenteus</i>	29	0.43	10.544	1.12	3	6
Totals: 10 species		-	99.99	-	5.89	744	1,488

[†] Pure Live Seed.

Replicated Plots. In 2006, plants were counted or estimated as percentage cover in the entire area of 7.43 m². In 2007 and 2008, plant counts were randomly conducted in six, 0.09 m² plots (fig. 4). In 2008, grasses were clipped for biomass production within a 2.97 m² plot. In all years, plant vigor and relative stand establishment were visually estimated for the entire plot. Plant height measurements were taken from representative plants in each sample plot. Additional comments were noted on items such as the presence of animal and bird life and grazing or browsing activity.

Mixture Plots. In 2006, plants of individual species in the broadcast- and hydroseeded treatments were counted in 20, 0.18 m² plots. In the drill-seeded treatment, plants were counted in twenty, 0.22 m² plots. In 2007 and 2008, plants of individual species were counted in 10 plots, each 0.89 m². Relative plant vigor and plant height in centimeters were assessed across an entire treatment area. The hydroseeded treatment was inspected for signs of improved plant establishment.



Figure 4. Plot evaluations, July 2008.

Results

Replicated Plots.

Grass. Based on an analysis of variance of the 2006-2008 data (Statistix, 2007), the establishment and survival, as determined by density, was significantly different among the grasses ($p \leq 0.05$). In 2006, entries of basin wildrye, slender wheatgrass, and bluebunch wheatgrass had the greatest densities of the 32 accessions planted (table 3). Densities decreased from 2006 to 2007 in all accessions except Rimrock Indian ricegrass. Eighteen grasses increased

densities from 2007 to 2008 (fig. 5). Over a 3-year period, L-46 basin wildrye remained the top performer, but had also declined in density along with 23 other entries. The most noticeable change was an increase in the slower-to-establish entries of bluegrass, Junegrass, and ricegrass. Considering a target of 66 plants per row-meter (USDA, 2007a), the plant densities of the top five species averaged 45 plants per row-meter. Mean biomass values were greatest ($p \leq 0.05$) in L-46 basin wildrye, but not significantly greater than six other accessions of *Leymus cinereus*, *Elymus lanceolatus*, *Elymus elymoides*, or *Pseudoroegneria spicata* (table 3). Heights of the grasses differed among accessions ($p \leq 0.05$) but were less variable over time than density (table 3). The grasses with the better establishment were not always the tallest, due to their inherent growth forms. The long-term drought, where precipitation is approximately 25% below normal (fig. 6), continued to negatively impact plant growth and development.



Figure 5. Grass replicated plot establishment, July 2008.

Table 3. Mean values for the 2006-2008 density, biomass, and height of 32 grasses in the Shell FEP replicated plots.

Accession/Common Name	Plants/m ²			Production kg/ha		Height in Centimeters	
	2006 [†]	2007	2008	2008	2006	2007	2008
L-46 basin wildrye	98 a*	46 a*	72 a*	179 a*	11 a*	14 abc*	73 a*
Washoe basin wildrye	64 bcd	22 cdefgh	29 bcdef	161 ab	9 abc	13 abcd	69 ab
Critana thickspike wheatgrass	32 defghij	28 abcdef	37 bc	158 ab	9 abc	12 a	63 abcd
Trailhead basin wildrye	55 bcdef	11 hijklm	18 defghi	139 abc	10 ab	14 ab	73 a
Sodar thickspike wheatgrass	64 bcd	46 a	47 b	131 abcd	7 cde	11 bcdefg	48 abcdefg
9019219 bottlebrush squirreltail	45 defgh	14 efghijkl	16 defghi	121 abcd	7 cde	12 abcde	33 efg
P-24 bluebunch wheatgrass	83 ab	36 abcd	28 bcdef	115 abcde	8 bcd	13 abcde	49 abcdefg
‘Continental’ basin wildrye	98 a	40 abc	30 bcde	102 bcdef	11 a	13 abcd	61 abcde
‘Magnar’ basin wildrye	80 abc	25 bcdefgh	21 cdefg	96 bcdefg	10 ab	13 abcd	64 abc
‘Rodan’ western wheatgrass	49 cdefg	12 ghijklm	16 defghi	84 cdefgh	7 cde	12 bcdef	49 abcdefg
‘Bannock’ thickspike wheatgrass	58 bcd	27 abcdefg	34 bcd	75 cdefghi	8 bcde	12 abcdef	41 bcdefg
Anatone bluebunch wheatgrass	56 bcde	25 bcdefgh	20 cdefg	74 cdefghij	9 abc	13 abc	40 bcdefg
Copperhead slender wheatgrass	99 a	42 ab	33 bcd	73 defghijk	6 cde	9 efg	38 cdefg
P-19 bluebunch wheatgrass	57 bcd	21 defghi	19 cdefgh	51 efghijkl	8 bcde	13 abcde	54 abcdef
‘Goldar’ bluebunch wheatgrass	38 defghi	17 efghijk	11 fghi	47 fghijkl	7 cde	12 abcde	32 efg
Pryor slender wheatgrass	47 defg	27 abcdefg	11 fghi	43 fghijkl	8 bcde	11 bcdefg	48 abcdefg
‘San Luis’ slender wheatgrass	55 bcdef	28 abcdef	19 cdefgh	39 fghijkl	8 bcd	15 abcde	44 abcdefg
Salina wildrye	47 defg	13 fghijkl	13 efghi [†]	32 ghijkl	7 cde	10 cdefgh	46 abcdefg
Rosana western wheatgrass	25 efghij	20 defghij	21 cdefg	25 hijkl	6 cde	9 fghi	27 fg
‘Secar’ Snake River wheatgrass	35 defghij	8 jklmno	8 ghi	25 hijkl	8 bcd	12 abcde	56 abcdef

* Means followed by the same letter within a column are not significantly different determined by LSD ($p \leq 0.05$).

[†] Density in some entries estimated from percentage basal cover.

Table 3. Mean values for the 2006-2008 density, biomass, and height of 32 grasses in the Shell FEP replicated plots--Continued.

Accession/Common Name	Plants/m ²			Production kg/ha		Height in Centimeters		
	2006 [†]	2007	2008	2008	2006	2007	2008	
P-22 bluebunch wheatgrass	51 bcdefg	15 efghijkl	9 ghi	24 hijkl	8 bcde	9 efgh	39 cdefg	
E-45 Snake River wheatgrass	35 defghij*	9 ijklmn*	5 ghi*	12 ijkl*	8 bcde*	9 fghi*	43 bcdefg*	
High Plains Sandberg bluegrass	8 ij	3 mnop	5 ghi	12 ijkl	5 e	8 ghij	50 abcdefg	
Opportunity Nevada bluegrass	3 j	2 nop	13 efghi [†]	12 ijkl	6 de	7 hij	46 cdefg	
'Sherman' big bluegrass	11 ij	6 klmnop	21 cdefg	8 jkl	6 cde	10 cdefgh	27 cdefg	
'Covar' sheep fescue	6 ij	1 p	8 ghi	7 kl	8 bcde	5 ij	56 defg	
9087539 prairie Junegrass	5 j	2 op	9 ghi	7 kl	6 cde	5 j	39 cdefg	
Rimrock Indian ricegrass	3 j	4 mnop	5 ghi	6 l	8 bcde	12 bcdef	43 fg	
Wapiti bottlebrush squirreltail	20 ghij	3 mnop	5 ghi	4 l	6 cde	5 ij	50 abcdefg	
Pueblo bottlebrush squirreltail	13 hij	6 lmnop	13 efghi [†]	4 l	6 cde	9 defghi	46 g	
9092261 prairie Junegrass	12 ij	4 lmnop	21 cdefg	4 l	6 de	11 bcdefg	27 cdefg	
'Nezpar' Indian ricegrass	24 fghij	7 klmnop	8 ghi	3 l	9 abc	12 abcde	56 abcdefg	

* Means followed by the same letter within a column are not significantly different determined by LSD ($p \leq 0.05$).

[†] Density in some entries estimated from percentage basal cover.

Forbs. The analysis of variance of the 2006-2008 data (Statistix, 2007) showed establishment and survival densities differed significantly among forb accessions ($p \leq 0.05$). In 2006, the significantly better entries were Appar blue flax, Maple Grove prairie flax, Old Works fuzzytongue penstemon, and the Richfield Selection of Eaton's penstemon (table 4). In 2007, densities of Rocky Mountain beeplant were significantly higher than the other entries. In 2007 and 2008, densities improved in 13% of the accessions. The densities of forbs were lower than expected and occurrences within a rep but outside a sample plot were noted. In 2007, 13 entries were sampled, with 10 entries present outside the plots. There were no plants of scarlet globemallow in the treatment. In 2008, 12 entries were sampled, with eight entries present outside the plots (fig. 6). American vetch, wavy Indian paintbrush, showy evening primrose, and pale evening primrose were not present on site. Forb heights differed among accessions ($p \leq 0.05$), but were less variable over time than densities. The forbs with better establishment were not always the tallest, due to their inherent growth form.



Figure 6. Forb replicated plot establishment, June 2008.

Shrubs. The analysis of variance of the 2006-2008 data (Statistix, 2007) showed establishment and survival measured by densities were different among shrub accessions ($p \leq 0.05$). The densities of shrubs were lower than expected and occurrences within a rep but outside a sample plot were noted. In 2006, the significantly better entries were two saltbush accessions (table 5). Fifteen of the 16 species were present in the sample area with fringed sagewort not observed on-

site. In 2007, densities improved in 44% of the entries over the previous year (table 5). Nine species were present in the sample area with six species noted outside the plots. There were no plants of spiny hopsage present in the treatment. In 2008, there were greater densities in 25% of the entries over the previous year (fig. 7). Ten species were present in the sample area with six species noted outside the plots. Over a 3-year period, the best performers were Wytana and Snake River Plains fourwing saltbush. Shrub heights differed among accessions ($p \leq 0.05$) but were less variable over time than densities. The shrubs with better establishment were not always the tallest, due to their inherent growth form.

Table 4. Mean values for the 2006-2008 density and height of 24 forbs in the Shell FEP replicated plots.

Accession/Common Name	Plants/m ²			Height in Centimeters		
	2006 [†]	2007	2008	2006	2007	2008
Appar prairie flax	5 abcd*	8. bc*	11 a*	3 b*	2 c*	26 a*
Old Works fuzzytongue penstemon	6 abc	5. bc	5 ab	2 bc	3 c	9 bc
Richfield Eaton's penstemon	8 ab	8 bc	5 ab	2 bcd	4 bc	20 ab
9087541 western yarrow	1 def	14 b	4 b	1 bcd	3 bc	18 abc
9087546 Palmer's penstemon	4 cdef	2 bc	3 b	3 b	8 b	34 a
Maple Grove Lewis flax	9 a	4 bc	3 b	1 bcd	5 bc	32 a
9087552 sulfurflower buckwheat	4 bcde	0	2 b	2 bcd	-	5 bc
9087553 gray aster	2 cdef	3 bc	1 b	2 bc	4 bc	10 bc
9087545 Eaton's penstemon	4 cdef	3 bc	1 b	2 bcd	1 c	13 abc
Stillwater prairie coneflower	2 cdef	0.5 c	1 b	2 bcd	1 c	15 bc
Antelope white prairie clover	1 ef	0	0.5 b	1 bcd	-	3 c
9087554 Pacific aster	1 def	0	0.5 b	1 bcd	-	9 bc
Great Northern western yarrow	1 def	0	0	1 cd	-	-
9087542 wavyleaf Indian paintbrush	0.5 ef	0	0	0.6 cd	-	-
9087543 Rocky Mountain beeplant	4 bcde	27 a	0	10 a	34 a	-
9087544 aspen fleabane	0.03 f	0	0	0.3 d	-	-
9087548 pale evening-primrose	0.1 f	0	0	2 bc	-	-
9087549 showy evening primrose	4 bcde	0.5 c	0	1 bcd	0.3 c	-
9087547 littleflower penstemon	0.3 f	0	0	0.3 d	-	-

[†] Means followed by the same letter within a column are not significantly different determined by LSD ($p \leq 0.05$).

Table 4. Mean values generated from ANOVA for the 2006-2008 density and height of 24 forbs in the Shell FEP replicated plots--Continued.

Accession/Common Name	Plants/m ²			Height in Centimeters		
	2006†	2007	2008	2006	2007	2008
Clearwater Venus penstemon	1 def*	0	0	2 bcd*	-	-
9081832 silverleaf phacelia	4 bcde	1 c*	0	2 bcd	2 c*	-
9087550 scarlet globemallow	0.03 f	0	0	0.6 cd	-	-
9087551 Munro's globemallow	0.1 f	0	0	1 bcd	-	-
9087540 American vetch	2 cdef	0.5 c	0	2 bc	0.3 c	-

* Means followed by the same letter within a column are not significantly different determined by LSD ($p \leq 0.05$).



Figure 7. Shrub replicated plot establishment, July 2008.

Drill Treatment.

Bridger Seed Mixture. In 2006, 40% of the species in the mix were present in the 0.41-ha sample area (table 6). Densities were greatest in Rimrock Indian ricegrass and Rosana western wheatgrass. Plant densities were lower than expected and occurrences outside the sampled areas were noted. These include Critana thickspike wheatgrass, Great Northern western yarrow, Maple Grove Lewis flax, and Open Range winterfat. The remaining 33% of the mix did not establish. There were approximately 4 plants/m² and the percentage richness was 50% grass, 17% forb, and 33% shrub. Percentage frequencies of occurrence in the test plots were Rimrock Indian ricegrass and Rosana western wheatgrass (25%), Pryor slender wheatgrass and Wyoming big sagebrush (10%), and Wytana fourwing saltbush and silverleaf phacelia (5%). In 2007, 53% of the species in the mix were present in the sampled plots. Fringed sagewort were present outside the sampled area and 40% of the species in the mix did not establish. There were 50% more grass species than in the previous year and a 50% decrease in non-grass species. Grass densities increased 14% over the previous year. Plant densities were greatest in Pryor slender wheatgrass and Trailhead basin wildrye. There were approximately 4 plants/m² and the percentage richness was 75% grass and 25% shrubs. Percentage frequencies of occurrence in the test plots were Pryor slender wheatgrass and Trailhead basin wildrye (50%), Rimrock Indian ricegrass, and Wytana fourwing saltbush (40%),

Table 5. Mean values generated from ANOVA for the 2006-2008 density and height of 16 shrubs in the Shell FEP replicated plots.

Accession/Common Name	Plants/m ²			Height in Centimeters		
	2006	2007	2008	2006	2007	2008
Wytana fourwing saltbush	4 a*	6 a*	7 a*	5 a*	18 ab*	25 ab*
Snake River Plains fourwing saltbush	3 a	4 b	4 b	6 a	24 a	34 a
9016134 Gardner's saltbush	1 b	0.4 c	1 bc	1 bcd	13 bc	14 cd
'Hatch' winterfat	1 b	1 c	1 bc	3 b	10 bcde	20 bc
Northern Cold Desert winterfat	1 b	2 bc	0.5 c	3 b	12 bcd	23 bc
9087557 black sagebrush	0.2 b	1 bc	0.5 c	0.3 d	8 cdef	5 d
9087558 basin big sagebrush	0.4 b	1 c	0.5 c	1 cd	17 ab	25 ab
9087559 Wyoming big sagebrush	0.1 b	0	0.5 c	1 cd	-	17 bc
9087563 spiny hopsage	0.3 b	0	0.5 c	2 bcd	-	15 bcd
Open Range winterfat	1 b	1 bc	0.5 c	2 bc	10 bcde	25 ab
9087555 fringed sagewort	0	0	0	-	-	-
9087556 white sagebrush (cudweed sagewort)	0.2 b	0	0	0.3 d	-	-
9087561 shadscale saltbush	0.6 b	0	0	1 cd	-	-
9087560 basin saltbush	0.03 b	0.4 c	0	0.3 d	7 cdef	-
9087562 antelope bitterbrush	1 b	0	0	3 b	-	-
'Maybell' antelope bitterbrush	0.3 b	0	0	2 bc	-	-

* Means followed by the same letter within the same column are not significantly different determined by LSD ($p \leq 0.05$).

Critana thickspike wheatgrass and Rosana western wheatgrass (30%), Open Range winterfat (20%), and High Plains Sandberg bluegrass (10%). In 2008, 53% of the species in the mix were present in the sample plots (fig. 8). There were 13% more forb species and 13% fewer shrubs from the previous year. Grass densities increased 24% from the previous year. Plant densities were greatest in Critana thickspike wheatgrass and Pryor slender wheatgrass. Over a 3-year period, there were 22% more plants/ha (5 plants/m²) and the percentage richness was 75% grass and 13% forbs and shrubs. Stillwater prairie coneflower, Maple Grove Lewis flax, Open Range winterfat, Wytana fourwing saltbush, and fringed sagewort were present outside the sample plots. Great Northern western yarrow and scarlet globemallow did not establish. Percentage frequencies of occurrence in the test plots were Critana thickspike wheatgrass (100%), Pryor slender wheatgrass (90%), Rosana western wheatgrass and Trailhead basin wildrye (40%), High Plains Sandberg bluegrass (30%), silverleaf phacelia (20%), and Rimrock Indian ricegrass and Wyoming big sagebrush (10%). Over the same time period, plant heights increased to an average of 15 cm. The native plant community, as described in the Ecological Site Description, is most closely represented in the plot establishment of the Bridger mix.

Shell Seed Mixture. In 2006, 50% of the species in the mix were present in the 0.41-ha treatment (table 7). Plant densities were greatest in Wyoming big sagebrush, silvery lupine, and Sandberg bluegrass. There were approximately 6 plants/m² and the percentage richness was 40% grass and shrubs and 20% forbs. Percentage frequencies of occurrence in the test plots were silvery lupine (30%), Wyoming big sagebrush (25%), Sandberg bluegrass (20%), Rimrock Indian ricegrass (15%), and winterfat (5%). An additional 40% of the species in the mix were accounted for outside the sampled plots at very low estimates of percentage basal cover, including fringed sagewort, Rydberg's penstemon, and yarrow. There were no plants of scarlet globemallow observed in the treatment area. In 2007, 60% of species in the mix did not establish in the sample area. Not present included fringed sagewort, yarrow, scarlet globemallow, and silvery lupine. Plant densities were greatest in fourwing saltbush and Wyoming big sagebrush, although there were 60% fewer sagebrush plants than in the previous year. The total number of plants in the treatment decreased 50% from the previous year to approximately 3 plants/m² in the sample area. Percentage richness was 33% grass, 17% forbs,

and 50% shrubs. Percentage frequencies of occurrence in the test plots were fourwing saltbush (70%), Wyoming big sagebrush (50%), Rimrock Indian ricegrass (30%), Sandberg bluegrass and winterfat (20%), and Rydberg's penstemon (10%). In 2008, 40% of species in the seeding mixture were present (fig. 8). Winterfat were present outside the sampled plots at a very low estimate of percentage basal cover. The remaining 50% of the species in the mixture not established included fringed sagewort, yarrow, scarlet globemallow, silvery lupine, and Rydberg's penstemon. Plant densities were greatest in Wyoming big sagebrush, fourwing saltbush, and Rimrock Indian ricegrass. The total number of plants in the treatment increased 16% from the previous year to approximately 4 plants/m². Over a 3-year period, there were 40% fewer plants/ha in the sample area and percentage richness was 50% grass and 50% shrubs. Percentage frequencies of occurrence in the test plots were Wyoming big sagebrush (80%), fourwing saltbush (50%), Rimrock Indian ricegrass (40%), and Sandberg bluegrass (10%). Over the same time period, plant heights increased to an average of 16 cm.



Figure 8. Drill treatment: Bridger mix (left) and Shell mix (right), July 2008.

Table 6. The Shell FEP 2006-2008 species performance in the drill treatment of the Bridger seed mixture.

Accession/Common Name	Plants Per Hectare			Height in Centimeters		
	2006	2007	2008	2006	2007	2008
Critana thickspike wheatgrass	0	4,483	17,895	-	10.16	16.81
Pryor slender wheatgrass	3,999	8,966	10,065	5.08	10.16	15.24
Rosana western wheatgrass	14,000	3,361	5,592	5.08	7.62	14.61
Trailhead basin wildrye	0	7,845	4,473	-	7.62	22.86
High Plains Sandberg bluegrass	0	1,121	3,449	-	5.08	4.57
Silverleaf phacelia	2,001	0	2,243	1.27	-	2.54
Rimrock Indian ricegrass	9,999	6,726	1,121	5.08	7.62	7.62
Wyoming big sagebrush	3,999	0	1,121	1.27	-	38.10
Open Range winterfat	0	2,243	0	-	7.62	-
Fringed sagewort	0	0	0	-	-	-
Wytana fourwing saltbush	810	4,483	0	2.54	17.78	-
Maple Grove Lewis flax	0	0	0	-	-	-
Stillwater prairie coneflower	0	0	0	-	-	-
Great Northern western yarrow	0	0	0	-	-	-
Scarlet globemallow	0	0	0	-	-	-
Total:	35,999	39,228	45,865	-	-	-

Table 7. The Shell FEP 2006-2008 species performance in the drill treatment of the Shell seed mixture.

Common Name	Plants Per Hectare			Height in Centimeters		
	2006	2007	2008	2006	2007	2008
Sandberg bluegrass	14,000	3,361	1,121	2.54	1.27	7.62
Rimrock Indian ricegrass	8,000	4,483	7,845	7.62	7.62	14.61
Rydberg's penstemon	0	1,121	0	-	1.27	-
Silvery lupine	14,000	0	0	1.27	-	-
Winterfat	2,001	2,243	0	7.62	15.24	-
Fourwing saltbush	0	10,087	7,845	-	7.62	15.24
Wyoming big sagebrush	20,000	7,845	17,895	2.54	15.24	27.43
Common yarrow	0	0	0	-	-	-
Scarlet globemallow	0	0	0	-	-	-
Fringed sagewort	0	0	0	-	-	-
Total:	58,001	29,140	34,706			

Broadcast Treatment.

Bridger Seed Mixture. In 2006, 33% of the species in the mix were present in the 0.2-ha sample area (table 8). An additional 27% of the species in the mix were outside the sample area at very low ratings of stand establishment. These included Maple Grove prairie flax, Open Range winterfat, silverleaf phacelia, and Wytana fourwing saltbush. The species not established were fringed sagewort, Great Northern western yarrow, scarlet globemallow, Stillwater prairie coneflower, and Trailhead basin wildrye. Plant densities were greatest in Rimrock Indian ricegrass and Pryor slender wheatgrass. There were approximately 6 plants/m² and percentage richness was 80% grasses and 20% shrubs. Percentage frequencies of occurrence in the test plots were Rimrock Indian ricegrass (30%), Pryor slender wheatgrass (25%), Wyoming big sagebrush (15%), Critana thickspike wheatgrass (10%), and High Plains Sandberg bluegrass (5%). In 2007, 73% of the species in the mix were present in the sample area. The species not established included High Plains Sandberg bluegrass, Stillwater prairie coneflower, fringed sagewort, and scarlet globemallow. Plant densities were greatest in Critana thickspike wheatgrass and Pryor slender wheatgrass. Densities increased nearly 50% from the previous year to approximately 10 plants/m², and percentage richness was 46% grass and 27% forbs and shrubs. Percentage frequencies of occurrence in the test plots were Critana thickspike wheatgrass (100%), Pryor slender wheatgrass (90%), Rimrock Indian ricegrass (70%), Wytana fourwing saltbush (60%), Wyoming big sagebrush (50%), Rosana western wheatgrass and Maple Grove prairie flax (40%), silverleaf phacelia (30%), Trailhead basin wildrye and Great Northern western yarrow (20%), and Open Range winterfat (10%).

In 2008, 53% of the species were present in the sample area (fig. 9). An additional 40% of the species in the mix were outside the sample area at very low ratings of stand establishment. These included Rimrock Indian ricegrass, Great Northern western yarrow, Stillwater prairie coneflower, fringed sagewort, silverleaf phacelia, and Open Range winterfat. Scarlet globemallow did not establish. Plant densities were greatest in Critana thickspike wheatgrass and Pryor slender wheatgrass. Densities declined 22% from the previous year to approximately 8 plants/m², but increased over 3 years by 25%. This treatment had 58% greater densities than in the drill-seeded treatment. Percentage richness was 63% grass, 13% forbs, and 25% shrubs.

Percentage frequencies of occurrence in the test plots were Pryor slender wheatgrass (70%), Critana thickspike wheatgrass and Trailhead basin wildrye (60%), Wytana fourwing saltbush (40%), High Plains Sandberg bluegrass and Wyoming big sagebrush (30%), and Rosana western wheatgrass and Maple Grove prairie flax (20%). Over 3 years, plant heights increased to an average of 15 cm.

Shell Seed Mixture. In 2006, 60% of the species in the mix was present in the 0.17-ha sample area (table 9). Native yarrow was identified outside the sampled plots at a very low estimate of percentage basal cover. Fringed sagewort, Rydberg's penstemon, and scarlet globemallow did not establish. Sandberg bluegrass and Wyoming big sagebrush had the greatest densities. There were approximately 3 plants/m² and the percentage richness was 33% grass, 17% forbs, and 50% shrubs. Percentage frequencies of occurrence in the test plots were Wyoming big sagebrush (40%), Sandberg bluegrass (25%), winterfat (10%), and fourwing saltbush, Rimrock Indian ricegrass, and silvery lupine (5%). In 2007, 40% of the species in the mix was present in the sample area. Rimrock Indian ricegrass, silvery lupine, fringed sagewort, Rydberg's penstemon, yarrow, and scarlet globemallow were not present in the treatment. Densities increased 39% in Sandberg bluegrass. There were approximately 7 plants/m² and the percentage richness was 25% grass and 75% shrubs. Percentage frequencies of occurrence in the test plots were Sandberg bluegrass (90%), Wyoming big sagebrush (70%), and winterfat and fourwing saltbush (30%). In 2008, 60% of the species in the mix was present in the sample area (fig. 9). Silvery lupine, Rydberg's penstemon, yarrow, and scarlet globemallow were not present in the treatment. Plant densities increased over the previous year 34% in Sandberg bluegrass and 63% in Wyoming big sagebrush. There were approximately 14 plants/m² and percentage richness was 33% grass and 67% shrubs. The broadcast-seeded treatment had four times greater densities than in the drill-seeded treatment. The broadcast-seeded treatments achieved the highest plant densities, with 56% more plants in the Shell mix than in the Bridger mix. Percentage frequencies of occurrence in the test plots were Sandberg bluegrass (80%); Wyoming big sagebrush (70%); winterfat, fourwing saltbush, and fringed sagewort (40%); and Rimrock Indian ricegrass (10%). The native plant community, as described in the Ecological Site Description, is most closely represented in the plot establishment of the Bridger mix.

Table 8. The Shell 2006-2008 species performance in the broadcast treatment of the Bridger seed mixture.

Common Name	Plants Per Hectare			Height in Centimeters		
	2006	2007	2008	2006	2007	2008
High Plains Sandberg bluegrass	2,801	0	4,485	2.54	-	3.30
Rimrock Indian ricegrass	19,614	14,571	0	2.54	5.08	-
Pryor slender wheatgrass	16,811	15,692	24,668	7.62	5.08	9.91
Rosana western wheatgrass	0	12,328	3,363	0	5.08	11.43
Critana thickspike wheatgrass	11,209	33,624	26,909	7.62	10.16	9.14
Trailhead basin wildrye	0	2,243	7,848	-	5.08	10.16
Great Northern western yarrow	0	2,243	0	-	5.08	-
Maple Grove prairie flax	0	4,483	2,244	-	7.62	38.10
Silverleaf phacelia	0	4,483	0	-	2.54	-
Open Range winterfat	0	1,121	0	-	5.08	-
Wytana fourwing saltbush	0	6,726	4,485	-	10.16	21.59
Wyoming big sagebrush	8,405	10,088	3,363	2.54	12.70	18.54
Fringed sagewort	0	0	0	-	-	-
Scarlet globemallow	0	0	0	-	-	-
Total:	58,840	100,876	78,309			

Table 9. The 2006-2008 species performance in the broadcast treatment of the Shell seed mixture.

Common Name	Plants Per Hectare			Height in Centimeters		
	2006	2007	2008	2006	2007	2008
Sandberg bluegrass	16,811	43,709	66,1250	2.54	1.27	4.83
Rimrock Indian ricegrass	2,801	0	1,121	2.54	-	10.16
Fourwing saltbush	2,801	4,483	5,592	5.08	7.62	16.51
Winterfat	5,604	4,483	5,592	2.00	12.70	17.15
Wyoming big sagebrush	56,039	21,294	57,040	2.54	10.16	16.76
Silvery lupine	2,801	0	0	2.54	-	-
Fringed sagewort	0	0	5,592	-	-	12.07
Rydberg's penstemon	0	0	0	-	-	-
Common yarrow	0	0	0	-	-	-
Scarlet globemallow	0	0	0	-	-	-
Total:	30,874	73,339	141,062			



Figure 9. Broadcast treatment: Bridger mix (left) and Shell mix (right), July 2008.

Hydroseeding. In 2006, 33% of the species in the mix were present in the 0.4-ha sample area (table 10). Fourwing saltbush, Rimrock Indian ricegrass, and silvery lupine were found outside the sampled plots. Fringed sagewort, Rydberg's penstemon, scarlet globemallow, and yarrow did not establish. Densities were highest in winterfat. The treatment had approximately 1 plant/m² and percentage richness was 33% grass and 67% shrubs. Percentage frequencies of occurrence in the test plots were winterfat (10%), and Sandberg bluegrass and Wyoming big sagebrush (5%). Overall vigor ratings were average and plant heights were approximately 5 cm. Due to the poor establishment, the area was hydroseeded again in October 2006. In 2007, 20% of the species in the mix were present in the reseeded treatment (fig. 10). There were no plants of Sandberg bluegrass, Wyoming big sagebrush, fourwing saltbush, silvery lupine, fringed sagewort, Rydberg's penstemon, scarlet globemallow, and the native yarrow. Rimrock Indian ricegrass had the highest plant densities and winterfat densities from the previous year declined 80%. The treatment had approximately 1 plant/m² and percentage richness was 50% grass and 50% shrubs. Percentage frequencies of occurrence in the test plots were Rimrock Indian ricegrass (30%) and winterfat (10%). Relative vigor ratings were very poor and plant heights were approximately 8 cm. The hydroseeding establishments were the lowest, and in fact, were twice considered a failure. Mixing seed directly into the slurry and applying as a one-step mulch application on a smooth-slope surface, promotes seed movement and seedling desiccation due to drying and shrinking of the mulch. To restrict seed movement and promote seed-to-soil contact,

a two-step approach is preferred where 1) the seed is separately mixed in a trace amount of mulch and applied directly to a roughened soil surface, followed by 2) a second application of mulch to reduce soil erosion and enhance micro-climate conditions necessary for germination and establishment (Holzworth, 2007). The natural terrain of the site is rolling and the percentage slope mostly ranged from less than 1 to 8, with up to 12% slope in portions of the hydroseeded treatment. In the steeper gradients, plots were tracked with minor rills where water moved downhill. Minor soil movement due to wind erosion was evident in small accumulations adjacent to the fence and in low lying areas.



Figure 10. Hydroseed treatment: October 2007 (left) and July 2008.

Discussion

The demand for affordable energy to fuel the economy is resulting in the rapid expansion of energy exploration and extraction in high elevation sagebrush ecosystems in Wyoming. Sagebrush plant communities support mule deer, antelope, and sage-grouse, among other wildlife species (Welch, 2005). They are also important to the livestock industry. Disturbances resulting from energy exploration differ from historic disturbances of wildfire and grazing predominantly in the extent of soil disturbance, soil compaction, and loss of soil structure.

Table 10. The 2006-2007 species performance in the hydroseeded treatment of the Shell seed mixture.

Common Name	Plants Per Hectare		% Stand		Vigor [†]		Height in Centimeters	
	2006	2007	2006	2007	2006	2007	2006	2007
Sandberg bluegrass	2,801	0	0.06	0	5	-	2.54	-
Rimrock Indian ricegrass	0	8,966	0	1.30	-	9	-	7.62
Winterfat	5,604	1,121	2.00	0.40	5	8	2.54	10.16
Wyoming big sagebrush	2,801	0	0.05	0	3	0	7.62	-
Fourwing saltbush	0	0	0	0	-	-	-	-
Silvery lupine	0	0	0	0	-	-	-	-
Fringed sagewort	0	0	0	0	-	-	-	-
Rydberg's penstemon	0	0	0	0	-	-	-	-
Common yarrow	0	0	0	0	-	-	-	-
Scarlet globemallow	0	0	0	0	-	-	-	-
Total:	11,206	10,087	0.08	0.07				

[†] Rated 1-9 with 1 best.

Restoration of native plant communities with a diversity of grass, forb, and shrub species important to key wildlife species is relatively unrealized (Hardegree et al, 2002). The short-term results of these field experiments and trials provide information to further our ability to restore native plant communities and reduce the impact of development on sensitive wildlife species.

The Bridger mix was mostly comprised of commercially available seed and the Shell seed mixture was mostly wildland-collected. Seed costs are conservatively estimated at \$125/acre for the Bridger mix and \$200/acre for the Shell mix. An ongoing debate over strict use of locally indigenous material, versus seeding with widely adapted native plant materials, will ultimately be determined by seed availability and the price associated with timely revegetation of disturbed sites (Hijar, 2003; Booth and Vogel, 2006).

Environmental factors such as low precipitation, higher temperatures, and increase of weedy species inhibit seedling establishment (Monsen et al, 2004). The difficulty associated with long-term establishment of Wyoming big sagebrush may require use of a higher seeding rate (Schuman and Belden, 2002). The native species with the highest establishment are those taking advantage of early spring moisture. Drought tolerance is the key to long-term survival in this harsh climate. The effects of mechanical site preparation and seeding techniques on disturbed sites may elevate soil erosion during the early stages of plant establishment (Pierson et al, 2007). Those factors, along with a need to determine appropriate planting techniques, should be taken into consideration during all aspects of planning for the exploration of oil and gas in southwest Wyoming.

Summary

The replicated plots indicated that plant material accessions, currently developed, are easily established using drill seeding under the environmental and disturbance conditions of the area. Accessions of *E. lanceolatus*, *E. trachycaulus*, *L. cinereus*, and *P. spicata* demonstrated rapid establishment important in stabilizing severely disturbed soils. This is supported in the results of a similar trial conducted from 1987-2002 at Soda Lake, near Pinedale (USDA, 2008). Although forb establishments were below expectations, *A. millefolium*, *L. perenne*, and *P. palmerii*, increased in densities and show the greatest promise for providing diversity of this functional

group important to wildlife habitat. Similarly, shrub establishments were disappointing with only four of 16 species important to wildlife established after three growing seasons. They were *A. aptera*, *A. canescens*, *A. gardnerii*, and *K. lanata*. Although establishments were below estimates of a full stand, these same species were most often encountered in the seeding mixture trials, suggesting an increased seeding rate may improve establishment.

Species performance of the drill-seeded mixture plots were substantially lower than in the broadcast-seeded mixture plots, suggesting seeding depth is an important factor for many of the small-seeded species. This is comparable to the findings of a similar trial conducted on the Express Pipeline near Greybull and Worland, Wyoming (USDA, 2002). Also, soil-roughing treatments may prevent wind loss of seed from the site. Results suggest the one-step practice of hydro-seeding may not be effective and should be seriously reconsidered as the planting method of choice in the restoration of native plant communities on these sites.

The dormant-seeded planting dates in the Shell trial coincide with the Soda Lake planting dates, while the Express Pipeline test sites were spring-seeded. Future seeding trials in the Pinedale Anticline and Jonah Field should consider experimenting, depending on species, with both spring and fall planting dates.

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Appendix Table 1. The origin and seed lot specifics of 32 grasses, 24 forbs, and 16 shrubs in the Shell FEP replicated plots in Sublette County, near Pinedale, Wyoming. Planted October 19, 2005.

Accession	Scientific Name	Common Name	Source [†]	Purity	Germ	PLS [‡]	Seed/pound	Seeds/m
Grass								
Rimrock	<i>Achnatherum hymenoides</i>	Indian ricegrass	MT PMC	99.83	99	98.80	155,000	98
Nezpar	<i>Achnatherum hymenoides</i>	Indian ricegrass	ID PMC	99.59	98	97.60	128,000	98
Pueblo	<i>Elymus elymoides</i>	bottlebrush squirreltail	CO PMC	92.05	92	84.69	180,000	98
Wapiti	<i>Elymus elymoides</i>	bottlebrush squirreltail	CO PMC	85.32	84	84.69	180,000	98
9019219	<i>Elymus elymoides</i>	bottlebrush squirreltail	MT PMC	-	-	~85	192,000	98
Sodar	<i>Elymus lanceolatus</i>	streambank wheatgrass	ID PMC	99.50	97	96.52	170,000	98
Bannock	<i>Elymus lanceolatus</i>	thickspike wheatgrass	ID PMC	99.15	94	93.20	145,000	98
Critana	<i>Elymus lanceolatus</i>	thickspike wheatgrass	MT PMC	-	-	~95	145,000	98
Salina	<i>Elymus salinus</i>	Salina wildrye	CO PMC	95.96	94	89.73	130,000	98
Copperhead	<i>Elymus trachycaulus</i>	slender wheatgrass	MT PMC	90.43	88	79.58	140,000	98
Pryor	<i>Elymus trachycaulus</i>	slender wheatgrass	MT PMC	98.25	89	87.4	140,000	98
San Luis	<i>Elymus trachycaulus</i>	slender wheatgrass	COPMC	98.48	80	78.78	140,000	98
Secar	<i>Elymus wawawaensis</i>	Snake River wheatgrass	MT PMC	98.15	93	91.3	155,000	98
E-45	<i>Elymus wawawaensis</i>	Snake River wheatgrass	UT-ARS	-	94	~90	130,460	98
Covar	<i>Festuca idahoensis</i>	sheep fescue	MT PMC	83.80	79	66.00	680,000	98
9092261	<i>Koeleria macrantha</i>	prairie Junegrass	CO PMC	74.60	70	52.22	685,000	98
9087539	<i>Koeleria macrantha</i>	prairie Junegrass	WRS	96.10	96	92.23	685,000	98
Trailhead	<i>Leynus cinereus</i>	basin wildrye	MT PMC	94.34	91	85.8	125,000	98
Magnar	<i>Leynus cinereus</i>	basin wildrye	ID PMC	99.40	91	90.45	125,000	98
Continental	<i>Leynus cinereus</i>	basin wildrye	UT-ARS	-	87	~80	106,075	98
L-46	<i>Leynus cinereus</i>	basin wildrye	UT-ARS	-	87	~80	123,706	98
Washoe	<i>Leynus cinereus</i>	basin wildrye	MT PMC	94.20	84	79.13	176,000	98
Rosana	<i>Pascopyrum smithii</i>	western wheatgrass	MT PMC	93.51	94	87.90	93,000	98
Rodan	<i>Pascopyrum smithii</i>	western wheatgrass	NDPMC	75.00	75	50.00	93,000	98
Sherman	<i>Poa secunda (ampla)</i>	big bluegrass	WRS	97.41	87	84.75	882,000	98
Opportunity	<i>Poa secunda (nevadensis)</i>	Nevada bluegrass	MT PMC	-	-	~90	890,000	98
High Plains	<i>Poa secunda (sandbergii)</i>	Sandberg bluegrass	MT PMC	-	-	~90	925,000	98
Anatone	<i>Pseudoroegneria spicata</i>	bluebunch wheatgrass	ID PMC	98.99	88	87.11	139,000	98
P-24	<i>Pseudoroegneria spicata</i>	bluebunch wheatgrass	UT-ARS	-	94	~90	101,339	98
Goldar	<i>Pseudoroegneria spicata</i>	bluebunch wheatgrass	IDPMC	99.60	92	91.63	139,000	98

[†] WRS Wind River Seed.

[‡] Pure-Live-Seed.

Appendix Table 1. The origin and seed lot specifics of 32 grasses, 24 forbs, and 16 shrubs in the Shell FEP replicated plots in Sublette County, near Pinedale, Wyoming. Planted October 19, 2005--Continued.

Accession	Scientific Name	Common Name	Source†	Purity	Germ	PLS‡	Seed/pound	Seeds/m
Grass--Continued								
P-19	<i>Pseudoroegneria spicata</i>	bluebunch wheatgrass	UT-ARS	-	95	~90	96,802	98
P-22	<i>Pseudoroegneria spicata</i>	bluebunch wheatgrass	UT-ARS	-	86	~80	93,996	98
Forbs								
9087541	<i>Achillea millefolium</i>	yarrow	WRS	96.83	92	89.08	4,500,000	98
Great Northern	<i>Achillea millefolium</i> var. <i>occidentalis</i>	western yarrow	MT PMC	93.91	98	92.00	4,500,000	98
9087542	<i>Castilleja applegatei</i>	wavyleaf Indian paintbrush	WRS	90.00	85	76.50	504,000	98
9087543	<i>Cleome serrulata</i>	Rocky Mtn beeplant	WRS	99.88	98	97.88	64,000	98
Antelope	<i>Dalea candida</i>	white prairie clover	MT PMC	99.65	97	96.70	278,000	98
9087544	<i>Erigeron speciosus</i>	Aspen fleabane	WRS	98.00	80	78.40	1,600,000	98
9087552	<i>Eriogonum umbellatum</i>	sulfurflower buckwheat	WRS	88.36	77	68.04	282,000	98
9087553	<i>Eurybia glauca</i>	gray aster	WRS	73.02	47	34.32	800,000	98
Maple Grove	<i>Linum lewisia</i>	prairie flax	ID PMC	99.18	91	90.25	278,000	98
Appar	<i>Linum perenne</i>	blue flax	ID PMC	99.97	98	97.97	286,690	98
9087548	<i>Oenothera pallida</i>	white evening primrose	WRS	99.56	81	80.64	700,000	98
9087549	<i>Oenothera speciosa</i>	showy evening primrose	WRS	99.32	78	78.46	800,000	98
Richfield	<i>Penstemon eatonii</i>	Eaton's penstemon	ID PMC	90.69	83	75.27	400,000	98
9087545	<i>Penstemon eatonii</i>	Eaton's penstemon	WRS	95.28	95	90.52	400,000	98
Old Works	<i>Penstemon eriantherus</i>	fuzzytongue penstemon	MT PMC	91.2	65	59.28	358,000	98
9087546	<i>Penstemon palmeri</i>	Palmer's penstemon	WRS	99.84	98	97.84	586,000	98
9087547	<i>Penstemon procerus</i>	littleflower penstemon	WRS	91.44	89	81.38	4,400,000	98
Clearwater	<i>Penstemon venustus</i>	Venus penstemon	ID PMC	82.19	94	77.26	1,090,000	98
9081632	<i>Phacelia hastata</i>	silverleaf phacelia	MT PMC	97.40	94	91.56	454,000	98
Stillwater	<i>Ratibida columnifera</i>	prairie coneflower	MT PMC	99.11	94	93.20	600,000	98
9087550	<i>Sphaeralcea coccinea</i>	scarlet globemallow	WRS	98.02	73	71.55	500,000	98
9087551	<i>Sphaeralcea munroana</i>	Munroes globemallow	WRS	98.00	73	71.54	750,000	98
9087554	<i>Symphyotrichum chilense</i> var. <i>chilense</i>	Pacific aster	WRS	86.21	94	81.04	800,000	98
9087540	<i>Vicia americana</i>	American vetch	WRS	95.74	87	83.29	32,833	98

† WRS Wind River Seed.

‡ Pure-Live-Seed.

Appendix Table 1. The origin and seed lot specifics of 32 grasses, 24 forbs, and 16 shrubs in the Shell FEP replicated plots in Sublette County, near Pinedale, Wyoming. Planted October 19, 2005--Continued.

Accession	Scientific Name	Common Name	Source [†]	Purity	Germ	PLS [‡]	Seed/pound	Seeds/m
Shrubs								
9087555	<i>Artemisia frigida</i>	fringed sagebrush	WRS	92.16	93	85.71	4,550,000	66
9087556	<i>Artemisia ludoviciana</i>	white sagebrush	WRS	96.84	95	92.00	3,750,000	66
9087557	<i>Artemisia nova</i>	black sagebrush	WRS	19.75	63	12.44	952,700	66
9087558	<i>Artemisia tridentata</i> ssp. <i>tridentata</i>	basin big sagebrush	WRS	21.85	79	17.26	2,358,000	66
9087559	<i>Artemisia tridentata</i> ssp. <i>wyomingensis</i>	Wyoming big sagebrush	WRS	18.08	74	13.38	2,400,000	66
Wytana	<i>Atriplex aptera</i>	fourwing saltbush	MT PMC	98.05	49	48.00	49,000	66
S.R.P.	<i>Atriplex canescens</i>	fourwing saltbush	ID PMC	98.85	48	47.45	49,000	66
9087561	<i>Atriplex confertifolia</i>	shadscale	WRS	94.61	47	44.47	60,585	66
9016134	<i>Atriplex gardnerii</i>	Gardner saltbush	MT PMC	-	-	~50	70,000	66
9087560	<i>Atriplex tridentata</i>	basin saltbush	WRS	98.33	61	60.00	65,000	66
9087563	<i>Grayia spinosa</i>	spiny hopsage	WRS	74.34	61	45.34	346,991	66
Open Range	<i>Krascheninnikovia lanata</i>	winterfat	MT PMC	-	-	~95	160,000	66
N.C.D. ^{¶§}	<i>Krascheninnikovia lanata</i>	winterfat	ID PMC	96.18	94	90.41	123,000	66
Hatch	<i>Krascheninnikovia lanata</i>	winterfat	CO PMC	38.29	90	34.46	112,000	66
Maybell	<i>Purshia tridentata</i>	bitterbrush	CO PMC	89.45	82	73.34	17,193	66
9087562	<i>Purshia tridentata</i>	bitterbrush	WRS	99.31	85	84.41	17,193	66

[†] WRS Wind River Seed.

[‡] Pure-Live-Seed.

[§] S.R.P. Snake River Plains.

[¶] N.C.D. Northern Cold Desert.