

EVALUATING SEEDING TECHNIQUES AND NATIVE PLANT ESTABLISHMENT IN THE PINEDALE ANTICLINE, WYOMING

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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, residential sprawl, and agriculture. The objective of the field studies is to evaluate the restoration of native plant species after disturbance. In October 2005, 72 entries of 50 native species were drill-seeded on a 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 hydro-seeded on disturbed areas adjacent to the plots. Cover and density were sampled in July 2006 and September 2007. The best performers in the replicated plots, determined by 2007 density counts, were 'Sodar' streambank wheatgrass, L-46 basin wildrye, Copperhead slender wheatgrass, Rocky Mountain beeplant, yarrow, 'Appar' blue flax, Richfield Eaton's penstemon, 'Wytana' and Snake River Plains fourwing saltbush, and Open Range and Northern Cold Desert winterfat. Establishment of the broadcast-seeded plots in the Bridger and Shell mixtures was 1.0 and 0.7 plants/ft², respectively, and of the drill-seeded plots 0.4 and 0.3 plants/ft², respectively. Establishment of the hydro-seeded Shell mix was 0.09 plants/ft². Low precipitation and high temperatures may have reduced establishment. On a second disturbed site, 25 shrub species were mechanically planted in single species replicated plots in October 2006. Density counts taken in 2007 showed extremely poor establishment. Short-term results provide recommendations for native grass restoration, however, low establishment of forbs and shrubs indicate more work is needed to develop plant materials and technology.

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 and Questar Exploration and Production Companies (hereby referred to as Shell and Questar), 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 working agreement, to date, encompasses two projects: the first tests plant materials in Field Evaluation Plantings (FEPs) in cooperation with Shell, and the second tests shrubs in cooperation with Questar (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, coarse soils with low 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), which will:

1. 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.
2. Test seeding methods, mixtures, and rates for adaptation and desired ecological diversity in the Pinedale Resource Area.
3. Distribute results to public and private land managers, as well as other interested individuals.

SITE DESCRIPTIONS

The two sites, Shell and Questar, are previously disturbed well-pads. The Shell project area is approximately 30 miles south of Pinedale, Wyoming (N ½ SW ¼ Section 10, T29N R107W), and the Questar project area is 9.5 miles south of Pinedale (SW ¼ SW ¼ Section 34, T33N R109W). The sites fall within the Cool Central Desertic Basins and Plateaus Major Land Resource Area (MLRA 34A) at elevations of 7,195 and 7,515 feet. Annual precipitation is approximately 10 inches, 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 5 inches 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 to calcareous shallow loam. The Questar site has moderately deep soils with root growth restricted by high amounts of lime or rock fragments at 10- to 12-inch depths. 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, bluebunch wheatgrass, and bottlebrush squirreltail. The forbs include aster, buckwheat, clover, evening primrose, fleabane, and phlox.

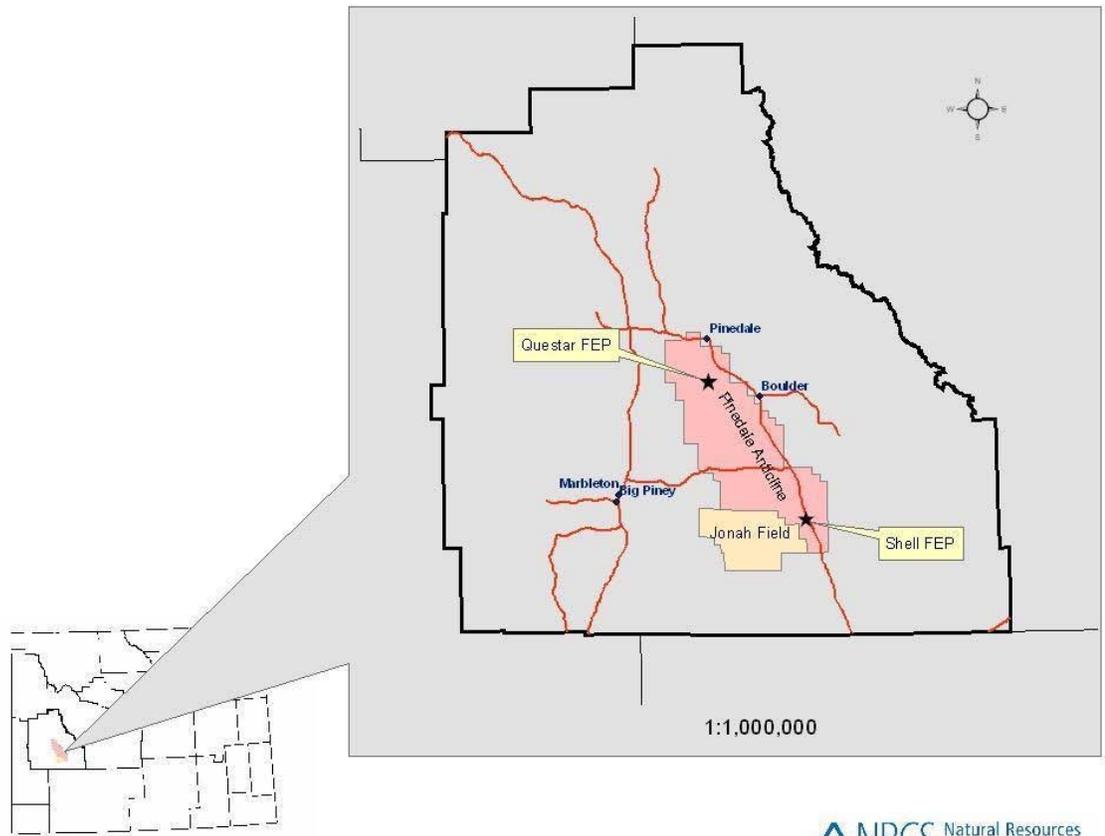


Fig. 1. Locational map of the Shell and Questar Field Evaluation Plantings in Sublette County, near Pinedale, Wyoming.



Shrub cover is dominated by Wyoming big sagebrush with minor components of other shrubs, including green and rubber rabbitbrush, Gardner’s saltbush, and winterfat. The potential total annual production (air-dry weight) ranges from 350 lb/acre in unfavorable years up to 1,500 lb/acre in favorable years.

METHODS AND MATERIALS

Shell. The 4.5-acre site was disturbed in 2002 and an oil and gas well-pad was constructed. Approximately 6 inches 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.

Adaptation 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 (tables 1-3). Plots were 4 feet by 20 feet (80 ft²), and the 72 entries were dormant-seeded in the fall of 2005 as monocultures using a Kincaid Precision Cone-seeder. Two seeding mixtures, Bridger and Shell (see tables 4 and 5 for species composition), were tested on adjacent plots. Each mixture was seeded with a Truax drill (1-acre plots) and an ATV-mounted broadcast seeder (0.5-acre plots).

Table 1. Mean values generated from ANOVA of the 2007 data for density, height, vigor, and relative stand establishment of 32 grass accessions seeded in replicated plots at the Shell Field Evaluation Planting near Pinedale, Wyoming--Means followed by the same letter are not significantly different determined by LSD (P<0.05).

Accession/Common Name	Scientific Name	Plants/ft ^{2†}	Height (in)	Vigor‡	Stand‡
Sodar streambank wheatgrass	<i>Elymus lanceolatus</i>	4.30 a	4.35 bcdefg	4.00 abcd	5.34 ab
L-46 basin wildrye	<i>Leymus cinereus</i>	4.26 a	5.43 abc	3.75 abc	3.84 a
Copperhead slender wheatgrass	<i>Elymus trachycaulus</i>	3.87 ab	3.60 efgh	3.50 ab	3.97 a
Continental basin wildrye	<i>Leymus cinereus</i>	3.67 abc	5.10 abcd	4.00 abcd	5.08 ab
P-24 bluebunch wheatgrass	<i>Pseudoroegneria spicata</i>	3.30 abcd	4.98 abcde	4.25 abcde	5.81 abc
San Luis slender wheatgrass	<i>Elymus trachycaulus</i>	2.61 abcdef	6.10 a	4.00 abcd	5.81 abc
Critana thickspike wheatgrass	<i>Elymus lanceolatus</i>	2.56 abcdef	4.85 abcde	4.00 abcd	5.15 ab
Bannock thickspike wheatgrass	<i>Elymus lanceolatus</i>	2.51 abcdefg	4.73 abcdef	4.00 abcd	5.45 ab
Pryor slender wheatgrass	<i>Elymus trachycaulus</i>	2.50 abcdefg	4.35 bcdefg	4.75 abcdef	6.18 bcd
Magnar basin wildrye	<i>Leymus cinereus</i>	2.36 bcdefgh	5.10 abcd	5.00 bcdef	6.59 bcdef
Anatone bluebunch wheatgrass	<i>Pseudoroegneria spicata</i>	2.29 bcdefgh	5.23 abc	5.25 bcdefg	7.30 cdefg
Washoe basin wildrye	<i>Leymus cinereus</i>	2.06 cdefgh	5.10 abcd	5.50 cdefgh	6.59 bcdef
P-19 bluebunch wheatgrass	<i>Pseudoroegneria spicata</i>	1.99 defghi	4.98 abcde	6.50 fghi	6.76 bcdef
Rosana western wheatgrass	<i>Pascopyrum smithii</i>	1.89 defghij	3.35 fghi	6.50 fghi	6.54 bcdef
Goldar bluebunch wheatgrass	<i>Pseudoroegneria spicata</i>	1.55 efghijk	4.85 abcde	5.00 bcdef	6.67 bcdef
P-22 bluebunch wheatgrass	<i>Pseudoroegneria spicata</i>	1.39 efghijkl	3.60 efgh	6.00 efghi	8.54 ghi
9019219 bottlebrush squirreltail	<i>Elymus elymoides</i>	1.26 efghijkl	4.85 abcde	3.00 a	6.30 bcde
Salina wheatgrass	<i>Elymus salinus</i>	1.25 fghijkl	4.10 cdefgh	6.25 fghi	7.58 defgh
Rodan western wheatgrass	<i>Pascopyrum smithii</i>	1.11 ghijklm	4.60 bcdef	4.25 abcde	7.79 efghi
Trailhead basin wildrye	<i>Leymus cinereus</i>	1.03 hijklm	5.60 ab	3.50 ab	7.02 bcdefg
E-45 Snake River wheatgrass	<i>Elymus wawawaensis</i>	0.88 ijklmn	3.35 fghi	7.50 i	7.83 efghi
Secar Snake River wheatgrass	<i>Elymus wawawaensis</i>	0.78 jklmno	4.85 abcde	5.75 defghi	7.76 defghi
Nezpar Indian ricegrass	<i>Achnatherum hymenoides</i>	0.65 klmnop	4.85 abcde	5.25 bcdefg	8.29 ghi
Sherman big bluegrass	<i>Poa secunda (P. ampla)</i>	0.58 klmnop	4.10 cdefgh	6.00 efghi	8.26 ghi
Pueblo bottlebrush squirreltail	<i>Elymus elymoides</i>	0.55 lmnop	3.60 defghi	6.00 efghi	8.06 fghi
9092261 prairie Junegrass	<i>Koeleria macrantha</i>	0.38 mnop	4.43 bcdefg	6.25 fghi	8.51 ghi
Rimrock Indian ricegrass	<i>Achnatherum hymenoides</i>	0.36 mnop	4.60 bcdef	6.50 fghi	8.76 hi
High Plains Sandberg bluegrass	<i>Poa secunda (P. sandbergii)</i>	0.32 mnop	2.98 ghij	7.00 ghi	8.29 ghi
Wapiti bottlebrush squirreltail	<i>Elymus elymoides</i>	0.31 mnop	2.10 ij	7.50 i	8.54 ghi
Opportunity Nevada bluegrass	<i>Poa secunda (P. nevadensis)</i>	0.20 nop	2.85 hij	7.25 hi	9.00 i
9087539 prairie Junegrass	<i>Koeleria macrantha</i>	0.19 op	1.85 j	6.25 fghi	9.00 i
Covar sheep fescue	<i>Festuca ovina</i>	0.13 p	2.10 ij	7.00 ghi	8.76 hi

† Seeding rate 30 pure-live-seeds/ft²; ‡ Rated 1-9 with 1 best.

Table 2. Mean values generated from ANOVA of the 2007 data for density, height, vigor, and relative stand establishment of 24 forb accessions seeded in replicated plots at the Shell Field Evaluation Planting near Pinedale, Wyoming--Means followed by the same letter are not significantly different determined by LSD (P<0.05).

Accession/Common Name	Scientific Name	Plants/ft ^{2†}	Height (in)	Vigor‡	Stand‡
9087543 Rocky Mountain beeplant	<i>Cleome serrulata</i>	2.54 a	13.50 a	3.50 ab	4.00 a
9087541 native yarrow	<i>Achillea millefolium</i>	1.29 b	1.85 cde	6.75 cdefg	8.25 def
Appar blue flax	<i>Linum perenne</i>	0.75 bc	0.75 def	7.25 cdefg	7.25 bc
Richfield Eaton's penstemon	<i>Penstemon eatonii</i>	0.71 bc	1.87 cd	5.00 abc	6.75 b
Old Works fuzzytongue penstemon	<i>Penstemon eriantherus</i>	0.50 bc	1.25 cdef	5.50 bcde	6.75 b
Maple Grove prairie flax	<i>Linum lewisia</i>	0.33 c	2.88 bc	5.75 bcdef	8.00 cde
9087545 Eaton's penstemon	<i>Penstemon eatonii</i>	0.29 c	1.00 def	5.25 bcd	7.50 bcd
9087553 gray aster	<i>Eurybia glauca</i>	0.25 c	2.75 bc	5.00 abc	8.50 ef
9087546 Palmer penstemon	<i>Penstemon palmeri</i>	0.21 c	4.00 b	2.75 a	7.00 b
9081632 silverleaf phacelia	<i>Phacelia hastata</i>	0.09 c	0.75 def	8.50 g	8.75 ef
9087549 showy evening primrose	<i>Oenothera speciosa</i>	0.04 c	0.13 ef	8.00 fg	9.00 f
Stillwater prairie coneflower	<i>Ratibida columnifera</i>	0.04 c	1.00 def	7.50 defg	9.00 f
9087540 American vetch	<i>Vicia americana</i>	0.04 c	0.25 def	8.50 g	9.00 f
Great Northern western yarrow	<i>Achillea millefolium</i> var. <i>occidentalis</i>	0	0	0	0
9087542 wavyleaf Indian paintbrush	<i>Castilleja applegatei</i>	0	0	0	0
Antelope white prairie clover	<i>Dalea candida</i>	0	0	0	0
9087544 aspen fleabane	<i>Erigeron speciosus</i>	0	0	0	0
9087552 sulfurflower buckwheat	<i>Eriogonum umbellatum</i>	0	0	0	0
9087548 pale evening primrose	<i>Oenothera pallida</i>	0	0	0	0
9087547 littleflower penstemon	<i>Penstemon procerus</i>	0	0	0	0
Clearwater Venus penstemon	<i>Penstemon venustus</i>	0	0	0	0
9087550 scarlet globemallow	<i>Sphaeralcea coccinea</i>	0	0	0	0
9087551 Munroe's globemallow	<i>Sphaeralcea munroana</i>	0	0	0	0
9087554 Pacific aster	<i>Symphotrichum chilense</i> var. <i>chilense</i>	0	0	0	0

† Seeding rate 30 pure-live-seeds/ft²; ‡ Rated 1-9 with 1 best.

Table 3. Mean values generated from ANOVA of the 2007 data for density, height, vigor, and relative stand establishment of 16 shrub accessions seeded in replicated plots at the Shell Field Evaluation Planting near Pinedale, Wyoming--Means followed by the same letter are not significantly different determined by LSD (P<0.05).

Accession/Common Name	Scientific Name	Plants/ft ^{2†}	Height (in)	Vigor‡	Stand‡
Wytana fourwing saltbush	<i>Atriplex aptera</i>	0.58 a	7.00 ab	4.23 ab	5.50 a
Snake River Plains fourwing saltbush	<i>Atriplex canescens</i>	0.34 b	9.50 a	2.75 a	5.00 a
Northern Cold Desert winterfat	<i>Krascheninnikovia lanata</i>	0.17 bc	4.75 bcd	5.00 abc	9.00 b
Open Range winterfat	<i>Krascheninnikovia lanata</i>	0.13 bc	4.00 bcde	4.50 abc	7.75 b
9087557 black sagebrush	<i>Artemisia nova</i>	0.13 bc	3.00 cdef	6.25 bcd	8.75 b
9087558 basin big sagebrush	<i>Artemisia tridentata</i> ssp. <i>tridentata</i>	0.08 c	6.75 ab	4.75 abc	8.50 b
Hatch winterfat	<i>Krascheninnikovia lanata</i>	0.08 c	4.00 bcde	5.00 abc	8.00 b
9016134 Gardner's saltbush	<i>Atriplex falcata</i> (<i>A. gardnerii</i>)	0.04 c	5.25 bc	4.25 ab	8.00 b
9087560 basin saltbush	<i>Atriplex tridentata</i>	0.04 c	2.75 cdef	6.50 bcd	9.00 a
9087555 fringed sagewort	<i>Artemisia frigida</i>	0	0	0	0
9087556 prairie sagewort	<i>Artemisia ludoviciana</i>	0	0	0	0
9087559 Wyoming big sagebrush	<i>Artemisia tridentata</i> ssp. <i>wyomingensis</i>	0	0	0	0
9087561 shadscale saltbush	<i>Atriplex confertifolia</i>	0	0	0	0
9087563 spiny hopsage	<i>Grayia spinosa</i>	0	0	0	0
Maybell antelope bitterbrush	<i>Purshia tridentata</i>	0	0	0	0
9087562 antelope bitterbrush	<i>Purshia tridentata</i>	0	0	0	0

† Seeding rate 20 pure-live-seeds /ft²; ‡ Rated 1-9 with 1 best.

Table 4. The species composition and seeding rates of the Bridger Mixture at the Shell Field Evaluation Planting near Pinedale, Wyoming.

Common Name	Scientific Name	Seeds	Mix	PLS [†]	Seeding Rate [†]	Drill Rate [†]	Broadcast Rate [†]
		lb	%	%	lb/acre	seeds/ft ²	seeds/ft ²
Pryor slender wheatgrass	<i>Elymus trachycaulus</i>	95,000	12.8	87.44	2.3	5	10
Critana thickspike wheatgrass	<i>Elymus lanceolatus</i>	145,000	12.8	~90.00	1.5	5	10
Rosana western wheatgrass	<i>Pascopyrum smithii</i>	93,000	12.8	87.90	2.3	5	10
High Plains Sandberg bluegrass	<i>Poa secunda (P. sandbergii)</i>	925,000	12.8	~80.00	0.25	5	10
Rimrock Indian ricegrass	<i>Achnatherum hymenoides</i>	155,000	12.8	98.83	1.4	5	10
Trailhead basin wildrye	<i>Leymus cinereus</i>	125,000	7.7	85.85	1.0	3	6
Great Northern western yarrow	<i>Achillea millefolium var. occidentalis</i>	4,500,000	5.1	~90.00	0.02	2	4
Stillwater prairie coneflower	<i>Ratibida columnifera</i>	600,000	5.1	93.16	0.15	2	4
Maple Grove prairie flax	<i>Linum lewisii</i>	278,000	5.1	90.25	0.31	2	4
Silverleaf phacelia	<i>Phacelia hastata</i>	454,000	5.1	91.57	0.19	2	4
Scarlet globemallow	<i>Sphaeralcea coccinea</i>	500,000	2.6	71.56	0.17	1	2
Wytana fourwing saltbush	<i>Atriplex aptera</i>	49,000	1.3	48.05	0.45	0.5	1
Open Range winterfat	<i>Krascheninnikovia lanata</i>	352,000	1.3	~90.00	0.06	0.5	1
Wyoming big sagebrush	<i>Artemisia tridentata ssp. wyomingensis</i>	2,400,000	1.3	13.38	0.01	0.5	1
Fringed sagewort	<i>Artemisia frigida</i>	4,550,000	1.3	85.71	0.005	0.5	1
Totals: 15 species		-	99.9	-	10	39	78

[†] Pure Live Seed.

Table 5. The species composition and seeding rates of the Shell Mixture at the Shell Field Evaluation Planting near Pinedale, Wyoming.

Common Name	Scientific Name	Seeds	Mix	PLS [†]	Seeding Rate [†]	Drill Rate [†]	Broadcast Rate [†]
		lb	%	%	lb/acre	seeds/ft ²	seeds/ft ²
Wyoming big sagebrush	<i>Artemisia tridentata ssp. wyomingensis</i>	2,500,000	41.50	5.269	0.50	28.70	57.40
Sandberg bluegrass	<i>Poa secunda (P. sandbergii)</i>	925,000	30.71	10.539	1.00	21.24	42.48
Fringed sagewort	<i>Artemisia frigida</i>	4,536,000	7.53	0.530	0.05	5.21	10.42
Rydberg's penstemon	<i>Penstemon rydbergii</i>	4,400,000	7.30	0.525	0.05	5.05	10.10
Indian ricegrass	<i>Achnatherum hymenoides</i>	141,000	4.68	10.541	1.00	3.245	6.48
Native yarrow	<i>Achillea millefolium</i>	2,770,000	4.60	0.529	0.05	3.18	6.36
Winterfat – bearded	<i>Krascheninnikovia lanata</i>	56,700	1.88	10.537	1.00	1.30	2.60
Fourwing saltbush	<i>Atriplex canescens</i>	52,000	0.86	5.268	0.50	0.60	1.20
Scarlet globemallow	<i>Sphaeralcea coccinea</i>	500,000	0.50	3.096	0.03	0.34	0.68
Silvery lupine	<i>Lupinus argenteus</i>	13,000	0.43	10.544	1.00	0.30	0.60
Totals: 10 species		-	99.99	-	5.18	69.16	138.16

[†] Pure Live Seed.

Following planting of the broadcast-seeded plots, the area was roughened with a wooden pallet pulled behind the ATV. In addition, the Shell mixture was hydro-seeded to a 1-acre plot on a smooth slope in a one-step mulch application. Scientific plant nomenclature standardized by the USDA NRCS Plants Database (USDA, 2008a).

Questar. The 0.69-acre site was disturbed in 2005 and site preparation was conducted in 2006. The area was ripped and reshaped prior to topsoil placement to assure no compaction layer existed. Weeds were controlled prior to planting with an English harrow and chemical application of glyphosate at 2 quarts/acre. Soil was packed for firmness so no more than a 1/8-inch imprint was left when walking over the site (USDA, 2007b). Substantive debris that could prevent consistent seeding, such as large rock or sagebrush litter, was removed. The study site was fenced with an 8-foot deer-proof fence prior to planting to prevent grazing by wildlife and domestic livestock.

On October 10, 2006, a total of 116 plots were seeded with 29 shrub entries of 25 species in a randomized complete block design with four replications (table 6). Three, single-row belt seeders were used to plant shrub entries in 4-row plots, 8 ft wide by 20 ft long (160 ft²). The shrub seeding rate was dependent on seed size and ranged from 10 to 40 pure-live-seed per foot. Seeding depth ranged from nearly surficial to 1 inch, depending on seed size. Five bluebunch wheatgrass varieties were broadcast seeded as a small observation area on the east end of the study site. The 0.23-acre grass plots were planted at 40 pure-live-seeds/ft².



Shell replicated plots, October 2005

According to the PRACWA, evaluations will be conducted for a minimum of 5 years post-planting on the Shell site and 15 years on the Questar site. In the event of a total stand failure (2 consecutive years with no establishment of planted species), replanting will be considered based on site and climatic conditions, as well as other factors. If there is partial stand failure (a large portion of plot area with no establishment), replanting with alternative or known adapted species will be considered.

Table 6. The native shrub species and seeding rates of the Questar Field Evaluation Planting, established on October 11, 2006, near Pinedale, Wyoming.

Accession/Common Name	Scientific Name	Pure-Live-Seed	Seeds	Seeds	Seeding Depth
		%	lb	ft	in
9087655 Saskatoon serviceberry	<i>Amelanchier alnifolia</i>	70.52	82,000	20	0.5
9087656 Utah serviceberry	<i>Amelanchier utahensis</i>	86.24	25,800	20	0.5
9087658 fringed sagewort	<i>Artemisia frigida</i>	87.65	4,550,000	40	<0.5
9087659 prairie sagewort	<i>Artemisia ludoviciana</i>	88.92	3,750,000	40	<0.5
9087660 black sagebrush	<i>Artemisia nova</i>	9.16	952,700	40	<0.5
9087661 basin big sagebrush	<i>Artemisia tridentata</i> ssp. <i>tridentata</i>	17.64	2,358,000	40	<0.5
9087663 Wyoming big sagebrush	<i>Artemisia tridentata</i> ssp. <i>wyomingensis</i>	23.67	2,400,000	40	<0.5
9087662 mountain big sagebrush	<i>Artemisia tridentata</i> ssp. <i>vaseyana</i>	8.75	1,360,000	40	<0.5
9087657 silver sagebrush	<i>Artemisia cana</i>	18.40	850,000	40	<0.5
Wytana fourwing saltbush	<i>Atriplex aptera</i>	32.20	49,000	20	0.5
Snake River Plains fourwing saltbush	<i>Atriplex canescens</i>	51.40	49,000	20	0.5
9016134 Gardner saltbush	<i>Atriplex falcata</i> (<i>A. gardnerii</i>)	29.45	70,000	20	0.5
9087664 curlleaf mountain mahogany	<i>Cercocarpus ledifolius</i>	55.92	51,900	20	0.5
9087665 alderleaf mountain mahogany	<i>Cercocarpus montanus</i>	82.00	47,406	20	0.5
9087666 rubber rabbitbrush	<i>Ericameria nauseosus</i>	16.83	693,000	40	<0.5
Open Range winterfat	<i>Krascheninnikovia lanata</i>	96.47	111,000	20	0.5
Northern Cold Desert winterfat	<i>Krascheninnikovia lanata</i>	74.99	111,000	20	0.5
9087667 chokecherry	<i>Prunus virginiana</i>	95.89	4,790	10	1.0
Maybell antelope bitterbrush	<i>Purshia tridentata</i>	65.69	15,400	20	0.5
9087668 antelope bitterbrush	<i>Purshia tridentata</i>	95.67	15,400	20	0.5
9087669 skunkbush sumac	<i>Rhus trilobata</i>	87.03	20,300	20	0.5
9087670 golden currant	<i>Ribes aureum</i>	77.60	233,000	20	0.5
9087671 wax currant	<i>Ribes cereum</i>	59.48	251,000	20	0.5
9087672 Wood's rose	<i>Rosa woodsii</i>	87.39	50,000	20	0.5
Prospectors common snowberry	<i>Symphoricarpos albus</i>	75.49	76,000	20	0.5
9087673 western snowberry	<i>Symphoricarpos occidentalis</i>	78.27	75,033	20	0.5
Trapper western snowberry	<i>Symphoricarpos occidentalis</i>	96.83	75,033	20	0.5
9087674 mountain snowberry	<i>Symphoricarpos oreophilus</i>	85.79	54,738	20	0.5

If stand failure is intermittent or limited to occasional species or replications, those completing the evaluation will recommend appropriate action. In all cases, weed control will be conducted on the entire plot area. The criteria for a site to be considered successful in reclamation for the chosen well-pad will be based on site stability, seeded species, and any additional criteria outlined in the PRACWA. If areas of bare ground larger than 30 ft² exist after the 5-year evaluation, or the site is considered unstable, replanting may be required.



Shell broadcast-seeded plots, October 2005.



Shell drill-seeded plots, October 2005

Questar replicated plots, October 2006

EVALUATIONS

Shell 2006. Treatments were evaluated on July 5 and 6. At that time, a total of only 1.25 inches precipitation was recorded for the previous 8 months. Evaluation variables included a relative rating of plant vigor and stand establishment, height in inches, percentage canopy cover and/or plant counts, and photo points. The replicated plots were sampled in two different ways,

depending on establishment. Plots deemed adequate in emergence were rated for estimated percentage canopy cover in a 36 ft² area. Plots with poor emergence received a plant count of all four rows in the 80 ft² area. Additional comments were noted on the presence of animal and bird life, grazing or browsing activity, weeds, and species contamination due to mechanical carry-over of seed.

In the broadcast- and hydro-seeded mixture treatments, plants were counted in 20 plots, each 1.92 ft². In the drill-seeded mixture treatments, plants were counted in 20 plots, each 2.69 ft². Plant height in inches was recorded, as well as relative ratings on vigor and stand establishment.

Shell and Questar 2007. On September 11 and 12, several teams worked to evaluate the plots. At the time of the evaluation, a total of 3.51 inches precipitation was recorded for the previous 8 months. Evaluation factors included a relative rating of plant vigor and stand establishment, height in inches, plant counts, and photo points. In the Shell replicated plots, seeded plants were counted within 1 linear row-foot at three randomly chosen locations in each of the middle two rows for a total of six, 1-foot samples per treatment plot. Plant height measurements were taken from representative plants in each sample plot. Plant vigor and relative stand establishment were visually estimated for the entire plot. Additional comments were noted on items such as the presence of animal and bird life and grazing or browsing activity.

In the Shell broadcast-, drill-, and hydro-seeded mixture treatments, plant density was determined in 10 plots, each 9.62 ft². A relative rating of plant vigor and stand establishment, and height in inches were recorded. In the Questar planting, all plants in each plot were counted.

RESULTS

Shell Replicated Plots. Totals of 72 different plant entries were evaluated in the replicated plots, which included 32 grasses, 24 forbs, and 16 shrubs. The 2006 data suggested that performance depended upon species (data not shown). The analysis of variance of the 2007 data (SAS, 2006) showed establishment and survival measured by the number of plants per row-foot was different among grass accessions ($p \leq 0.0001$). Grass performance data is reported in table 1. Two accessions, Sodar streambank wheatgrass and L-46 basin wildrye, established with greater numbers compared to most of the other accessions. The establishment of these two species was not significantly different than seven other accessions, which were accessions of *Elymus lanceolatus*, *Elymus trachycaulis*, or *Pseudoroegneria spicata*. Considering a target of 20 plants per row-foot, the plant densities of the top nine species ranged from about 13% to 22% of a full stand (USDA, 2007a). The height of the grasses also differed among accessions ($p \leq 0.0001$). However, the grasses with the better establishment were not always the tallest, due more to their inherent growth form. Differences among accessions in vigor ratings ($p \leq 0.0001$) and relative stand establishment ratings ($p \leq 0.0001$) were more in line with density counts than height measurements.

It is difficult to compare plot establishment between years due to the different methods of evaluation (percentage canopy cover versus density). There may be an increase in establishment of the basin wildryes and several of the wheatgrasses (slender, thickspike, and western). The bluebunch entries were much the same. A decrease was observed in bluegrass, bottlebrush squirreltail, Indian ricegrass, prairie Junegrass, and sheep fescue.

The establishment of forbs and shrubs in 2006 was very low with an average of four and two plants per plot, respectively. The best performing forbs included Maple Grove prairie flax with 18 plants per plot, silverleaf phacelia with 16 plants per plot, Appar blue flax with 14 plants per plot, and Old Works fuzzytongue penstemon with 10 plants per plot. The best performing shrubs were Wytana and Snake River Plains fourwing saltbush at seven and five plants per plot, respectively. The five sagebrush entries established an average of less than one plant per plot. Fringed sagewort was not observed on-site. The forb and shrub stands rated moderately poor to very poor, and the vigor ratings were moderate to moderately poor. The forb and shrub plants were extremely short and most were less than 1 inch in height.

On October 11, 2006, in conjunction with the installation of the Questar FEP, a short field review was conducted on the Shell plots. The Jonah area received approximately 3.5 inches in the 2006 period and 5.15 inches in the 2007 period (fig. 2). The study site is extremely droughty, and plant growth and development continued to be minimal. Species to note in the replicated plots included Rocky Mountain beeplant (an annual wildflower that was tremendously successful at completing its reproductive cycle during the establishment year), Wytana and Snake River Plains fourwing saltbush, penstemons, flax, silverleaf phacelia, and primrose. The fourwing saltbush put on considerable growth since the July evaluation.

The analysis of variance (Statistix, 2007) of the 2007 data showed a substantial decline in more than 90% of the forb entries. The best performing forbs, as reported in table 2, were Rocky Mountain beeplant, native yarrow, and several penstemons. Thirteen entries were present in the sample area, with 9 entries noted outside the plots. Plant establishment was very low compared to the actual seeding rate, with an estimated stand of 0.3 plant/ft. The average vigor and stand rating was moderately poor and poor, respectively. Height was very short and averaged 1.8 inches. Showy evening primrose and scarlet globemallow were not observed on-site.

At least one cow and an antelope were discovered inside the fenced plot for an unknown amount of time, but it was assumed to be for less than 2 days. Several grass species were grazed and browse was noted in the fourwing saltbush, winterfat, flax, penstemon, yarrow, and not surprisingly, Antelope white prairie clover. Sage-grouse and rabbits were also noted as visitors to the plots.

The analysis of variance (Statistix, 2007) of the 2007 data showed Wytana fourwing saltbush as the best performer followed by Open Range and Northern Cold Desert winterfat (table 3). Eleven of the 16 species were present in the sample area, with five species noted outside the plots. Spiny hopsage was not observed on-site. Plant establishment was very low compared to the actual seeding rate, with an average 0.1 plant/ft. The average vigor and stand ratings were moderately poor and poor, respectively. Height was very short and averaged 3.8 inches.

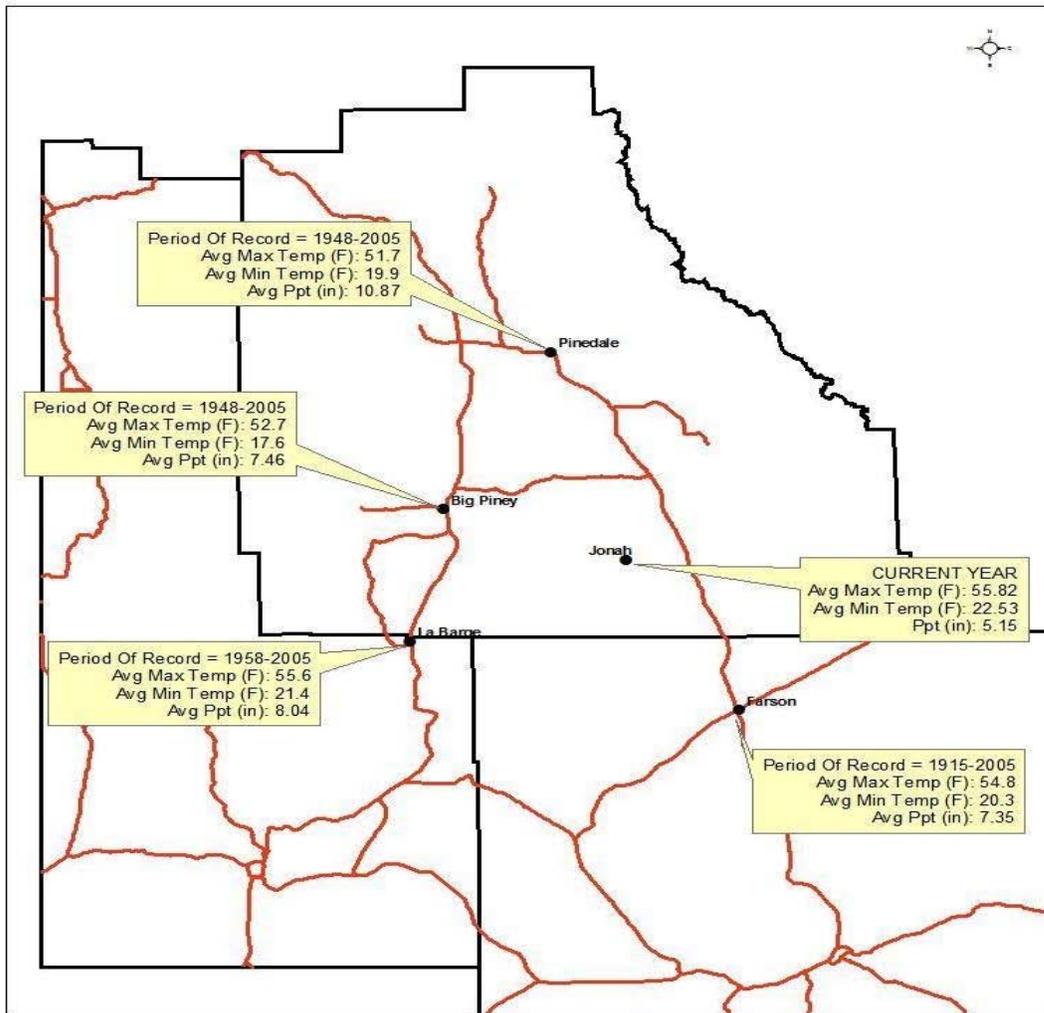


Fig. 2. Climate summaries for weather stations near the Shell and Questar Field Evaluation Plantings.



Shell replicated plots: Copperhead slender wheatgrass in 2006 (left) and 2007 (right).



Shell replicated plots: Rocky Mountain beeplant in July 2006 and October 2007.



Shell replicated plots: fourwing saltbush in July 2006 and October 2007.

Shell Mixture Plots.

Drill-Seeded. The two seed mixtures are composed differently in species richness, relative proportion of life forms, and seeding rate. The 15-species Bridger mix is 40% grass, 33% forb, and 27% shrub, and was seeded at a rate of 10.12 lb pure-live-seeds/acre (table 4). The 10-species Shell mix is 20% grass, 40% forb, and 40% shrub, and was seeded at a rate of 5.18 lb pure-live-seeds/acre (table 5). The Shell mix was extremely fluffy due to the chaffy conditioning of the winterfat and several of the sagebrushes.

In 2006, 40% of the Bridger mix species was present in the sampled plots of the 1-acre treatment (table 7). The species, in order of most to least frequency, 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%). Overall vigor was moderately poor and plant height was approximately 1 inch. An additional 27% of the species mix was present outside the sample plots at very low estimates of percentage basal cover. They included 'Critana' thickspike wheatgrass, Great Northern western yarrow, Maple Grove prairie flax, and Open Range winterfat. The remaining 40% of the species in the mix was not present and included fringed sagewort, High Plains Sandberg bluegrass, scarlet globemallow, Stillwater prairie coneflower, and 'Trailhead' basin wildrye.

In 2007, there was a 50% increase in the number of Bridger mix grass species and a 50% decrease in non-grass species (table 7). Of the species in the mix, 53% were present in the sampled area. The species, in order of most to least frequency, were Pryor slender wheatgrass and Trailhead basin wildrye (50%), Rimrock Indian ricegrass and Wytana fourwing saltbush (40%), Critana thickspike wheatgrass and Rosana western wheatgrass (30%), Open Range winterfat (20%), and High Plains Sandberg bluegrass (10%). Overall vigor was moderate and plant height was approximately 4 inches.

Fringed sagewort and silverleaf phacelia were present outside the sample area. The remaining 40% of the species in the mix was not present and included Great Northern western yarrow, Maple Grove prairie flax, Stillwater prairie coneflower, scarlet globemallow, and Wyoming big sagebrush.

In 2006, in the 1-acre treatment with the Shell mix, 50% of the species was present in the sample area (table 8). The species, in order of most to least frequency, were silvery lupine (30%), Wyoming big sagebrush (25%), Sandberg bluegrass (20%), Rimrock Indian ricegrass (15%), and winterfat (5%). Overall vigor was poor and plant height was approximately 1 inch. An additional 40% of the species in the mix was accounted for outside the sampled plots at very low estimates of percentage basal cover, including fringed sagewort, Rydberg's penstemon, and native yarrow. Silvery lupine was estimated at 13% basal cover outside the sampled plots. Scarlet globemallow was not observed in the treatment area.



Shell drill-seeded plots 2007: Bridger mixture (left) and Shell mixture (right).

In 2007, in the 1-acre treatment with the Shell Mix, 60% of species in the mix was present in the sample area (table 8). The species, in order of most to least frequency, are fourwing saltbush (70%), Wyoming big sagebrush (50%), Rimrock Indian ricegrass (30%), Sandberg bluegrass and winterfat (20%), and Rydberg's penstemon (10%). The total number of plants in the treatment declined approximately 50% from the previous year. Overall vigor was moderately fair and plant height was approximately 3 inches. The remaining 40% of the species in the mix not present included fringed sagewort, native yarrow, scarlet globemallow, and silvery lupine.

There was higher plant density in the Bridger mixture plots, with 44% fewer seeds planted per acre, compared to the Shell mixture. The proportion of life forms was unchanged in the drill-seeded plots of the shrub-dominated Shell mixture, but non-grass plant density declined by more than 40%--silvery lupine (*Lupinus argenteus*) was completely absent and Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) dropped 61%.

Broadcast-Seeded. Establishment in the treatment was erratic due to the fluffy nature of the seed mix and uneven flow through the seeder. In 2006, 33% of the species was present in the sampled area of the 0.5-acre treatment with the Bridger seed mix (table 9). The species, in order of most to least frequency, were Rimrock Indian ricegrass (30%), Pryor slender wheatgrass (25%), Wyoming big sagebrush (15%), Critana thickspike wheatgrass (10%), and High Plains Sandberg bluegrass (5%). The overall vigor was moderate and plant height was approximately 1 inch. An additional 27% of the species in the mix was 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 observed were fringed sagewort, Great Northern western yarrow, scarlet globemallow, Stillwater prairie coneflower, and Trailhead basin wildrye.

Table 7. The species performance of the drill-seeded Bridger mix at the Shell Field Evaluation Planting near Pinedale, Wyoming.

Accession/Common Name	Scientific Name	Plants/acre [†]		% Stand		Vigor [‡]		Height (in)	
		2006	2007	2006	2007	2006	2007	2006	2007
Rimrock Indian ricegrass	<i>Achnatherum hymenoides</i>	4048	2723	1.9	1.3	7	5	2	3
Pryor slender wheatgrass	<i>Elymus trachycaulus</i>	1619	3630	0.7	1.7	5	6	2	4
Rosana western wheatgrass	<i>Pascopyrum smithii</i>	5668	1361	2.6	0.6	5	5	2	3
Critana thickspike wheatgrass	<i>Elymus lanceolatus</i>	0	1815	0	0.8	-	6	0	4
Trailhead basin wildrye	<i>Leymus cinereus</i>	0	3176	0	2.4	-	5	0	3
High Plains Sandberg bluegrass	<i>Poa secunda (P. sandbergii)</i>	0	454	0	0.2	-	6	0	2
9081632 silverleaf phacelia	<i>Phacelia hastata</i>	810	0	0.9	0	5	-	0.5	0
Open Range winterfat	<i>Krascheninnikovia lanata</i>	0	908	0	4.2	5	4	0	3
Wytana fourwing saltbush	<i>Atriplex aptera</i>	810	1815	3.7	8.3	5	3	1	7
Wyoming big sagebrush	<i>Artemisia tridentata ssp. wyomingensis</i>	1619	0	7.4	0	3	-	0.5	0
Total:		14,574	15,881	0.85	0.93				

[†] Seeding rate 39 pure-live-seeds/ft² (10 PLS lb/acre); [‡] Rated 1-9 with 1 best.

Table 8. The species performance of the drill-seeded Shell mix at the Shell Field Evaluation Planting near Pinedale, Wyoming.

Common Name	Scientific Name	Plants/acre [†]		% Stand		Vigor [‡]		Height (in)	
		2006	2007	2006	2007	2006	2007	2006	2007
Sandberg bluegrass	<i>Poa secunda (P. sandbergii)</i>	5668	1361	0.6	0.2	5	8	1	0.5
Rimrock Indian ricegrass	<i>Achnatherum hymenoides</i>	3239	1815	2.3	1.3	5	5	3	3
Rydberg's penstemon	<i>Penstemon rydbergii</i>	0	454	0	0.2	-	5	0	0.5
silvery lupine	<i>Lupinus argenteus</i>	5668	0	43.0	0	5	-	0.5	0
winterfat	<i>Krascheninnikovia lanata</i>	810	908	1.4	1.6	5	5	3	6
fourwing saltbush	<i>Atriplex canescens</i>	0	4084	0	15.6	-	7	0	3
Wyoming big sagebrush	<i>Artemisia tridentata ssp. wyomingensis</i>	8097	3176	0.6	0.3	3	5	1	6
Total:		23,482	11,798	0.8	0.4				

[†] Seeding rate 69 pure live seeds/ft² (5.2 PLS lb/acre); [‡] Rated 1-9 with 1 best.

In 2007, 73% of the species was present in the sample area of the 0.5-acre treatment with the Bridger seed mix (table 9). The species, in order of most to least frequency, 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%). The total number of plants in this treatment was up nearly 50% from the previous year. Overall vigor was moderate and plant height was approximately 3 inches. The remaining 27% of the species in the mix not present included High Plains Sandberg bluegrass, Stillwater prairie coneflower, fringed sagewort, and scarlet globemallow.

In 2006, in the 0.42-acre treatment with the Shell seed mix, 60% of the species was present in the sample area (table 10). The species, in order of most to least frequency, were Wyoming big sagebrush (80%), Sandberg bluegrass (25%), winterfat (10%), and fourwing saltbush, Rimrock Indian ricegrass, and silvery lupine (5%). Overall vigor was moderately poor and plant height was approximately 1 inch. Native yarrow was found outside the sampled plots at a very low estimate of percentage basal cover. The remaining 30% of the species in the mix not observed were fringed sagewort, Rydberg's penstemon, and scarlet globemallow.

In 2007, in the 0.42-acre treatment with the Shell Mix, 40% of the species was present in the sample area (table 10). The species, in order of most to least frequency, were Sandberg bluegrass (90%), Wyoming big sagebrush (70%), and winterfat and fourwing saltbush (30%). Overall vigor was moderate and plant height was approximately 3 inches. The remaining 60% of the species in the mix not present included Rimrock Indian ricegrass, silvery lupine, fringed sagewort, Rydberg's penstemon, native yarrow, and scarlet globemallow.

The broadcast-seeded plots of both mixes achieved the highest plant densities, with the Bridger mix 31% greater than the Shell mix. Both of the broadcast-seeded densities were more than twice that of the drill-seeded densities. The original composition of the Bridger mix was maintained at slightly greater than 70% grass. The Shell mix broadcast plot, seeded 80% non-grass, is now composed of nearly 60% grass. The native plant community, as described in the Ecological Site Description, is most closely represented in the plot establishment of the Bridger mix.



Shell broadcast-seeded plots 2007: Bridger mixture (left) and Shell mixture (right).

Hydro-Seeded. In 2006, 33% of the species mix was present in the sample area of the 1-acre treatment with the Shell mix (table 11). The species, in order of most to least frequency, were winterfat (10%), and Sandberg bluegrass and Wyoming big sagebrush (5%). Overall vigor was average and plant height was approximately 2 inches. Fourwing saltbush, Rimrock Indian ricegrass, and silvery lupine were found outside the sampled plots at very low estimates of percentage basal cover. Fringed sagewort, Rydberg's penstemon, scarlet globemallow, and the native yarrow were not present. Due to the poor establishment, the area was hydro-seeded again in October 2006.

In 2007, 20% of the species mix was present in the 1-acre, reseeded treatment with the Shell mix (table 11). The species frequency was Rimrock Indian ricegrass (30%) and winterfat (10%). The estimated percentage stand establishment was down slightly compared to the first hydro-seeding. Overall vigor was very poor and plant height was approximately 3 inches. 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.

The hydro-seeding method was the least successful, and in fact, was 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).



Shell hydro-seeding with Shell seed mixture: December 2005 (left) and October 2007 (right).

The natural terrain of the site is rolling and the percentage slope mostly ranges from less than 1 to 8, with up to 12% slope in portions of the hydro-seeded 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.

Questar Replicated Shrub Plots. Spring monitoring in 2007 showed traces of initial emergence from Gardner's saltbush, chokecherry, curlleaf and alderleaf mountain mahogany, Prospector common snowberry, Open Range and Northern Cold Desert winterfat, Snake River fourwing saltbush, 9087673 western snowberry, and 'Maybell' antelope bitterbrush. The second accession of bitterbrush, 9087668, had a high level of emergence in all four plots. All bluebunch wheatgrass plots showed an initial level of emergence with 'Goldar' showing a slight advantage over the other entries.

Density counts taken in September indicate the ongoing drought severely impacted plant survival. Only three of the 25 shrub species (12%) were counted, as shown in table 12. Woody species were present in 13 of 116 plots (11%). There was considerable predation on the bitterbrush by rodents in addition to an aggressive Russian thistle infestation. Very few bluebunch wheatgrass could be found in the fall.

In spring 2008, the Questar site will be monitored for shrub establishment. The difficulty associated with long-term establishment of Wyoming big sagebrush may require use of a higher seeding rate (Schuman and Belden, 2002). A determination will be made whether or not to continue or replant in the near future.

Table 9. The species performance of the broadcast-seeded Bridger mix at the Shell Field Evaluation Planting near Pinedale, Wyoming.

Common Name	Scientific Name	Plants/acre [†]		% Stand		Vigor [‡]		Height (in)	
		2006	2007	2006	2007	2006	2007	2006	2007
High Plains Sandberg bluegrass	<i>Poa secunda (P. sandbergii)</i>	1134	0	0.3	0	5	-	1	0
Rimrock Indian ricegrass	<i>Achnatherum hymenoides</i>	7941	5899	1.8	1.4	7	7	1	2
Pryor slender wheatgrass	<i>Elymus trachycaulus</i>	6806	6353	1.6	1.5	5	6	3	2
Rosana western wheatgrass	<i>Pascopyrum smithii</i>	0	4991	0	1.2	-	7	0	2
Critana thickspike wheatgrass	<i>Elymus lanceolatus</i>	4538	13,613	1.0	3.1	5	7	3	4
Trailhead basin wildrye	<i>Leymus cinereus</i>	0	908	0	0.4	-	8	0	2
Great Northern western yarrow	<i>Achillea millefolium var. occidentalis</i>	0	908	0	0.4	-	7	0	2
Maple Grove prairie flax	<i>Linum lewisia</i>	0	1815	0	1.0	-	7	0	3
silverleaf phacelia	<i>Phacelia hastata</i>	0	1815	0	1.0	-	4	0	1
Open Range winterfat	<i>Krascheninnikovia lanata</i>	0	454	0	1.0	-	5	0	2
Wytana fourwing saltbush	<i>Atriplex aptera</i>	0	2723	0	6.3	-	5	0	4
Wyoming big sagebrush	<i>Artemisia tridentata ssp. wyomingensis</i>	3403	4084	7.8	9.4	3	5	1	5
Total:		22,822	43,563	0.7	1.3				

[†] Seeding rate 78 pure live seeds/ft² (20 PLS lb/acre); [‡] Rated 1-9 with 1 best.

Table 10. The species performance of the broadcast-seeded Shell mix at the Shell Field Evaluation Planting near Pinedale, Wyoming.

Common Name	Scientific Name	Plants/acre [†]		% Stand		Vigor [‡]		Height (in)	
		2006	2007	2006	2007	2006	2007	2006	2007
Sandberg bluegrass	<i>Poa secunda (P. sandbergii)</i>	6806	17,696	0.4	1.0	5	7	1	0.5
Rimrock Indian ricegrass	<i>Achnatherum hymenoides</i>	1134	0	0.4	0	7	-	1	0
silvery lupine	<i>Lupinus argenteus</i>	1134	0	4.3	0	5	-	1	0
fourwing saltbush	<i>Atriplex canescens</i>	1134	1815	2.2	3.5	5	4	2	3
winterfat	<i>Krascheninnikovia lanata</i>	2269	1815	2.0	1.6	5	5	<1	5
Wyoming big sagebrush	<i>Artemisia tridentata ssp. wyomingensis</i>	22,688	8621	0.9	0.3	3	4	1	4
Total:		35,165	29,948	0.6	0.5				

[†] Seeding rate 138 pure live seeds/ft² (10.4 PLS lb/acre); [‡] Rated 1-9 with 1 best.

Table 11. The species performance of the hydro-seeded Shell mix at the Shell Field Evaluation Planting near Pinedale, Wyoming.

Common Name	Genus & Species	Plants/acre [†]		% Stand		Vigor [‡]		Height (in)	
		2006	2007	2006	2007	2006	2007	2006	2007
Sandberg bluegrass	<i>Poa secunda (P. sandbergii)</i>	1134	0	0.06	0	5	-	1	0
Rimrock Indian ricegrass	<i>Achnatherum hymenoides</i>	0	3630	0	1.3	-	9	0	3
winterfat	<i>Krascheninnikovia lanata</i>	2269	454	2	0.4	5	8	1	4
Wyoming big sagebrush	<i>Artemisia tridentata ssp. wyomingensis</i>	1134	0	0.05	0	3	-	3	0
Total:		4,537	4,084	0.08	0.07				

[†] Seeding rate 138 pure live seeds/ft² (10.4 PLS lb/acre); [‡] Rated 1-9 with 1 best.

Table 12. The 2007 performance of the replicated shrub plots at the Questar Field Evaluation Planting near Pinedale, Wyoming.

Accession/Common Name	Scientific Name	Total plants/160 ft ² plot
9087668 antelope bitterbrush	<i>Purshia tridentata</i>	75
Open Range winterfat	<i>Krascheninnikovia lanata</i>	3
Northern Cold Desert winterfat	<i>Krascheninnikovia lanata</i>	3
9087671 wax currant	<i>Ribes cereum</i>	1



Questar replicated plot 2007: antelope bitterbrush in May (left) and October (right).

DISCUSSION

The demand for affordable energy to fuel our nation's 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. 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/lb 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 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 on the Shell site indicate accessions, currently developed, that 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, 2008b). Although forb establishment was below expectations, *C. serrulata*, *A. millefolium*, *L. perenne*, *P. eatonii*, *P. eriantherus*, and *P. hastata* showed the greatest promise for providing diversity of this functional group important to wildlife habitat. Similarly, shrub establishment was disappointing with only four of 16 species important to wildlife established after two growing seasons. They were *A. aptera*, *A. canescens*, two accessions of *K. lanata*, and *A. tridentata* ssp. *tridentata*. Although establishment was 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 was 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 and Questar trials 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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