Establishing shrubs to achieve bond release on Colorado coal mines – A demonstration of methods

Final Report

Prepared by:

Mark W. Paschke
Department of Forest, Rangeland and Watershed Stewardship
Colorado State University
Fort Collins, CO 80523-1478

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EXECUTIVE SUMMARY

Two main limitations to shrub establishment at Colorado reclaimed mines are browsing and competition from aggressive herbaceous species. The goal of this study was to evaluate methods for enhancing shrub establishment after mining. To meet this goal, study plots were established in 2000 to evaluate reclamation techniques to overcome these obstacles. The experimental design used large-scale demonstration plots that were constructed with normal reclamation equipment to test shrub establishment techniques that have commercial practicality. Plots were established at three surface mines (Colowyo, Trapper and Seneca) in northwestern Colorado. Several treatments were tested to evaluate shrub establishment on spoil material, 15 cm of topsoil, and 46 cm of topsoil. Plots were strip seeded with native seed mixes, alternating rows of herbaceous species and shrub species. Native shrub transplants were planted at one mine. Half of each treatment was fenced to prevent browsing.

In 2007, the vegetation in each test plot was evaluated to determine the relative success of the various treatments for establishing shrubs. Based on this data collected in the 7th growing season several conclusions can be drawn. First, shrub establishment is favored by fencing to exclude big game. However, the long-term potential of shrubs that have established outside the fence, where browsing occurs, is unknown. Secondly, the use of shrub transplants may increase initial success, but the observed success of seeding several shrub species such as sagebrush and bitterbrush illustrate the potential utility of this less-costly approach. However, the establishment of tall shrub species such as serviceberry and chokecherry may require the use of transplants and protection from browsing. Results from this study also indicate that lesser amounts of topsoil (15 cm) appear to be better for shrub establishment relative to deeper topsoil treatments (50 cm) or no topsoil.

Since shrubs are long-lived plants, the establishment and persistence of shrub communities should be monitored over many years in order to make ecologically-relevant conclusions. Continued maintenance and future monitoring of these demonstration plots may yield valuable insights that are not yet apparent.

Overall, it seems that successful shrub establishment is possible in these habitats so long as important factors that reduce shrub establishment are considered in reclamation planning. These factors include minimizing shrub damage by wildlife and reducing competition from aggressive invasive or seeded grass species, which might be accomplished by using lesser depths of topsoil.

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PROJECT OBJECTIVES

The purpose of this project was to evaluate the long-term response (7 years after implementation) of various shrub establishment techniques at three coal mine sites within mountain shrub habitats in northwestern Colorado. Research plots were established in the autumn of 2000 and initially monitored for four growing seasons (2001 – 2004). Here, we report on data collected on these plots during the summer of 2007 in order to evaluate these methods over a longer and more ecologically-meaningful time frame. Results from this study have provided critical information regarding what is, or is not feasible for shrub establishment in these habitats. Increasing shrub establishment will result in improved wildlife habitat and long-term surface stabilization.

BACKGROUND

There is a need for an increased knowledge of the biology and methods for establishment of woody plants on disturbed lands in mountain shrub zones of the Rocky Mountains. This region contains many economically important natural resources including minerals, wildlife, water, timber, forage, recreational opportunities, and food. The development of these resources often leads to degradation of plant communities, which may require restoration efforts. In the Rocky Mountains, where mineral extraction is an important part of local economies, the restoration of mountain shrub communities on mined lands is an important and difficult task.

Areas of coal extraction in the Rocky Mountains often occur in habitats of shrubby vegetation that are referred to as "mountain brush" or "mountain shrub". This is an important habitat type in much of the Rocky Mountains because big game is concentrated in mountain shrublands during winter periods. The quality of these habitats is often the key determinant of the ecosystem carrying capacity for big game population (Wallmo et al. 1976). Mountain shrublands also serve as habitat for a wider variety of wildlife including threatened Columbian sharp-tailed grouse and sage grouse. Mountain shrubland species such as bitterbrush (*Purshia tridentata*), serviceberry (*Amelanchier* sp.) and mountain mahogany (*Cercocarpus montanus*) are some of the most palatable North American plant genera for big game, while sagebrush (*Artemisia tridentata*) is less palatable but among the most important browse species due to its abundance and availability (Merrill 1971).

The mountain shrub plant association is widespread in the Rocky Mountain region from western Colorado through Utah and Nevada and from western Wyoming south to northern Arizona. Mountain shrublands typically occur above valley and foothill sagebrush or pinyon-juniper communities and below montane conifer or aspen (*Populus tremuloides*) forests. These mountain shrub communities are diverse and vary in species composition with elevation, aspect, soils, and disturbance history. Despite the wide diversity of mountain shrub habitat types, there are relatively few dominant shrub species found in this vegetation type. Notable among these common shrubs are big sagebrush, antelope bitterbrush, mountain mahogany, Saskatoon serviceberry (*Amelanchier alnifolia*), black chokecherry (*Prunus virginiana*), snowberry (*Symphoricarpos* sp.), maple (*Acer sp*.), and Gambel oak (*Quercus gambelii*) (Terwilliger 1978, Tiedeman and Terwilliger 1978, Hoffmann 1979, Hoffman and Alexander 1980, Hess 1982, Hoffman and Alexander 1983, Alexander 1985, Hess and Alexander 1986, Alexander 1987, Banner 1992, Colorado Natural Areas Program 1998).

On surface-mined lands in Rocky Mountain shrublands, the establishment of woody plants at densities required for bond release, and within the ten-year liability period, has proven to be very difficult (Mathews and Savage 1990). This difficulty arises from numerous factors including grazing and browsing pressures, competition from other plant species, short growing season, lack of seeds or planting stock and, a lack of technical information regarding the cost-effective methods for establishing shrubs on disturbed lands.

Over the years many attempts have been made to reestablish the native shrubs that dominate a majority of the mined lands in western Colorado. These techniques included transplanting native shrub islands (Carlson 1982), planting shrub seeds along with a standard reclamation mix (Schuman et al. 2000), transplanting small shrub tubelings (Hansen 1989), and strip seeding rows of shrub seed between rows reclamation seed mixes (Krzyszowska-Waitkus et al. 2000). The results of these attempts have been inconsistent and variable.

METHODS

This study was an extension of a field demonstration study that was initiated in 2000. The same methods that were employed in previous years of the study to assess the vegetative communities were used in the present study during 2007. These methods are presented below.

The mines that initially volunteered to participate in the field study are all large surface mines in northwestern Colorado: the Colowyo Mine, the Seneca Mine, and the Trapper Mine. All three mines are in dense mountain shrublands that provide valuable wildlife habitat. Elevations range from 6500 to 8100 feet at the mines. Local climate is characteristic of semi-arid steppe regions with average precipitation ranging from 16.1 inches to 18 inches at the mines, and increases with local elevation. Soils are typical of soils found in cold, semi-arid regions of the western United States. They are moderately deep (20 to 40 inches) to shallow (10-20 inches). The dominant vegetation types are sagebrush grasslands and mountain shrublands. Current and historic land uses in the vicinity of these operations is grazing for livestock, and wildlife habitat. Herds of mule deer and elk are common, especially on reclaimed areas during the winter.

The treatments used in the demonstration study were designed to overcome the two primary obstacles to shrub establishment - competition from aggressive herbaceous species and browsing. The herbaceous competition is primarily from introduced cool season grass species. These species are often planted in reclamation settings because they are reliable and serve as quick erosion control. They thrive where topsoil is replaced and become well established, often at the expense of other desirable species. Seed mixes for the demonstration plots were carefully evaluated to eliminate the competitive introduced species and include native species. Strip seeding was used to isolate the shrub species to further reduce competition from the herbaceous species. Topsoil depths were varied and included seeding directly on spoil. This was done to reduce the competition from introduced herbaceous species that thrive where topsoil has been replaced and to better represent the rocky substrate found in the typical habitat of several of the shrub species.

Young shrub plants are highly desirable browse for deer and elk. Since the reclaimed lands are located in heavily used wildlife habitat, the deer and elk are drawn to the wide open fields of reclamation. To determine the impact of wildlife browsing, half of each treatment was fenced.

With the reduced seeding rate and the lack of aggressive species that establish quickly it was necessary to consider erosion control on the treatment plots. Surface roughening using a dozer to create depressions was included on several of the treatments. This treatment slows erosion and the depressions create microhabitats that may enhance shrub establishment.

These demonstration plots were large-scale plots constructed with standard reclamation equipment to test shrub establishment techniques that could have commercial practicality. At each mine, six treatments were evaluated. The treatments varied slightly between mines to accommodate the reclamation techniques and material availability at each mine. Test plots for each treatment ranged in size from 100 x 100 ft at the Seneca Mine to 60 x 1000 ft at the Colowyo Mine. All seeded plots were drill-seeded using standard equipment.

Colowyo Mine

The test plots at Colowyo are located in the East Pit, Section 11 area (UTM 13T 261304 4458557) at an average elevation of 7480 feet. The selected site for the test plots has a northeast aspect. The plots are located adjacent to each other in one contiguous block. Each treatment measures 60 ft wide and 1000 ft long (Figure 1). To alleviate soil compaction caused by scraper and truck traffic on the plots, the non-topsoiled plots were ripped with a motor grader to a depth of 15 to 25 cm. After ripping, the non-topsoiled plots and the 15 cm topsoil plots were chisel plowed to smooth the areas. The study area was then fertilized with 11-52-0 fertilizer at a rate of 375 lbs per acre. After fertilization, the entire study area was again chisel plowed to incorporate the fertilizer. A description of each treatment is presented below.

Plot 1. 18 inches (46 cm) of live-haul topsoil over spoil with strip seeding. The strip seeding included a strip of native shrubs and native low-competitive forbs that alternated with a strip of native grasses, forbs, and shrubs. The seed mixtures for this treatment are presented in Tables 1 and 2. The Table 1 mixture was placed in the left grass box of the rangeland drill, and the Table 2 mix was placed in the right grass box.

Plot 2. 6 inches (15 cm) of live haul topsoil over spoil and seeded with native shrubs and low-competitive native forbs. Surface manipulations included to enhance soil moisture conditions. The seed mixture for this treatment is presented in Table 1.

Plot 3. 6 inches (15 cm) of live-haul topsoil over spoil, strip seeded as described in No. 1 above.

Plot 4. Non-topsoiled spoil, strip seeded as described in No. 1 above.

Plot 5. Non-topsoiled spoil seeded with relatively unpalatable native shrubs, low-competitive native forbs, and low-competitive native grasses. See Table 3 for the seed mixture used in this treatment.

Construction of the plots was conducted in the summer of 2000 and seeding was completed in October 2000. At Colowyo Mine, no chains or other devises were used behind the seed drill. This was done to create a broad range of conditions from buried seed to seed laying on the surface. Fencing of half the study area (Figure 1) was completed in the spring of 2002. It was noted that initial seedling establishment was good in 2001 prior to fence construction.

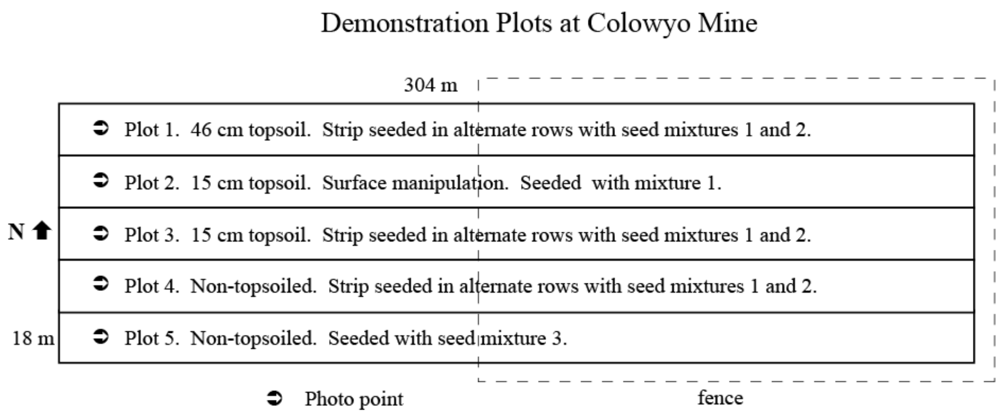

Figure 1. Shrub establishment demonstration plots at Colowyo mine.

Table 1. Native shrub and forb seed mixture (seed mix #1) for demonstration plots at Colowyo and Trapper Mines.

Scientific Name	Common name	Seeding rate in lbs pls/ac
Shrubs:		
Purshia tridentata	Antelope bitterbrush	5.0
Artemisia cana	Silver sagebrush	0.20
Artemisia tridentata vaseyana	Big sagebrush	0.25
Prunus virginiana	Chokecherry	4.0
Ericameria nauseosus	Rubber rabbitbrush	0.5
Amelanchier alnifolia	Serviceberry	1.0
Symphoricarpos oreophilus	Snowberry	3.0
Rosa woodsii	Woods rose	2.0
Forbs:		
Linum lewisii	Lewis flax	1.0
Penstemon palmeri	Palmer penstemon	0.5
Penstemon strictus	Rocky Mountain penstemon	0.5
Balsamhoriza sagittata	Arrowleaf balsamroot	0.5
Achillea lanulosa	Western yarrow	0.1
TOTAL		18.55

Table 2. Native grass, forb, and shrub seed mixture (seed mix #2) for demonstration plots at Colowyo and Trapper Mines.

Scientific name	Common name	Seeding rate in lbs pls/ac
Grasses:		
Agropyron spicatum	Bluebunch wheatgrass	1.0
Festuca ovina	Sheep fescue	0.5
Bromus marginatus	Mountain brome	1.0
Forbs:		
Linum lewisii	Lewis flax	1.0
Penstemon palmeri	Palmer penstemon	0.5
Penstemon strictus	Rocky Mountain penstemon	0.5
Balsamhoriza sagittata	Arrowleaf balsamroot	0.5
Achillea lanulosa	Western yarrow	0.1
Shrubs	Shrubs	
Purshia tridentata	Antelope bitterbrush	5.0
Artemisia cana	Silver sagebrush	0.2
Artemisia tridentata vaseyana	Big sagebrush	0.25
Prunus virginiana	Chokecherry	4.0
Ericameria nauseosus	Rubber rabbitbrush	0.5
Amelanchier alnifolia	Serviceberry	1.0
Symphoricarpos oreophilus	Snowberry	3.0
Rosa woodsii	Woods rose	2.0
TOTAL		21.05

Table 3. Seed mixture of unpalatable native shrubs and low-competitive native grasses and forbs (seed mix #3) for demonstration plots at Colowyo and Trapper Mines.

Scientific name	Common name	Seeding rate in lbs pls/ac
Shrubs:		
Ericameria nauseosus	Rubber rabbitbrush	1.0
Chrysothamnus viscidiflorus	Douglas rabbitbrush	1.0
Rosa woodsii	Woods rose	3.0
Artemisia cana	Silver sagebrush	0.20
Artemisia tridentata vaseyana	Big sagebrush	0.50
Shepherdia argentea	Silver buffaloberry	3.0
Rhus trilobata	Skunkbush sumac	3.0
Forbs:		
Linum lewisii	Lewis flax	1.0
Penstemon palmeri	Palmer penstemon	0.5
Penstemon strictus	Rocky Mountain penstemon	0.5
Balsamhoriza sagittata	Arrowleaf balsamroot	0.5
Achillea lanulosa	Western yarrow	0.1
Grasses:		
Agropyron spicatum	Bluebunch wheatgrass	1.0
Festuca ovina	Sheep fescue	0.5
Bromus marginatus	Mountain brome	1.0
Agropyron trachycaulum	Slender wheatgrass	1.0
TOTAL		17.80

Trapper Mine

The test plots at Trapper are located in the F pit backfill area (UTM 13T 282979 4478354) at an average elevation of 7200 feet. The selected site for the test plots has a north aspect. The plots are located adjacent to each other in one contiguous block. Each treatment measures 180 ft wide and 363 ft long (Figure 2). A description of each treatment is presented below.

Plot 1. 6 inches (15 cm) of live-haul topsoil over spoil with strip seeding. The strip seeding included a strip of native shrubs and native low-competitive forbs that alternated with a strip of native grasses, forbs, and shrubs. The seed mixtures for this treatment are presented in Tables 1 and 2.

Plot 2. 20 inches (46 cm) of live-haul topsoil over spoil, strip seeded as described in No. 1 above.

Plot 3. 6 inches (15 cm) of live haul topsoil over spoil and seeded with native shrubs and low-competitive native forbs. Surface manipulations included to enhance soil moisture conditions. The seed mixture for this treatment is presented in Table 1.

Plot 4. Non-topsoiled spoil seeded with relatively unpalatable native shrubs, low-competitive native forbs, and low-competitive native grasses. See Table 3 for the seed mixture used in this treatment.

Plot 5. Non-topsoiled spoil, strip seeded as described in No. 1 above.

Test plot construction was completed in November 2000. Unfavorable weather prevented seeding in the fall of 2000, so plots were seeded in April, 2001. Fencing of half the study area (Figure 2) was completed in the spring of 2002. Commercial mycorrhizal inoculum was applied to 1.5-m wide strips in each plot at Trapper Mine in order to evaluate the potential for such a treatment to improve shrub establishment. This inoculation treatment was applied in May, 2001 by Trapper Mine personnel.

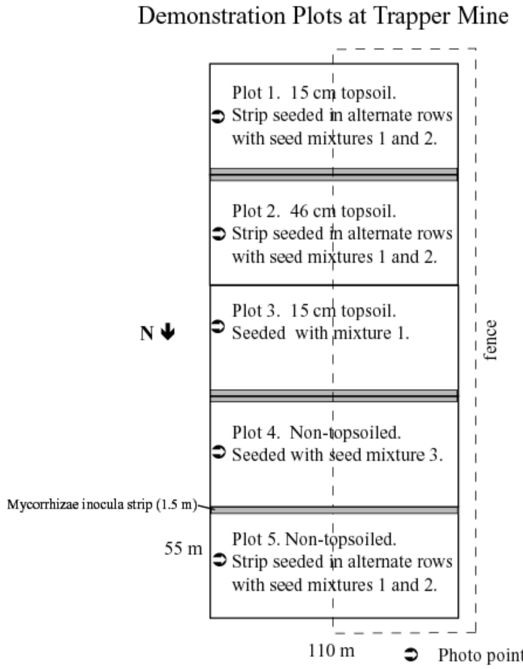

Figure 2. Shrub establishment demonstration plots at Trapper mine.

Seneca Mine

The test plots at Seneca are located adjacent to each other in one contiguous block in the Wadge Pit area (UTM 13T 322555 4476182) at an average elevation of 7600 feet. The selected site for the test plots has an east aspect. A description of each treatment is presented below. It should be noted that one treatment originally proposed was modified. The proposed treatment of no topsoil with seeding and transplanting was replaced with a treatment of no topsoil and transplanting, without the seeding. Species of transplants used were boxelder maple, Saskatoon serviceberry, black chokecherry, Gamble oak, Wood's rose, skunkbush sumac and mountain snowberry. All shrub transplants used at the Seneca demonstration plots were grown from local seed sources by Bitterroot Restoration, Inc. and were inoculated with a local soil community to facilitate the establishment of appropriate root microsymbionts.

Plot 1. 6 inches (15 cm) of stockpiled topsoil over spoil and native shrub transplants as tubelings. Surface manipulation incorporated to reduce run off. This treatment is represented by one unfenced 100- x 100-ft plots.

Plot 2. 20 inches (50 cm) of stockpiled topsoil over spoil and native shrub transplants as tubelings. Surface manipulation incorporated to reduce run off. This treatment is represented by one fenced and one unfenced 100- x 100-ft plots.

Plot 3. 20 inches (50 cm) of stockpiled topsoil over spoil with strip seeding. The strip seeding included a strip of native shrubs and native low-competitive forbs that alternated with a strip of native grasses, forbs, and shrubs. The seed mixtures for this treatment are presented in Tables 4 and 5. This treatment is represented by one fenced 100- x 100-ft plot.

Plot 4. Non-topsoiled spoil with native shrub transplants as tubelings. Surface manipulation incorporated to reduce run off. This treatment is represented by one fenced and one unfenced 100- x 100-ft plots.

Plot 5. 6 inches (15 cm) of stockpiled topsoil over spoil with strip seeding. The strip seeding included a strip of native shrubs and native low-competitive forbs alternated with a strip of native grasses, forbs, and shrubs. The seed mixtures for this treatment are presented in Tables 4 and 5. This treatment is represented by one fenced and one unfenced 100- x 100-ft plots.

Plot 6. Non-topsoiled spoil with strip seeding. The strip seeding included a strip of native shrubs and native low-competitive forbs alternated with a strip of native grasses, forbs, and shrubs. The seed mixtures for this treatment are presented in Tables 4 and 5. No transplants. This treatment is represented by one unfenced 100- x 200-ft plot.

Seeding and transplanting of the test plots was completed in November 2000. Transplants (tubelings) were planted at a rate of one per 20 square ft or a 4 ft by 5 ft pattern. Transplanted species included *Acer negundo, Amelanchier alnifolia, Prunus virginiana, Quercus gambelli, Symphoricarpos oereophilus, and Rosa woodsii*. Not all of these species were planted in each plot and no records were made for species planted or numbers for each plot. Fencing of the study was completed in the spring of 2001. The fence was installed in such a fashion that treatments 2, 4 and 5 have fenced and unfenced plots (Figure 3).

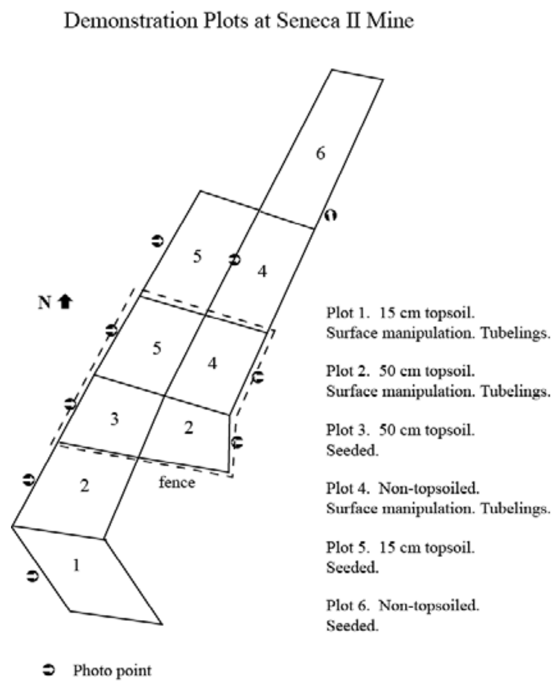

Figure 3. Shrub establishment demonstration plots at Seneca mine.

Table 4. Native grass, forb, and shrub seed mixture (seed mix #4) for demonstration plots at the Seneca Mine.

Scientific name	Common name	Seeding rate in lbs pls/ac
Grasses:	Grasses	
Agropyron spicatum	Bluebunch wheatgrass	1.0
Bromus marginatus	Mountain brome	1.0
Agropyron trachycaulum	Slender wheatgrass	1.0
Poa ampla	Big bluegrass	1.0
Forbs:		
Balsamorhiza sagittata	Arrowleaf balsamroot	1.0
Lupinus alpestris	Mountain lupine	1.0
Linum lewisii	Lewis flax	1.0
Penstemon palmeri	Palmer penstemon	0.5
Penstemon strictus	Rocky Mountain penstemon	0.5
Shrubs:		
Purshia tridentata	Antelope bitterbrush	3.0
Amelanchier utahensis	Serviceberry	3.0
Symphoricarpos albus	Snowberry	3.0
Rosa woodsii	Woods rose	2.0
Ribes aureum	Golden currant	2.0
Prunus virginiana	Chokecherry	4.0
TOTAL		25.0

Table 5. Native shrub and forb seed mixture (seed mix #5) for demonstration plots at the Seneca Mine.

Scientific name	Common name	Seeding rate in lbs pls/ac
Shrubs:		
Purshia tridentata	Antelope bitterbrush	3.0
Amelanchier utahensis or alnifolia	Serviceberry	3.0
Symphoricarpos oreophilus	Snowberry	3.0
Rosa woodsii	Woods rose	2.0
Ribes aureum	Golden currant	2.0
Prunus virginiana	Chokecherry	4.0
Forbs:		
Balsamorhiza sagittata	Arrowleaf balsamroot	1.0
Lupinus alpestris	Mountain lupine	1.0
Linum lewisii	Lewis flax	1.0
Penstemon palmeri	Palmer penstemon	0.5
Penstemon strictus	Rocky Mountain penstemon	0.5
TOTAL		21.0

Vegetation Sampling

In July of 2007, the demonstration plots were sampled for vegetative cover by species, bare ground, rock and litter using a point-intercept method. Sampling was stratified in the fenced and non-fenced areas in order to examine the effects of game exclusion. Within each fenced (five plots) and unfenced (five plots) plot at Colowyo and Trapper Mines (Figures 1 and 2), five 50-m transects were randomly located. Cover data was collected every one meter along each transects (250 cover points per plot). At the Seneca Mine, where plots are considerably smaller (Figure 3), we used three 30-m transects and collected cover data every one meter (90 cover points per plot). Only three plots at the Seneca Mine were divided into subplots by a fence.

In addition to cover sampling we estimated shrub establishment and shrub height in each demonstration plot using 1-m wide by 50-m long belt transects. Along a random 50-m transect in each plot, a 1-m wide belt was identified and each shrub that fall within this belt was identified to species and each shrub height was recorded. In plots where few shrubs were encountered, we extended this sampling to include the full 250-m cover transect. This shrub sampling technique varies from that used in the preliminary study, in that the 2007 method was much more intensive and designed to provide more meaningful data.

At the Seneca Mine shrub tubelings were planted in September of 2000 in select demonstration plots. To evaluate the success of this operation, survival of transplants was quantified during the vegetation sampling. Shrub survival within each demonstration plot was estimated by following rows of transplants and scoring seedlings as either alive or dead. A minimum of 25% of the transplant rows within each plot was surveyed as such.

During the vegetation sampling, voucher specimens of plant taxa were collected for positive identification and for archival in the Restoration Ecology Lab Herbarium. Permanent photo reference points established in 2001 in each demonstration plot were photographed annually to illustrate long-term changes in the vegetation.

RESULTS AND DISCUSSION

Results from the demonstration plots illustrate the complex interactions of various cultural and environmental factors in the establishment of woody vegetation on reclaimed surface mines. Shrub establishment and seeding success has been variable across the three mine sites (Figure 4, Tables 6-11) likely owing to timing of the seeding, spoil quality and variable local climatic conditions at the three sites after seeding.

Figure 4. Various non-topsoiled plots at Colowyo (left), Trapper (middle) and Seneca (right) mines in July 2007 showing differing shrub establishment success.

Colowyo Mine

Of the three sites, shrub establishment has been greatest at Colowyo mine (Table 6). Establishment of mountain big sagebrush, the dominant late-seral shrub in the region, has been very good in nearly all plots at Colowyo (Table 7) where this species occupies as much as 23% ground cover. In general, shrub densities have declined or remained steady over time in the plots at Colowyo (data from previous years not shown but are available from the PI upon request). Some declines are likely attributed to natural thinning of dense shrub populations or removal by browsers. Increases in shrub densities over time in some plots can be attributed to the delayed establishment of silver sagebrush at this site, which did not appear in most plots until 2004. In general, shrub establishment at Colowyo has been better in fenced plots relative to unfenced plots.

Table 6. Density and average height of shrubs and cover of various plant life forms in the Colowyo demonstration plots during July of 2007.

Plot	Treatments				# Shrubs / ac	Shrub Ht (cm)	Cover (%)			
	Fence	Topsoil (cm)	Seed Mix	Other			Shrub	Grass	Forb	Plant
1	no	46	1+2*		13759	23	6	67	22	95
1	yes	46	1+2*		8094	37	32	46	17	94
2	no	15	1	SM†	12788	23	27	36	16	78
2	yes	15	1	SM	52609	13	36	26	13	75
3	no	15	1+2*		6637	22	18	34	17	69
3	yes	15	1+2*		12140	29	28	34	17	79
4	no	0	1+2*		2104	19	4	17	19	39
4	yes	0	1+2*		7284	19	16	16	14	46
5	no	0	3		1079	17	3	16	12	32
5	yes	0	3		10845	20	18	11	11	40

*Seeded in alternate drill strips. †SM = Surface manipulation.

Results from Colowyo mine indicate that the autumn 2000 seeding operation was very successful as most of the seeded species continue to be found on the site in 2007 (Table 7). Lewis flax, big sagebrush, silver sagebrush and western yarrow are seeded species, which have established in all plots. The seeded grass species are also well established. The weedy invasive species Russian thistle, which was dominant in previous years, has been reduced to a very minor component in 2007. The weedy invasive species cheatgrass and Japanese brome appeared at Colowyo in 2004 and are now dominant species in some plots. These annual weeds have invaded all of the plots that contain topsoil. This observation likely reflects the observed nitrophylic nature of these species (Paschke et al. 2000) and their ability to be transported by wildlife. The long-term nature of shrub persistence in these plots is of concern due to the reputation of annual bromes for displacing shrubs (Billings 1994).

Table 7. Percent vegetative cover of dominant (greater than 1%) and seeded species in demonstration plots at Colowyo Mine in July, 2007. Values are raw numbers for each plot (n=1).

			Fenced					Unfenced				
		Topsoil Depth (cm)	46	15	15	0	0	46	15	15	0	0
		Plot Number	1	2	3	4	5	1	2	3	4	5
Genus	species	common name [a]										
Forbs:												
Achillea	***lanulosa***	**western yarrow**	1.59	1.60	2.00	3.20	2.00	6.75	4.00	3.98	2.44	0.80
Astragalus	*cicer*	cicer milkvetch		0.40	0.40	3.20	1.60	0.40	0.80	0.80	6.91	1.60
Grindelia	*squarrosa*	curlycup gumweed		1.20	0.40			0.40		0.40		
Linum	***lewisii***	**Lewis flax**	11.11	7.60	13.20	6.00	4.40	9.52	8.80	9.96	6.10	8.80
Penstemon	***palmeri***	**Palmer's penstemon**										
Penstemon	***strictus***	**Rocky Mtn. penstemon**		0.40		1.60	3.20		0.40	0.40	3.25	1.20
Sisymbrium	*altissimum*	tall tumblemustard	1.19					1.19				
Veronica	*biloba*	twolobe speedwell		1.20	0.40				1.60	0.40		
Grasses:												
Bromus	*inermis*	smooth brome	3.17	2.80	12.40	0.40	0.40	7.54	4.80	0.80	0.81	1.60
Bromus	*japonicus*	Japanese brome	4.37	8.00	6.00			8.33	4.40	5.98	3.66	3.60
Bromus	*tectorum*	cheatgrass	12.70	1.60	2.00			11.90	4.00	3.59	1.22	0.40
Elymus	*trachycaulus*	slender wheatgrass	3.57	4.00	1.60	10.40	9.60	15.08	0.40	10.76	8.13	8.80
Festuca	***ovina***	**sheep fescue**	4.76	0.40	3.20	5.60	0.80			0.80		0.40
Pascopyrum	*smithii*	western wheatgrass	0.40	2.00	0.40			1.98	1.20	0.40		
Poa	*pratensis*	Kentucky bluegrass	15.48	6.00	3.20			20.63	20.40	11.95	1.22	
Pseudoroegneria	spicatum	Bluebunch wheatgrass	0.79	1.20	4.00			0.79			0.41	
Shrubs:												
Artemisia	***cana***	**silver sagebrush**	8.33	19.20	8.40	3.20	1.60	5.56	17.20	5.98	1.22	1.20
Artemisia	***tridentata***	**mtn. big sagebrush**	23.41	16.00	17.20	4.80	15.20	0.40	9.20	10.76	2.44	1.20
Purshia	***tridentata***	**antelope bitterbrush**	0.40	1.20	2.40	7.60				0.40		
		Total Plant	94	75	79	46	40	95	78	69	39	32

[a] Bold names indicate seeded plant species.

Trapper Mine

Shrub establishment at Trapper mine was slow relative to the other sites, likely due to dry conditions after the spring 2001 seeding (plots were scheduled to be seeded in the fall or early spring but conditions precluded the seeding operation until April). The poor initial establishment may also be related to the spring planting not providing proper vernalization of the seed. As a result of poor establishment of seeded species, the site was quickly colonized and dominated by weedy herbaceous species. However, by 2007 shrubs and other seeded species had appeared in the Trapper plots (Tables 8 and 9). Most of the vegetative cover in demonstration plots at Trapper continues to be weedy invasive species (Table 9), especially the annual grasses cheatgrass and Japanese brome. These weedy annual grasses have increased in recent years while weedy forbs such as Russian thistle and tall tumble mustard have declined. The recent increase in dominance of these weedy grasses in the Trapper plots may pose a long-term threat to the establishing shrubs.

Table 8. Density and average height of shrubs and cover of various plant life forms in the Trapper demonstration plots during July of 2007.

	Treatments					Cover (%)			
Plot	Fence	Topsoil (cm)	Seed Mix	# Shrubs / ac	Shrub Ht (cm)	Shrub	Grass	Forb	Plant
1	no	15	1+2*	534	9	0	76	6	82
1	yes	15	1+2*	1651	31	2	63	8	74
2	no	46	1+2*	243	14	0	93	5	97
2	yes	46	1+2*	923	30	0	69	11	80
3	no	15	1	275	13	0	74	9	83
3	yes	15	1	1295	26	1	77	12	91
4	no	0	3	227	13	0	37	16	53
4	yes	0	3	356	34	0	33	11	43
5	no	0	1+2*	987	11	0	10	11	21
5	yes	0	1+2*	1667	26	11	5	12	28

*Seeded in alternate drill strips.

Despite the poor initial (2001-2004) establishment of shrubs and the dominance of weeds at the Trapper site, there was modest establishment of some shrub species at Trapper by 2007, especially within the fenced portion of the plots (Figure 5). The lack of substantial shrub cover outside the fence (Table 9) despite the presence of some individual shrubs as indicated in Table 8, might be due to the small stature of these browsed shrubs and the dominance of weeds in the unfenced portion of the plots. .

Figure 5. Robust bitterbrush shrubs such as this one are abundant inside the fenced portion of plot 5, but not outside the fence at the Trapper mine demonstration plots. Photo taken in July 2008.

Table 9. Percent vegetative cover of dominant (greater than 1%) and seeded species in demonstration plots at Trapper Mine in July, 2007. Values are raw numbers for each plot (n=1).

			Fenced					Unfenced				
		Topsoil Depth (cm)	15	46	15	0	0	15	46	15	0	0
		Plot Number	1	2	3	4	5	1	2	3	4	5
Genus	species	common name [a]										
Forbs:												
Achillea	***lanulosa***	**western yarrow**	2.00	3.22	0.50				0.52			
Cardaria	*draba*	whitetop*						2.46	2.01	3.27	3.06	
Cirsium	*arvense*	Canada thistle		0.25		0.25			0.77	2.26	2.04	
Lactuca	*serriola*	Prickly lettuce			1.21	1.59		0.25	0.52	2.51		0.24
Linum	***lewisii***	**Lewis flax**	2.74	4.20	3.46	1.09	1.00		0.26	0.25		
Polygonum	*aviculare*	prostrate knotweed				0.25	3.75					0.73
Salsola	*kali*	Russian thistle				4.02	7.25	0.25		0.51	9.25	6.93
Thlaspi	*arvense*	field pennycress		1.00	0.25			0.25				
Tragopogon	*dubius*	yellow salsify	1.49	1.49	1.46			0.25			1.27	2.00
Veronica	*biloba*	twolobe speedwell		0.25	0.96			1.23				
Grasses:												
Bromus	***marginatus***	**mountain brome**		**1.72**				**0.50**				
Bromus	*inermis*	smooth brome			0.75		0.25	2.94	4.49	0.25		
Bromus	*japonicus*	Japanese brome	2.74	7.48	6.71		0.25	19.98	11.14		3.02	5.63
Bromus	*tectorum*	cheatgrass	12.49	12.19	58.54	7.61	3.00	25.31	28.89	48.67	8.41	1.71
Elymus	*lanceolatus*	streambank wheatgrass			0.75			0.50	2.53	6.29		
Elymus	*trachycaulus*	slender wheatgrass	8.46	4.22	0.75	7.61	0.50	7.94	15.88	3.53	14.27	
Festuca	***ovina***	**sheep fescue**	**13.97**	**4.68**	**0.25**	**10.87**	**0.25**	**2.26**	**6.08**		**4.58**	
Pascopyrum	*smithii*	western wheatgrass	23.68	19.14	1.25			7.21		1.01	4.33	
Poa	*pratensis*	Kentucky bluegrass	1.49	7.91	6.85	6.52	0.75	2.51	6.24	8.55	2.29	1.49
Thinopyrum	*intermedium*	intermediate wheatgrass*		10.39	1.00		0.50	6.41	16.61	5.05		
Shrubs:												
Artemisia	***tridentata***	**mtn. big sagebrush**	**1.00**		**1.21**		**0.25**					
Purshia	***tridentata***	**antelope bitterbrush**	**1.00**				**9.00**					
Symphoricarpos	***oreophilus***	**mountain snowberry**	**0.50**				**1.25**					
		Total Plant	**74**	**80**	**91**	**43**	**28**	**82**	**97**	**83**	**53**	**21**

[a] Bold names indicate seeded plant species.

Seneca Mine

Shrub establishment at Seneca mine has been intermediate relative to Trapper and Colowyo mines. While shrub density is low at Seneca relative to Colowyo, the shrubs at Seneca are very robust at this site as indicated by height measures (Table 10 and Figure 7). The large size of these shrubs is likely due to the fact that transplants were used. Shrub tubelings planted in some of the plots continue to show high survival (61%) in 2007 and many flowering and fruiting shrubs were observed at this time. Among all of the mines, Seneca was the only location where the tall shrub species such as serviceberry and chokecherry became established. These species did not establish well from seeding on the other mines, whereas they did establish from the transplants at Seneca. The fall 2000 seeding at the Seneca mine appears to have been somewhat successful. Many of the seeded species were encountered in some of the plots at Seneca in 2007 (Table 11). Similar to the other sites, the initial dominance of weedy forbs such has Russian thistle has subsided at Seneca. However, the recently established invasive weeds yellow sweet clover and Japanese brome are now dominant species in most plots at Seneca. It is likely that yellow sweet clover will not be a persistent problem, but Japanese brome is of concern.

Table 10. Density and average height of shrubs and cover of various plant life forms in the Seneca demonstration plots during July of 2007.

	Treatments						Cover (%)			
Plot	Fence	Topsoil (cm)	Seed Mix	Other	# Shrubs / ac	Shrub Ht (cm)	Shrub	Grass	Forb	Plant
1	no	15		SM†, TP	1376	18	0	13	57	70
2	no	50		SM, TP	890	21	2	52	30	84
2	yes	50		SM, TP	2428	38	14	37	26	76
3	yes	50	yes		1781	24	3	25	51	79
4	no	0		SM, TP	1700	24	6	13	39	57
4	yes	0		SM, TP	2266	38	17	9	33	59
5	no	15	yes		0		0	24	29	53
5	yes	15	yes		324	26	1	36	43	79
6	no	0	yes		2752	10	0	14	45	59

*Seeded in alternate rows. †SM = Surface manipulation, TP = transplants.

Figure 7. Robust serviceberry transplants inside the fenced area at Seneca Mine in 2007.

Table 11. Percent vegetative cover of dominant (greater than 1%) and seeded (or planted for shrubs) species in demonstration plots at Seneca Mine in July, 2007. Values are raw numbers for each plot (n=1).

			Fenced						Unfenced					
		Topsoil Depth (cm)		50	50	0	15		15	50		0	15	0
		Plot Number	1	2	3	4	5	6	1	2	3	4	5	6
Genus	species	common name [a]												
Forbs:														
Achillea	*millefolium*	common yarrow			2.76		2.00		0.67			2.00	2.72	1.35
Astragalus	*cicer*	cicer milkvetch		0.68	1.38		0.67		0.67	3.33		1.33		0.68
Balsamhoriza	***sagittata***	**arrowleaf balsamroot**					0.67					4.00		0.68
Bidens	*cernua*	nodding beggartick		6.76	3.45									
Circium	*arvense*	Canada thistle		0.68					13.42	4.67				
Circium	*vulgare*	bull thistle							2.01	0.67				
Cynoglossum	*officinale*	gypsyflower							0.67	0.67		0.67	0.68	1.35
Epilobium	*brachycarpum*	tall annual willowherb					5.33		2.01			2.67		
Grindelia	*squarrosa*	curlycup gumweed		5.41	1.38	5.36	0.67		6.71	2.00		4.00	3.40	4.05
Lactuca	*serriola*	prickly lettuce		0.68		1.97			2.68			0.67		
Linum	***lewisii***	**Lewis flax**			2.07	5.92	4.00		3.36	1.33		2.00	12.93	12.16
Medicago	*sativa*	alfalfa		1.35	6.90	2.63	4.00		7.38	15.33		0.67	3.40	9.46
Melilotus	*officinalis*	yellow sweet clover		6.08		7.24	12.00		11.41	0.67		16.00	0.68	12.84
Penstemon	***strictus***	**Rocky Mtn. penstemon**			29.66	0.66	6.00						3.40	1.35
Thlaspi	*arvense*	field pennycress		1.35		0.66								
Tragopogon	*dubius*	yellow salsify		0.68	1.38	3.29	5.33		2.68	0.67		0.67	0.68	
Verbascum	*thapsus*	common mullein			2.07									
Veronica	*biloba*	twolobe speedwell		1.35		5.26	2.00		2.01			3.33		0.68
Grasses:														
Bromus	*inermis*	smooth brome		2.03	1.38	1.32	2.67		2.01	19.33		3.33	2.72	
Bromus	***marginatus***	**mountain brome**				1.97								6.76
Bromus	*japonicus*	Japanese brome		3.38		2.63	2.67		2.01	1.33		3.33		
Dactylis	*glomerata*	orchardgrass		1.35	1.38	0.66	9.33		1.34				0.68	
Elymus	*elymoides*	squirreltail							1.34			2.00		
Elymus	***trachycaulus***	**slender wheatgrass**			1.38		12.67					2.00	17.01	
Hordeum	*jubatum*	foxtail barley				1.32								
Koleria	*macrantha*	prairie Junegrass			5.52		2.00						0.68	0.68
Pascopyrum	*smithii*	western wheatgrass		3.38	1.38	0.66			3.36	18.67		0.67		1.35
Poa	*pratensis*	Kentucky bluegrass		12.84	9.66		2.67		2.01	12.00				
Pseudoroegneria	*spicatum*	Bluebunch wheatgrass					1.33							1.35
Thinpyrum	*intermedium*	intermediate wheatgrass		14.19	3.45		2.00		0.67			1.33	2.04	3.38

Table 11 (continued).

Genus	species	common name[a]	Fenced						Unfenced					
			1	2	3	4	5	6	1	2	3	4	5	6
Shrubs:														
Amelanchier	***alnifolia***	**Saskatoon serviceberry**		6.76		9.21						2.67		
Prunus	***virginiana***	**black chokecherry**		0.68		1.97				0.67		0.67		
Purshia	***tridentata***	**antelope bitterbrush**			2.76		0.67			0.67				
Rosa	***woodsii***	**Woods' rose**		4.05		3.95								
		Total Plant		76	79	59	79		70	84		57	53	59

[a] Bold names indicate seeded plant species.

Overall Trends

The fence treatment at the mines appears to have generally resulted in increased shrub density, average height and cover (Tables 7, 9, 11 and 12). This is especially apparent for preferred browse species such as bitterbrush (Tables 7, 9 and 11). Since deer, elk and antelope are known to browse shrub species, this is the expected result. However, many of the unfenced plots have modest numbers of (heavily browsed) shrubs that could survive in the long-term. Since browsing is an episodic phenomenon in these habitats, it is likely that the fencing treatment will become more significant with increasing time as the chances for destructive browsing events increase with time. Future monitoring of the plots and maintenance of the fences would be needed to gauge the true impact of fencing on shrub establishment over a more ecologically-relevant time frame. Due to the unbalanced nature of the experimental design, we are unable to evaluate the various seed mixtures that were used in the demonstration plots.

Table 12. Mean density of shrubs and cover of various plant life forms in fenced versus unfenced demonstration plots in 2007 averaged across all treatments and all three mine sites.

		Cover (%)			
Fence	# Shrubs / ac	Shrub	Grass	Forb	Plant
No	3023	3.32	43.20	18.83	65.35
Yes	7404	10.21	38.55	17.44	66.21

The effect of topsoil depth on shrub establishment is less clear, but the intermediate topsoil depth of 15 cm appears to have resulted in the best shrub establishment overall (Table 13). While the no topsoil plots had the poorest initial shrub establishment, these plots have shown the greatest increases in shrub numbers over the course of the entire study (2001-2007). These results illustrate the importance of continued monitoring of the plots in order to determine the effects of topsoil depth on shrub community development.

Table 13. Mean density of shrubs and cover of various plant life forms in demonstration plots in 2007 receiving various depths of topsoil averaged across all treatments and all three mine sites.

		Cover (%)			
Topsoil Depth	# Shrubs / ac	Shrub	Grass	Forb	Plant
0	2842	5.67	17.69	18.06	41.42
15	8147	7.87	52.11	17.43	77.41
50	4017	6.37	61.04	19.52	86.94

The individual effects of other treatments such as seed mix, surface manipulations and mycorrhizae inoculation are difficult to assess due to the lack of a complete factorial design and the confounding effects of paired treatments at differing sites. In terms of shrub density, the best overall results from this study are from the fenced portion of plot #2 at Colowyo where over 52,000 shrubs per acre were observed in 2007. This plot, in addition to being fenced, received surface manipulations and the use of a “grass-less” seed mix containing low-competitive native forbs. Although not replicated, this observation is consistent with the observation that competition with grasses is detrimental to woody plant establishment.

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MANAGEMENT IMPLICATIONS

In summary, the following conclusions can be drawn from this study:

- **Shrub establishment is favored by fencing to exclude big game. However, the long-term potential of shrubs that have established outside the fence is unknown.**
- **The use of shrub transplants may increase initial success, but the success of seeding several shrub species such as sagebrush and bitterbrush at Colowyo mine relative to Seneca mine illustrate the potential utility of this less-costly approach. The establishment of tall shrub species such as serviceberry and chokecherry may require the use of transplants and protection from browsing as evidenced by results from the Seneca demonstration plots.**
- **Lesser amounts of topsoil (15 cm) appear to be better for shrub establishment relative to deeper topsoil treatments (50 cm) or no topsoil.**
- **Since shrubs are long-lived plants, the establishment and persistence of shrub communities should be monitored over many years in order to make ecologically-relevant conclusions. Continued maintenance and future monitoring of these demonstration plots may yield valuable insights that are not yet apparent.**

Overall, it seems that successful shrub establishment is possible in these habitats so long as important factors that reduce shrub establishment are considered in reclamation planning. These factors include reducing competition from aggressive grass species, minimizing shrub damage by wildlife, and reducing competition from weedy invasive or seeded grass species by using lesser depths of topsoil.

These lessons were shared with the reclamation community during a tour of the demonstration plots on July 22, 2008. This tour was attended by 26 professionals from various government agencies, mining companies, consulting firms, nurseries and universities.