Shrub Densities on Pre-1985 Reclaimed Mine Lands in Wyoming

D. Terrance Booth[1]
James K. Gores[2]
Gerald E. Schuman[1]
Richard A. Olson[3]

Abstract

The reestablishment of native shrubs is part of the mandate under which mining companies extract mineral resources in Wyoming and other western states. Post-mining shrub density and species mixtures have been topics debated by various mine reclamation stake holders. By law, coal-mined lands in Wyoming must now meet a post-mining shrub density of 1 shrub/m² on 20% of the affected area. To better understand the long-term results of shrub reclamation methods, we measured shrub density by species in 14 pre-1985 seedings at eight mines in three geographic regions of Wyoming. The sites studied were selected as *Atriplex canescens* (Pursh) Nutt. (fourwing saltbush) and grass or as *Artemisia tridentata* Nutt. ssp. *wyomingensis* (Beetle and Young) (Wyoming big sagebrush), fourwing saltbush, and grass post-mining communities. Shrub density and composition varied by site but typically reflected the seed mixtures used. Seedings that used a diversity of shrub species generally had greater 1994 shrub densities. Seeding rates between 60 and 1000 shrub seeds/m² had a positive, linear relationship with shrub density up to 0.6 shrubs/m² when sagebrush was part of the shrub seed mixture. We conclude that the likelihood of meeting the shrub standard can be enhanced by seeding diverse shrub mixtures at high seeding rates.

Introduction

Mine reclamation in Wyoming was mandated with the passage of the 1969 Open Cut Land Reclamation Act. Shrubs were included in revegetation seed mixtures in 1973 after the Wyoming Legislature passed the Environmental Quality Act. In 1977, Congress passed the Surface Mining Control and Reclamation Act, and in 1980 the Wyoming Coal Program was approved by the Office of Surface Mining. Between 1980 and the present there has been a continual process of rule making, debate, negotiation, litigation, and rule changes regarding the reestablishment of shrubs (Appendix 1). The issues have been the post-mining shrub densities and the shrub species that should predominate (Boles 1983; Colbert & Colbert 1983; Tessman & Kleinman 1989). Much debate has centered on *Artemisia tridentata* Nutt. ssp. *wyomingensis* (Beetle and Young) (Wyoming big sagebrush), the dominant shrub across much of Wyoming and the Rocky Mountain region and on *Atriplex canescens* (Pursh) Nutt. (fourwing saltbush), which was used extensively in early shrub reclamation but is usually a minor component of the pre-mining shrub community (Boles 1983; Booth 1985).

Boles (1983) reviewed shrub densities in Wyoming and found that average densities ranged from 1.3 shrub/m² in the Powder River Basin, to 3.7 shrubs/m² in southwest Wyoming. High shrub densities on unmined rangeland often contrast with the lower densities of reclaimed land (Fig. 1). Lommasson (1948) reported that big sagebrush densities on a mesic site in Montana varied between one and two plants/m² during a 31-year study. Boles (1983) recommended a general post-mining shrub density of "1 shrub/9 m²," with high-density patches (1 shrub/m²) along drainage ways, ridges, and rock piles. He argued that if either density were achieved, surviving plants would colonize suitable surrounding areas.

As of August 1996, new coal-mined lands in Wyoming must meet a post-mining shrub density of 1 shrub/m² on 20% of the affected area. We assessed the effectiveness of shrub reclamation technology by measuring shrub density by species on Wyoming mines and comparing the results with reclamation records supplied by the mines. Our objective was to provide information that would help the coal mines evaluate their shrub revegetation programs in light of the new requirements.

[1]High Plains Grasslands Research Station, 8408 Hildreth Road, Cheyenne, WY 82009, U.S.A.
[2]Wind River Publishing, P.O. Box 81, Laramie, WY 82070, U.S.A.
[3]Department of Rangeland Ecology and Watershed Management, University of Wyoming, Laramie, WY 82070, U.S.A.

Appendix 1. Continued.

Typical plants:
Betula pendula (the most common tree)
Acer pseudoplatanus
Fraxinus excelsior
Stage comment: stage mixes with one or more adjacent stages

(b)
(1) Successional path 62: Succession on mine dumps, open-cast type, not moist, steep slope. This path has three stages, numbered (1.1) to (1.3)
(1.1) Usually bare substrate, no vegetation
Year: 1
Typical plants: none
(1.2) Stage with dominant perennial forbs
Years: 2–limit
Typical plants:
Tussilago farfara
Stage comment: stage mixes with one or more adjacent stages
(1.3) Stage with dominant graminoids
Years: 15–limit
Typical plants:
Calamagrostis epigeios (only locally present)
Stage comment: stage mixes with one or more adjacent stages

(c)
(1) Successional path 63: Succession on mine dumps, open-cast type, permanently wet depressions, often flooded. This path has three stages, numbered (1.1) to (1.3)
(1.1) Usually bare substrate, no vegetation
Year: 1
Typical plants: none
(1.2) Stage with dominant graminoids
Years: 2–10
Typical plants:
Typha latifolia
Stage comment: occasionally *Alopecurus aequalis, Agrostis stolonifera*
(1.3) Stage with dominant graminoids
Years: 11–limit
Typical plants:
Phragmites australis (strong dominance)
Stage comment: occassionally *Eleocharis palustris, Schoenoplectus tabernaemontani*

Figure 1. Fourteen-year-old reclaimed coal-mined land in southwest Wyoming extends from the foreground into the background. The appearance of this grassland landscape contrasts with adjacent shrublands on unmined rangeland (left top).

Materials and Methods

Descriptions of Mine Sites and Seed Mixtures

Fourteen 10-year-old or older reclaimed sites on eight mines in three geographic regions were selected for study. The three regions were the northeast region (prairie), the southwest region (shrub-grassland), and the central region, an area where the prairie and shrub-grassland meet (Stoddart & Smith 1955; Hart 1994). The post-mining vegetation at these sites was dominated by fourwing saltbush and grass (five sites), or by sagebrush, fourwing saltbush, and grass (nine sites).

Northeast mines included the coal mines of Black Thunder, 20 km east of Wright; Belle Ayr, 28 km south of Gillette; and WyoDak, 4 km east of Gillette. These three mines are located in the Powder River Basin and have similar climatic and soil characteristics (Table 1).

Table 1. Climate and soil information for study sites at eight Wyoming mines.*

Geographic Region and Mine	*Elevation (m)*	*Mean Annual Precipitation (mm)*	*Mean Annual Temperature (°C)*	*Mean Number of Frost-Free Days*	*Soil Parent Material*
Northeast					
Black Thunder	1433	280	6.8	125	Tertiary sandstone & clay shale
Belle Ayr	1433	422	6.8	125	Tertiary sandstone & clay shale
WyoDak	1341	422	6.8	125	Tertiary sandstone & clay shale
Central					
Pathfinder	2195	244	4.1	100	Tertiary sandstone & clay shale
Dave Johnston	1646	328	8.8	123	Cretaceous clay shale
Seminoe I	2012	261	5.5	106	Cretaceous clay shale
Southwest					
Bridger Coal	2073	225	5.9	112	Cretaceous clay shale
Kemmerer	2225	274	3.5	71	Carboniferous limestone, redbed sandstone, loamstone and clay shale

*Young & Singleton 1977; Martner 1986; Owenby & Ezell 1992.

Study sites in the central region included sites at the Pathfinder uranium mine in the Shirley Basin, 78 km southeast of Casper; the Dave Johnston Coal Mine, 40 km east of Casper; and the Seminoe I Mine (coal), 28 km northwest of Hanna. The southwest region included sites at the Bridger Coal Company mine, 53 km northeast of Rock Springs; and the Kemmerer Coal Mine, 23 km southwest of Kemmerer. Climate and soils information for these mines is also given in Table 1.

The seed mixtures that produced the post-mining communities varied, but fourwing saltbush and sagebrush dominated the shrub species (Table 2). *Chrysothamnus nauseosus* (Pall.) Britt. (rubber rabbitbrush), *Eurotia lanata* (Pursh) Moq., syn. *Krascheninnikovia lanata* (Pursh) Mueese & Smit, syn. *Ceratoides lanata* (Pursh) J. T. Howell (winterfat), *Gutierrezia sarothrae* (Pursh) Britt. & Rusby (broomsnakeweed), *Artemisia frigida* Willd. (fringed sagebrush), and *Atriplex confertifolia* (Torr. & Frem.) S. Wats. (shadscale) occurred in some seed mixtures of fourwing saltbush-dominated communities and in some seed mixtures of sagebrush-dominated communities (Table 3). Seed mixtures for the fourwing saltbush communities, particularly the older seedings, tended to have greater grass-seeding rates and lower shrub-seeding rates than were used on the sagebrush sites (Table 3). They also had fewer shrub species in the mixture. Seed mixtures used for sagebrush communities usually contained more sagebrush than fourwing saltbush. Wyoming big sagebrush has 4–5.4 million seeds/kg (Meyer 1999) and dewinged fourwing saltbush 120,000 seeds/kg (Foiles 1974). Therefore, where sagebrush and fourwing were both seeded at the same pure-live-seed (pls) rate, there were 33–45 times more sagebrush seeds sown. Seed mixtures, rates, methods and seeding history are summarized in Tables 2 and 3. When choosing study sites, we avoided sites with steep slopes and, with one exception, sites grazed by domestic livestock. All seedings were completed by 1985, making the sites now eligible for bond release. Shrub density was measured between 29 June and 24 August 1994.

Vegetation Measurements

At each study site, twenty 50-m transects were systematically located across the site. They were oriented perpendicular to the long axis of the site by means of a compass. Transect distances were paced. Transect numbers were reduced on the Belle Ayr (5 transects) and WyoDak (10 transects) sites because of the small size of those areas (Table 3). Thirty transects were used at Pathfinder sites (the first studied). Shrub density by species was determined in a 200-m^2 area by counting the number of shrubs rooted within a strip 4 m wide along the transect (Pieper 1978). Also, we specifically looked for shrub seedlings (plants less than 10 cm in height) at each site.

Standing-dead shrubs were also counted. Shrubs that established and grew to the extent that they left recognizable skeletons 10 or more years after seeding are indicative of seeding success. Also, standing-dead shrubs continue to influence the developing system by affecting the immediate microclimate. Standing-dead and living shrubs were measured to determine average height.

Shrub densities—total live and standing dead—and standard deviations were calculated for each site. The shrub density standard is an average of 1 shrub/m^2 on 20% of the land affected after August 1996 (Federal

Table 2. Reclamation information for study sites at eight Wyoming mines: mine, site, and dominant shrub are indicated with comments on methods.

Mine Site	*Dominant Shrub*	*Comments*
Black Thunder Mine	*Atriplex canescens*	Site was fertilized and slopes mulched
Belle Ayr Mine	*Atriplex canescens*	Soil was direct haul; site was fertilized and mulched
WyoDak Mine #1	*Artemisia tridentata*	Site was fertilized
WyoDak Mine #2	*Artemisia tridentata*	
Pathfinder Mines Corp. #1	*Atriplex canescens*	
Pathfinder Mines Corp. #2	*Artemisia tridentata*	
Dave Johnston Coal Mine	*Artemisia tridentata*	Site was fertilized and mulched
Seminoe I Mine #1	*Atriplex canescens*	
Seminoe I Mine #2	*Artemisia tridentata*	
Bridger Coal Company #1	*Artemisia tridentata*	Soil was direct haul from an upland shrub community; site was mulched
Bridger Coal Company #2	*Artemisia tridentata*	Soil was direct haul from an upland community; site was mulched
Kemmerer Coal Mine #1	*Atriplex canescens*	
Kemmerer Coal Mine #2	*Artemisia tridentata*	
Kemmerer Coal Mine #3	*Artemisia tridentata*	

Table 3. Reclamation information for study sites at eight Wyoming mines by location number.[a]

				Seeding Rates (kg/ha)[c]						
Mine	*Area (ha)*	*Year(s) Seeded*	*Seeding Method*[b]	*All Grasses*	*All Forbs*	*ATCA*	*ARTR*	*CHNA*	*EULA*	*Other Shrubs*
Black Thunder	26.3	1981	D & B	21.3	—	1.1	—	—	—	—
Belle Ayr	2	1981	D	28.0	5.3	3.4	—	0.1	1.1	ROWO = 0.1, SAVE = 0.1
WyoDak #1	4.5	1982	D & B	15.1	0.6	1.1	0.6	3.4	2.2	ATGA = 3.4, ARCA = 0.6
WyoDak #2	4.5	1984	D & B	16.1	0.6	5.6	0.6	3.4	—	ATGA = 3.4
Pathfinder #1	15.8	1977	D	?	?	2.2	—	—	—	—
Pathfinder #2	21.5	1982	D	15.1	2.2	2.2	1.1 (bulk)	—	1.1	—
Dave Johnston	23.9	1981	D & B	20.2	1.1	0.6	0.6	—	0.6	CHVI = 2.2, ARCA = 0.6
Seminoe I #1	22.7	1984	?	16.8	—	1.7	—	0.6	0.6	SAVE = 0.6, ATCO = 1.7
Seminoe I #2	7.7	1984	D	16.8	—	1.7	0.3	0.6	0.6	SAVE = 0.6, ATCO = 0.6
Bridger #1	6.5	1981	D & B	19.5	2.8	—	—	0.6	1.7	
	6.5	1984	D & B	24.4	6.7	2.2	—	1.1	1.1	ATGA = 2.2, ARFR = 1.1
	6.5	1984	D & B	—	—	—	3.9	1.1	2.2	ATGA = 5.6, ARFR = 3.4, ATCO = 0.6
Bridger #2	33.2	1980	B	13.4	0.6	—	—	—	—	—
	33.2	1981	B	19.5	2.8	—	—	0.6	1.7	—
	33.2	1984	B	29.1	5.6	—	2.2	—	1.1	ATGA = 1.1
	33.2	1984	B	—	—	—	3.9	1.1	2.2	ATGA = 5.6, ARFR = 3.4, ATCO = 0.6
Kemmerer #1	36.5	1980	D	15.7	—	2.2	0.3	—	—	—
Kemmerer #2	3.0	1980	D	15.7	—	2.2	0.3	—	—	—
Kemmerer #3	37.7	1981	D	15.7	—	2.2	0.3	—	—	—

[a]Information obtained from records at individual mines.
[b]D, drilled; B, broadcast.
[c]Indicates pure live seed unless otherwise noted. Plant symbols: ARCA, *Artemisia cana*; ARFR, *Artemisia frigada*; ARTR, *Artemisia tridentata*; ATCA, *Atriplex canescens*; ATCO, *Atriplex confertifolia*; CHNA, *Chrysothamnus nauseosus*; CHVI, *Chrysothamnus viscidiflorus*; EULA, *Eurotia lanata*; ROWO, *Rosa woodsii*; SAVE, *Sarcubatus vermiculatus*.

Register 1996). This was extrapolated to 0.2 shrubs/m^2 on 100% of the land and compared to shrub densities on pre-1985 seedings by means of a one-tailed t-test ($p \leq 0.05$) to determine if individual site densities were significantly less than the standard.

Results

Comparison of Shrub Densities to the Standard

Total shrub densities on one of five saltbush communities and seven of nine sagebrush communities were significantly greater than 0.2 shrubs/m^2 (single, paired t tests where $p \leq 0.05$) (Table 4). Shrub densities varied between sites within a mine and between mines. Densities for all shrub species on the saltbush sites ranged from 0.09 to 0.14 plants/m^2 among four sites. The density was 0.70 plants/m^2 at Kemmerer #1, giving an overall mean of 0.23 plants/m^2; for the sagebrush sites the range was 0.09 to a maximum 1.92 plants/m^2 at Bridger #1. The mean was 0.61 shrubs/m^2 (Table 4).

The Bridger Coal Company sites had the highest densities, due to large numbers of seedlings that appeared during the cool, wet summer of 1993, one year prior to our study (Norm Hargus, Reclamation Coordinator Bridger Coal, personal communication). The density of mature plants for the dominant shrubs was 0.22 and 0.90 shrubs/m^2 at Bridger #1 and #2, respectively (Table 5).

Shrub Seeding Rates

Shrub density on sagebrush sites correlated with seeding rates ($p < 0.001$). No correlation was found between seeding rates and density among saltbush sites. Regression analysis of seeding rate (pls seeds/m^2) and density at the nine sagebrush sites gave an $r^2 = 0.85$. The same analysis without the two Bridger Coal sites gave an $r^2 = 0.97$ (Fig. 2).

Standing-Dead Shrubs

The number of standing-dead shrubs was low on most sites. Among the fourwing saltbush communities, however, the Pathfinder site had about equal numbers of live and dead shrubs, while Seminoe I #1, had a standing-dead shrub for every two alive (Table 6). Among big sagebrush communities, the Dave Johnston and Pathfinder sites had one standing dead for each 4.3 and 6.5 live shrubs, respectively (Table 6).

Observations on Reclamation Procedures

There is some benefit to comparing observed characteristics of the post-mining shrub community with reclamation procedure. We urge caution in making conclusions based on this comparison because of the limited sample number or lack of desirable controls. But we also recognize that observations can provide important insight into reclamation methods.

Table 4. Shrub densities (plants/m²) for dominant shrub and total shrubs compared to proposed standard with single paired *t* tests by site.

Mine Site	*Atca/Artr** ± *SD*	t *Value*	*Total Shrubs* ± *SD*	t *Value*	*Critical* t *(p = 0.05)*
Atriplex canescens Communities					
Black Thunder	0.09 ± 0.04	−11.9	0.10 ± 0.05	−11.9	1.73
Belle Ayr	0.14 ± 0.07	−1.9	0.14 ± 0.08	−1.8	2.13
Kemmerer #1	0.69 ± 0.14	16.0	0.70 ± 0.29	39.3	1.73
Pathfinder #1	0.08 ± 0.04	−5.9	0.12 ± 0.09	−11.4	1.73
Seminoe I #1	0.06 ± 0.04	−17.1	0.09 ± 0.03	−35.4	1.73
Overall Mean	0.22		0.23		
Artemisia tridentata Communities					
Bridger #1	1.71 ± 0.51	13.3	1.92 ± 0.62	71.8	1.73
Bridger #2	0.77 ± 0.3	8.4	1.11 ± 0.36	50.0	1.73
Dave Johnston	0.16 ± 0.09	−1.7	0.51 ± 0.15	21.6	1.73
Kemmerer #2	0.09 ± 0.07	−6.6	0.09 ± 0.05	−18.9	1.73
Kemmerer #3	0.02 ± 0.02	−43.7	0.22 ± 0.09	2.3	1.73
Pathfinder #2	0.03 ± 0.04	−23.6	0.14 ± 0.06	−11.0	1.7
Seminoe I #2	0.17 ± 0.18	−0.7	0.22 ± 0.10	1.8	1.73
WyoDak #1	0.45 ± 0.18	4.4	0.64 ± 0.25	11.1	1.8
WyoDak #2	0.37 ± 0.30	1.7	0.62 ± 0.21	8.8	0.8
Overall Mean	0.42		0.61		

*Atca, *Atriplex canescens*; Artr, *Artemisia tridentata*.

Effect of Seeding Grass with Shrubs. Grass-seeding rates ranged from 15 to 29 kg pls/ha (Table 3), but no correlation was found between shrub density and grass-seeding rates. Schuman et al. (1998) also found no difference in sagebrush seedling density when grasses were seeded at 16 or at 32 kg pls/ha. They found, however, that sagebrush seedling density was significantly greater where sagebrush was seeded without grass.

Sagebrush Immigration. Sagebrush occurred in three of the four saltbush communities where sagebrush was not included in the original seed mix. It has apparently immigrated into the saltbush communities at Black Thunder and Seminoe I, has either immigrated or was recruited from scattered plants in the initial seeding at Kemmerer #1, and was also successfully oversown into 3- and 4-year-old stands of saltbush at Bridger #1 and #2.

Non-local Seed. At three sites, Kemmerer #2, Kemmerer #3, and Seminoe I #2, plant stature and leaf configuration (Barker & McKell 1986) suggested that *Artemisia tridentata* Nutt. ssp. *tridentata* (basin big sagebrush) was seeded into Wyoming big sagebrush habitat. The shrub density on these seedings (Table 4) and our observations indicate that the nonlocal subspecies have established significant stands.

Table 5. Shrub densities ± SD (plants/m²) by seedlings and mature plants for dominant shrubs at the Bridger Coal Company sites.*

	Atriplex canescens		Artemisia tridentata	
	Seedlings	*Mature Plants*	*Seedlings*	*Mature Plants*
Site #1	<0.01 ± 0.01	0.02 ± 0.01	1.50 ± 0.93	0.20 ± 0.09
Site #2	0.07 ± 0.09	0.20 ± 0.08	0.07 ± 0.05	0.70 ± 0.55

*Seedlings were defined as plants ≤10 cm height.

Discussion

Comparison of Shrub Densities to the Standard

Eight of 14 shrub communities had densities exceeding the extrapolated standard of 0.2 shrub/m². Four of the six seedings not meeting the extrapolated standard were fourwing saltbush communities with low shrub seeding rates and few species (Table 3). We acknowledge that the inclusion of standing-dead shrubs in the counts may give benefit of the doubt to earlier practices. Also, while the extrapolation provides a means of comparing pre-1985 seedings with the new standard, we recognize two limitations. First, the extrapolation ignores the current requirement for shrub patches (spatial diversity). Second, it ignores the difficulty and cost of increasing shrub densities above 0.2 shrub/m².

Shrub Seeding Rates

High seeding rates coupled with seed dormancy in Wyoming big sagebrush (McDonough & Harniss 1974; Booth et al. 1995) appear to increase opportunities for

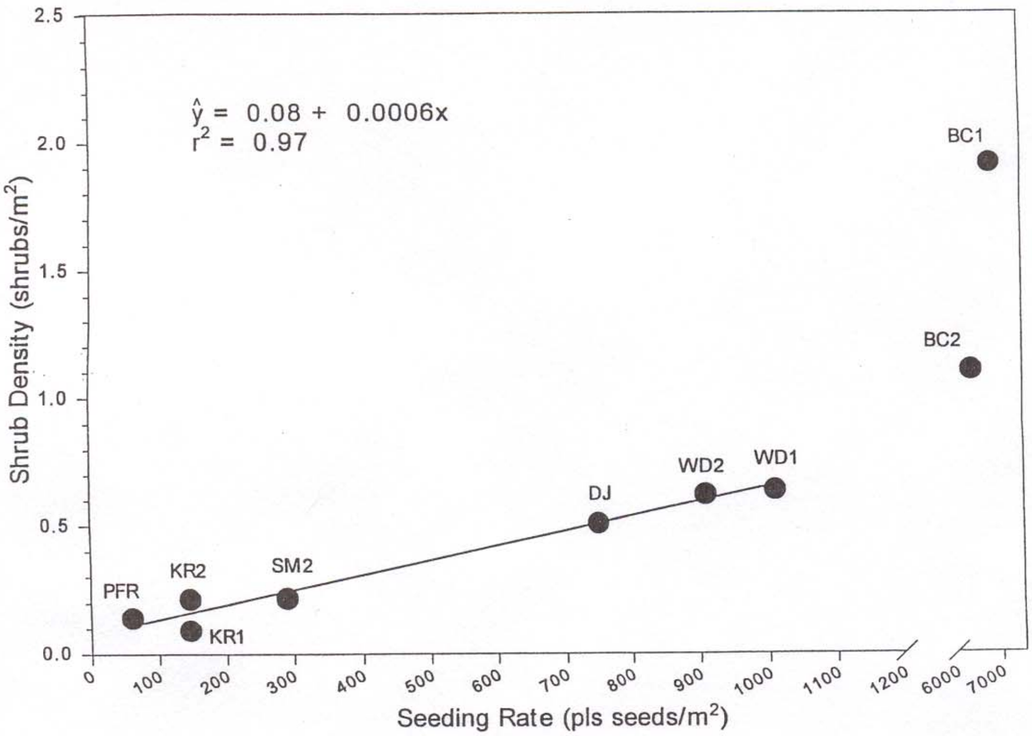

Figure 2. Shrub density as influenced by the number of pure live seeds sown. The regression equation does not include data from the Bridger Coal Company sites. Note the break in the *x* axis between 1200 and 6000 seeds/m^2. KR2, Kemmerer #2; PFR, Pathfinder #2; KR3, Kemmerer #3; SM2, Seminoe I #2; J, Dave Johnston; WD2, WyoDak #2; WD1, WyoDak #1; BC2, Bridger Coal #2; BC1, Bridger Coal #1.

shrub recruitment. Richardson et al. (1986) reported that shrub densities for sagebrush, rabbitbrush, and bitterbrush all increased on phosphate-mined lands in southeastern Idaho when the seeding rate was increased. They reported that increasing the bulk seeding rate from 5 to 56 kg/ha doubled the total shrub density as measured 7 years after seeding.

We found that seed densities between 60 and 1000 shrub seeds/m^2 had a positive, linear relationship with shrub densities up to 0.6 shrubs/m^2. We doubt that shrub densities significantly greater than 0.6 shrubs/m^2 can be expected to result from further increases in seeding rate or in seed-mix species diversity. Consider that the Bridger seedings were on freshly stripped topsoil,

Table 6. Number of standing-dead and live shrubs and mean height (cm) with standard deviation for the dominant shrubs by shrub community at 14 study sites.[a]

	Atriplex canescens				*Artemisia tridentata*			
	Number		*Mean Height ± SD*		*Number*		*Mean Height ± SD*	
Mine Site	*Dead*	*Live*	*Dead (cm)*	*Live (cm)*	*Dead*	*Live*	*Dead (cm)*	*Live (cm)*
Atriplex canescens Communities								
Black Thunder	11	328	30.3 ± 16	73.2 ± 18.3	1	1	—	11.0
Belle Ayr (5 transects)	2	89	82 ± 7.0	74.3 ± 23.2	0	0	—	—
Kemmerer #1	13	392	50.9 ± 25.8	51.5 ± 24.5	0	6	—	27.7 ± 9.7
Pathfinder #1 (30 transects)	226	256	35.6 ± 13.2	45.9 ± 18.1	0	4	—	10.5 ± 2.4
Seminoe I #1	83	166	52.8 ± 17.0	72.2 ± 25.6	0	40	—	11.6 ± 10.4
Artemisia tridentata Communities								
Bridger #1	0	46	—	38.2 ± 23.6	5	562	12.6 ± 5.9	34.7 ± 15.5
Bridger #2	3	416	17.3 ± 24.5	55.4 ± 41.5	3	242	8.0 ± 6.5	33.1 ± 14.4
Dave Johnston	0	5	—	20.2 + 8.8	77	331	18.9 ± 7.9	20.1 ± 6.7
Kemmerer #2	28	255	56.4 ± 17.9	65.8 ± 29.2	1	80	17.0	42.2 ± 20.6
Kemmerer #3	0	0	—	—	4	267	81.0[b]	59.4 ± 25.3
Pathfinder #2 (30 transects)	80	568	47.0 ± 26.8	51.2 ± 24.7	26	123	8.2 ± 2.6	10.0 ± 4.0
Seminoe I #2	0	46	—	82.3 ± 28.0	15	638	33.2 ± 25.2	46.4 ± 26.8
WyoDak #1 (10 transects)	0	50	—	14.1 ± 10.0	0	186		64.1 ± 31.1
WyoDak #2 (10 transects)	0	1	—	84.0	24	156	29 ± 12.0	33.5 ± 12.6

[a]Data are from 20 transects unless otherwise indicated. Data for living shrubs are given for comparison.
[b]Height measured on only one plant; other standing-dead plants were trampled by grazing livestock.

were seeded two and three times with a diversity of species, and had total shrub seeding rates of 24 and 27 kg pls/ha (Tables 2 and 3). This resulted in more than 6000 shrub (and half-shrub) seeds/m^2 (Fig. 2). Also, these sites occur in a shrub-dominated ecosystem with an average density of 3.7 shrubs/m^2 in natural stands (Boles 1983). Yet neither of these reclaimed sites supported one mature shrub/m^2.

Obtaining a shrub density at or above one mature shrub/m^2 may require favorable climatic conditions such as those that occurred at some sites in 1993 and resulted in the emergence of many sagebrush seedlings (Schuman et al. 1998; N. Hargus, personal communication). Lommasson (1948) concluded, after his 31-year study, that "Correlation of the 61-year-old stand with periodic weather conditions indicates that its establishment in 1885 coincides with a period of growing conditions favorable for seedling establishment and that the new stand in the companion plot established itself during a period of favorable moisture conditions. It may be concluded, therefore, that moisture conditions favorable for seedling establishment are necessary for the beginning of development of a *thick* stand of sagebrush . . ." (italics added).

Episodic recruitment of plants has also been reported by Went (1955) and others. West et al. (1979) tested for "pulse" recruitment to grazed sagebrush-grass communities of southeastern Idaho, finding that "Although exceptionally high numbers of seedlings were observed in certain years, overall age-class-density distributions do not usually deviate significantly from the log-normal model." They acknowledged, however, that, while recruitment of age-class 1 individuals follows an approximately log-normal distribution, open space for recruitment within the community may contribute "to some deviations from this model."

The unoccupied space of reclaimed-site seedbeds allows recruitment "pulses." The clean linear relationship between seed and shrub density (Fig. 2) is evidence that seeding rates influence the size of the shrub recruitment pulse up to a point. High-density recruitment, even with high seed density, is limited by moisture and other factors. Thus the establishment of *thick* shrub stands depends on an unusual lack of limitations. That is why a large flush of 1993 seedlings did not occur at each of our study sites, and, as shown by West et al. (1979), that is why a seedling flush may not become a high-density stand of mature shrubs. It is hoped that establishing shrub patches on the most suitable parts of the landscape will result in greater shrub seedling survival and thus greater stand densities.

Standing-Dead Shrubs

Heavy browsing by wildlife was evident from severely hedged shrubs at the mines with the greatest number of standing-dead shrubs. Also, neither Pathfinder nor Seminoe I sites appeared to have naturally occurring fourwing saltbush (Wyoming Department of Environmental Quality–Land Quality, and Natural Resources Conservation Services, personal communications). So it is logical to question the adaptability of the fourwing saltbush seeded on the two sites where the greatest numbers of standing-dead shrubs were encountered.

Observations on Reclamation Procedures

Our study has addressed some long-standing questions about shrub reclamation in Wyoming and adjacent states. One of these is whether sagebrush will immigrate into the fourwing saltbush sites (Boles 1984). Several authors have suggested that fourwing saltbush on mined lands might function as a pioneer shrub (Wagner & Aldon 1978; Boles 1984; Booth 1985) and that, over time, a site planted to fourwing would be recolonized by shrubs dominant in the pre-mining community. Sagebrush and other shrubs have established and are being recruited into seedings where fourwing saltbush was seeded as high as 2.2 kg pls/ha. But natural immigration is limited to areas adjacent to established sagebrush communities (Young & Evans 1989; Lyford 1995). Natural immigration of other shrubs into the nearly pure stands of fourwing will likely require more than two or three decades unless these stands are overseeded. The success at Bridger #1 and #2 suggests that over-seeding (broadcasting) sagebrush and other shrubs can be an effective means of increasing the shrub density and diversity of early seedings.

A second question has been whether fourwing stands will persist for 10 or more years. We found that fourwing was reproducing in all but one of the plant communities we studied, and that it has persisted on all 14 sites for more than 10 years. Therefore, fourwing saltbush appears to have reasonably stable populations.

Protecting the watershed and restoring wildlife habitat and livestock forage are important reclamation objectives. *Antilocapra americana* (Ord.) (antelope), *Odocoileus* ssp (deer), and *Centrocercus urophasianus* Bonaparte (sage grouse)—species common on pre-mining rangelands—all prefer a diverse shrub community over monocultures of any single shrub species (Postovit 1981; Roberson 1984; Yoakum 1984). Fourwing saltbush can help meet the habitat requirements of these species (Yoakum & Dasmann 1969; Boles 1984; Medcraft 1984) and the forage needs of livestock (Shoop et al. 1985), but it should not be used exclusively as it once was.

Conclusions

Shrub densities on pre-1985 seedings of Wyoming mined lands were correlated with shrub-seeding rates up to 1000 seeds/m^2 and shrub densities up to 0.6 shrubs/m^2 where sagebrush was part of the shrub-seed mixture. Seedings where a diversity of shrub species were used generally had greater 1994 densities. Therefore, we conclude that the likelihood of meeting the shrub standard can be enhanced by seeding diverse shrub mixtures and by using high shrub-seeding rates.

Acknowledgments

Our work was supported in part by the Abandoned Coal Mine Lands Research Program at the University of Wyoming. Support was administered by the Wyoming Department of Environmental Quality from funds returned to Wyoming from the Office of Surface Mining of the U.S. Department of the Interior. We thank the following mines and their reclamation specialists for cooperating in this study: Belle Ayr (Amax Coal West, Inc.), Black Thunder (Thunder Basin Coal Co.), Bridger Coal (Bridger Coal Co.), Dave Johnston (Glenrock Coal Co.), Kemmerer Coal (Pittsburg & Midway Coal Mining Co.), Pathfinder (Pathfinder Mines Corp.), Seminoe I (Arch Minerals), and Wyo-Dak (WyoDak Resources Development Corp.). We also thank G. V. Richardson, Statistician, U.S. Department of Agriculture–Agricultural Research Service, Ft. Collins, Colorado, for suggestions on experimental design and statistical analysis, and W. A. Laycock, F. G. Lindzey, E. F. Redente, C. L. Wambolt, C. Skilbred, and P. Smith for their critical review of this manuscript.

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Appendix 1. Historical summary of events affecting shrub revegetation regulations on coal-mined lands in Wyoming.*

Year	*Action*
1980	Wyoming Coal Program approved, but shrub density standards differ from federal requirements.
1983	The Office of Surface Mining (OSM) adopts new regulations and indicates its intent to require that shrubs and trees be restored to a density equal to that of the pre-mining density. OSM is subsequently sued by the coal industry and by several environmental groups. The state of Wyoming forms a task force subcommittee charged with developing an alternative to the 100% requirement.
1986	The Wyoming Department of Environmental Quality (WDEQ) and OSM accept a Wyoming task force subcommittee recommendation for a post-mining shrub density goal of 1 shrub/m^2 on 10% of the affected area.
1987	Judge Thomas Flannery of the District Court of the District of Columbia completes a three-part decision on the suit against OSM.
1988	OSM issues revised federal rules as a result of Judge Flannery's decision. The new rules require state agencies responsible for forestry and wildlife programs to approve revegetation regulations and standards when wildlife is part of the post-mining land use.
1989	Wyoming Game and Fish Department (WGFD), claiming authority under the new OSM rules, petitions WDEQ for a standard (instead of a goal) post-mining shrub density of 1 shrub/m^2 on 20% of the affected area, and the right to specify species composition. The 20% standard was debated extensively by the Land Quality Advisory Board (LQAB). WGFD refused to accept a compromise ruling. A committee was formed of WGFD, WDEQ, and industry personnel to negotiate an acceptable compromise.
1990	The LQAB votes to recommend a proposed density standard of 1 shrub/m^2 on 20% of the affected surface.
1991	The Wyoming legislature passes laws that limit WGFD's approval to mined lands dedicated to the management of fish or wildlife. Consultation with WGFD, but not its approval, is required on grazing lands that support wildlife.
1992	OSM concurs with Wyoming's limit on WGFD approval authority. The proposed density standard is submitted to OSM.
1993	The Wyoming legislature passes a bill defining kinds of land use, setting the shrub density standard at 1 shrub/9 m^2 on 10% of the affected surface, and specifying that the pre-mining dominant shrub need not be the post-mining dominant. These changes are submitted to OSM as a formal program amendment.
1994	OSM disapproves Wyoming's program amendment.
1995	The Wyoming legislature passes a law that defines grazing land and critical wildlife habitat, requires that native shrubs be used in reclamation, allows that no shrub species be required to be more than one-half of the shrubs in the post-mining community, and provides authority for promulgating a proposed rule stating that, "Except where a lesser density is justified from pre-mining conditions . . . at least 20% of the eligible lands shall be restored to shrub patches supporting an average density of 1 shrub/m^2. Patches shall be no less than .05 acres each and shall be arranged in a mosaic that will optimize habitat interspersion and edge effect . . . . This standard shall apply upon approval by OSM to all lands affected thereafter."
1996	In August, OSM approves the 1995 proposed rule and it becomes final.

*Wyoming Environmental Quality Council (WEQC) 1995; Federal Register 1996.