Topsoil Depth Effects on Reclaimed Coal Mine and Native Area Vegetation in Northeastern Wyoming

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Abstract

Mandated uniform topsoil replacement may hinder or prevent compliance with reclamation bond release standards such as canopy cover, aboveground production, shrub density, and diversity. This investigation was conducted at a coal mine in northeastern Wyoming in order to evaluate the relationship between variable topsoil replacement depths of 15, 30, and 56 cm and short-term revegetation success. Vegetation variables of total cover, total vegetation canopy cover, total number of species, and average number of species (based on cover sampling) were determined on both reclaimed and 2 native reference areas (Upland Grass and Breaks Grass) during 2000, 2001, and 2002, with aboveground production being measured in 2002. The highest total number of species encountered based on canopy cover and aboveground production sampling was in the 30-cm reclaimed treatment, many of which were desirable seeded and volunteer perennial grasses and forbs. In 2001, total vegetation cover on the 56-cm reclaimed treatment was significantly greater than on the 15-cm treatment. Comparison of the current study area to a 1991 reclaimed site indicated a consistent general pattern of species establishment. Aboveground production was also higher in the current reclaimed area than in the native reference areas, while total cover and total vegetation cover were lower. Shannon–Wiener H′ values, based on absolute total vegetation canopy cover, were greater in the 30-cm reclaimed treatment; however, a majority of diversity indices indicated that the Breaks Grass native reference area was more diverse than either Upland Grass or Reclaimed sites. From observations made at the North Antelope/Rochelle Mine, a mosaic of different topsoil depths, including the shallow 15- and 30-cm depths as well as the mandated 56-cm depth, creates the broadest range of vegetation response under a standard regime of revegetation practices. Thus, the capacity to replace different thickness of topsoil should be a reclamation practice available to mine operators.

Resumen

Remplazar la capa superficial del suelo a la profundidad establecida por mandato puede retardar o impedir el alcanzar los estándares de rehabilitación tales como: la cobertura de copa, la producción de biomasa aérea, la densidad y diversidad de arbustos. Esta investigación se condujo en una mina de carbon en el nordeste de Wyoming para evaluar las relación entre el remplazo variable de la capa superficial del suelo a profundidades de 15, 30, y 56 cm y el éxito a corto plazo de la revegetación. Durante el 2000, 2001, y 2002 se determinaron variables de vegetación como la cobertura total, la cobertura de copa de la vegetación total, el número total de especies y el número promedio de especies (basado en muestreos de cobertura), la medición de las variables se realizó en el área rehabilitada así como en dos áreas nativas de referencia (Upland Grass y Breaks Grass) y en el 2002 se midió la producción de biomasa aérea. El mayor número total de especies encontrados en base los muestreos de cobertura de copa y la producción de biomasa aérea ocurrió en el tratamiento de rehabilitación de 30 cm, muchas de las cuales fueron especies deseables sembradas y zacates perennes y hierbas voluntarias. En el 2001, la cobertura total de la vegetación en el tratamiento de restauración de 56 cm fue significativamente mayor que en el tratamiento de 15 cm. Comparaciones entre el área actual de estudio con un sito rehabilitado en 1991 muestran un patrón general consistente del establecimiento de especies. La producción de biomasa aérea también fue mayor en el sitio actual de rehabilitación que en las áreas nativas de referencia, mientras que la cobertura total y la cobertura total de la vegetación total fueron menores. Los valores de H′ de Shannon–Wiener, basados en la cobertura absoluta de copa de la vegetación total, fueron mayores en el tratamiento de 30 cm; sin embargo, la mayoría de índices de diversidad mostraron que el área nativa de referencia Breaks Grass fue más diversa que el área de referencia de Upland Grass y el área rehabilitada. De observaciones hechas en la mina North Antelope/Rochelle se deriva que un mosaico de diferentes profundidades de remplazo de la capa superficial del suelo, incluyendo las profundidades someras de 15 y 30 cm, así como la obligatoria de 56 cm, crea el más amplio rango de respuesta de la vegetación bajo el régimen estándar de prácticas de revegetación. Así, la capacidad para remplazar diferentes espesores de la capa superficial del suelo debe ser una práctica disponible para los operadores de minas.

Key Words: plant production and diversity, species richness, Shannon–Wiener diversity indices

INTRODUCTION

Reclamation success is determined, in part, by appropriate revegetation that is evaluated quantitatively by measuring

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plant production, cover, and species diversity (Ries and Nilson 2000). The federal requirements for "diverse, effective and permanent" vegetation cover (Code of Federal Regulations 1982, 1983) lead to 3 questions: 1) what constitutes "diverse, effective and permanent" plant cover, 2) how should plant species diversity be measured, and 3) what operational practices might affect or promote plant species diversity? The first 2 questions are often debated because of numerous interpretations of diversity, lack of coordination between regulating agencies, and deficiencies in qualitative and quantitative evaluation of diversity (Wade 1999). Challenges to achieving reclamation success in the western United States, including plant species diversity, consist of various conditions such as low precipitation, high temperatures, and high evapotranspiration rates, where water may be the most limiting factor (Ries and Nilson 2000). To address these challenges in the context of the third question, some researchers have investigated reclamation techniques, in addition to varying topsoil replacement depth, that may promote plant species diversity. These include seeding method, seeding rate, number of species seeded, direct-haul topsoiling, variable topsoil replacement depths, seeding date, irrigation, burning, and grazing (DePuit et al. 1980; DePuit 1984; Nilson et al. 1985; Ogle and Redente 1988; Munshower 1994; Buchanan et al. 1999).

Vegetation diversity requirements of the Surface Mining Control and Reclamation Act incorporate small-scale ecological concepts such as plant species and structural diversity, as well as plant species composition, which may include dominant and rare species. "Seasonal variety" incorporates the concepts of phenology and life-form, while "effective, permanent self-regeneration" is related to vegetation establishment, production, competition, reproduction stability, and resilience (Allen 1990). Wali (1999) indicated that ecological stability and vegetation diversity are often linked, an important concept to consider on mined lands where short- and long-term successional stability is critical. Whatever method selected for determining diversity, data should be collected over time to assess trends (Kern 1999; Schuman 1999). Natural differences in populations based on factors other than mining need to be evaluated. Premine baseline data and ongoing reclaimed area monitoring studies that include native reference areas and postmine vegetation comparisons can assist in addressing this temporal issue. Ultimately, during evaluation of diversity and reclamation success, one must also consider the concept of chance in achieving comparable life-form composition and seasonality (Sindelar 1980).

A lack of research on this subject was noted between the early to mid-1980s and the mid- to late 1990s. The only research during this time frame conducted in northeastern Wyoming was published by Barth and Martin (1984). Therefore, in order to address concerns about utilizing varying topsoil replacement depths to enhance plant diversity within a given permit area in northeastern Wyoming, a 3-year study was conducted to assess the effect of topsoil replacement depths on plant species diversity, vegetation cover, and production as well as to determine whether variable soil depth replacement enhances the development and/or differentiation of postmine vegetation communities.

MATERIALS AND METHODS

Treatment Design and Selection

Our study site is located on the North Antelope/Rochelle Mine (NARM) (lat 43°32′15″N, long 105°15′19″W) about 32 km southeast of Wright, Wyoming (Schladweiler 2003). Topsoil replacement depth treatments included 1) 15-cm depth, 2) 30-cm depth, and 3) 56-cm "mine designated permit" depth. Triplicate reclaimed treatment plots were constructed on a uniform site to control variables other than topsoil depth (e.g., similar slope, aspect, stockpiled topsoil, subsoil and backfill sources, and seed mix) and to reflect a landscape position that would best represent a pre- and postmine Breaks Grass community. The backfill material at this study site had pH, electrical conductivity (EC), and sodium absorption ratio (SAR) values that were determined as suitable for plant growth (WDEQ-LQD 2001; Schladweiler et al. 2004).

Native reference sites in both Upland Grass and Breaks Grass areas in the northern mixed-grass prairie were established on the mine in 1997 within a 10-km distance from the reclaimed study area. Reference areas were selected for purposes of baseline vegetation sampling to compare with the resulting reclaimed environment. Although the Breaks Grass site was selected to best represent the seed mix utilized on the treatments, the Upland Grass site was also selected since many reclaimed areas result in a vegetation community more similar to Upland Grass. Within the Breaks Grass and Upland Grass native reference areas, 3 noncontiguous blocks with similar slope and aspect as the reclaimed treatments were selected. Comparisons were made between the 15-, 30-, and 56-cm reclaimed treatments and the top, middle, and bottom slope positions within the native areas under the assumption that native undisturbed soil is most shallow at the top of the hill or on the slope shoulder, while the deepest soil is present at the toe of the slope. Reclaimed treatment replicate size was about 53 × 76 m. Dimensions of the native reference area plots varied somewhat based on topographic position but were generally 18 × 50 m. All soil and vegetation sample locations within the reclaimed and native reference areas were randomly determined and the latitude and longitude coordinates recorded by mine surveyors during all 3 sample years.

Three-year-old stockpiled topsoil salvaged from Breaks Grass areas was used for the reclaimed treatment area. Final slope contouring, backfill ripping, and topsoil replacement activities were conducted from February to October 1998. "Schuyler" barley (*Hordeum vulgare* L.) was seeded (34 kg/ha) in early December 1998 to establish a stubble mulch. The barley was mowed during the 1999 growing season (mid-July), which is a normal practice at NARM to reduce competition from volunteer barley plants with the permanent perennial seed mix (S. Belden, NARM Environmental Supervisor, personal communication, 2001). To reflect current reclamation practices at NARM, the reclaimed area was fertilized during seeding operations at the rate of 61 kg/ha of NPK 11-52-0 fertilizer. Nitrogen use at NARM is generally reduced to limit weed competition, while phosphorus is used to promote root growth. The permanent reclamation seed mix was planted in late November 1999 (Table 1).

Table 1. Shrub-grass seed mix used at the variable topsoil reclaimed study site on the North Antelope/Rochelle Mine in northeastern Wyoming in fall 1999.

Species	Common name	Variety	Life-form[1]	PLS[2] (kg/ha)	Mix (%)
Drilled (grain box) mix					
Elymus lanceolatus (Scribn. & Sm.) Gould	Thickspike wheatgrass	Critana	CSPG	2.25	13.3
Elymus smithii (Rydb.) Gould	Western wheatgrass	Rosana	CSPG	1.12	6.7
Andropogon scoparius Michx.	Little bluestem		WSPG	1.12	6.7
Calamovilfa longifolia (Hook.) Scribn.	Prairie sandreed	Goshen	WSPG	0.56	3.3
Poa secunda Presl	Sandberg bluegrass		CSPG	1.12	6.7
Stipa viridula Trin.	Green needlegrass	Lodorm	CSPG	1.12	6.7
Astragalus cicer L.	Cicer milkvetch	Lutana	PF	1.68	10.0
Penstemon strictus Benth.	Rocky Mountain penstemon		PF	1.12	6.7
Spharalcea munroa (Dougl. ex Lindl.) Spach ex Gray	Munro globemallow		PF	0.56	3.3
Atriplex canescens (Pursh) Nutt.	Fourwing saltbush	Wytana	FS	1.12	6.7
Atriplex gardneri (Moq.) Dietr.	Gardner saltbush		HS	1.12	6.7
Dribbled (fluffy box) mix					
Bouteloua gracilis (Kunth) Lag. ex Griffiths	Blue grama	Hachita	WSPG	1.12	6.7
Artemisia tridentata Nutt. var. *wyomingensis* (Beetle & Young)	Big sagebrush	Wyoming	FS	1.68	10.0
Krascheninnikovia lanata (Pursh) Meeuse & Smit	Winterfat		FS	1.12	6.7
Total				16.8	100

[1]CSPG indicates cool-season perennial grass; WSPG, warm-season perennial grass; PF, perennial forb; FS, full shrub; HS, half shrub.
[2]PLS indicates pure live seed.

Sampling Methods

Vegetation sampling was conducted during June and July, 2000, 2001, and 2002. All taxonomic nomenclature for encountered species followed Dorn (1992). Five 30-m point intercept cover transects, origin and direction randomly determined, were sampled within each reclaimed treatment replicate. A total of 3 30-m transects, origin and direction randomly determined, were sampled in each native reference area plot for an overall total of 9 transects per slope position (i.e., top, middle, and bottom).

Total vegetation canopy cover consisted of all live plant species encountered as a first hit on the point intercept transect, while total cover included total vegetation cover as well as litter (which included standing dead) and rock (WDEQ-LQD 2001). Within cover transects, sample hits were read at 1-m intervals along the entire length of the 30-m transect, and categories included individual plant species, litter/rock, and bare ground. Recorded hit information was used to assess absolute cover and relative cover. Absolute cover is the derivation of percent cover of a given category in a fashion that is operationally independent of the other categories, whereas relative cover is not operationally independent (WDEQ-LQD 2001). As a measure of species richness, both the average number of species per transect and the total number of species per treatment were calculated for each site. Aboveground plant production was measured in 2002 by clipping all major plant species by life-form within a 1-m^2 circular plot and oven drying the samples for 24 hours at 18°C. Data were averaged over all transects in each plot.

Statistical analyses were conducted in 2 phases. The first involved just the reclaimed treatment area to test the null hypothesis that percent total cover (TOTCOV), percent total vegetation cover (TOTVEG), average number of plant species per transect (ASPEC), and total number of plant species (TOTSPEC) were the same among the reclaimed treatments using a 1-way analysis of variance set in a completely randomized design. These analyses were conducted separately by year. The second involved the reclaimed and 2 reference areas to test the null hypothesis that TOTCOV, TOTVEG, ASPEC, and TOTSPEC were the same among the reclaimed area and the 2 reference areas using a split plot in time factorial analysis of variance set in a completely randomized design (Steele and Torrie 1980). As production (PROD) was just measured in 2002, we tested the null hypothesis that PROD was the same among the reclaimed area and the 2 reference areas using a 2-factor factorial analysis of variance set in a completely randomized design (the second factor was the reclaimed treatment or reference area slope position). Finally, we tested the null hypothesis that absolute and relative cover were the same among the reclaimed area and the 2 reference areas using a split plot in time factorial analysis of variance set in a completely randomized design. These analyses were conducted separately by life-form. Means were separated by Tukey's separation technique (Snedecor and Cochran 1967). All calculations were facilitated by use of the GLM procedure of the Statistical Analysis System (SAS Institute 1990), and all tests were conducted at the $\alpha = 0.05$ level of type I error.

Average number of plant species and total number of plant species were used to describe 2 types of species richness in this study. Average number of plant species is the mean number of plant species encountered on any given transect within a par-

Table 2. Comparison of plant parameter means for each treatment and year at the reclaimed study site on the North Antelope/Rochelle Mine in northeastern Wyoming.[1]

Treatment	Year		
	2000	2001	2002
	Average no. species[2] (no./transect)		
15 cm	4.1	5.5	5.8
30 cm	4.2	6.6	6.0
56 cm	4.1	5.3	4.9
	Total vegetation cover[3] (%)		
15 cm	51.8	42.4b	33.1
30 cm	49.8	44.4ab	36.4
56 cm	52.2	57.6a	36.4

[1]Means for a parameter within a treatment in a particular year that are followed by the same letter are not statistically different ($P > 0.05$) based on Tukey's HSD. Data without letters are not significant. Plant parameter values were combined by reclaimed treatment for each sample year and analyzed using analysis of variance.
[2]Results from 2-factor analysis of variance.
[3]Results from 1-factor analysis of variance.

ticular vegetation type. Total number of species is the sum of all plant species encountered within a particular reclaimed treatment or reference area slope position.

Shannon–Wiener comparisons were selected for evaluation of diversity in this study based on its previous wide use (Shannon and Weaver 1949; Magurran 1988). In the current study, both absolute total vegetation cover and production data were used to generate Shannon–Wiener values of H′ as a measure of diversity. In addition to the Shannon–Wiener index, diversity indices were also calculated according to Simpson (1948), McIntosh (1967), Berger and Parker (1970), and Magurran (1988). These were chosen because they used more than 1 vegetation attribute (Peet 1974). The Shannon–Wiener diversity index was calculated on a replicate basis and analyzed by 1-factor analyses of variance to determine differences in reclaimed treatments or reference area slope positions. All remaining indices were calculated on an overall treatment or reference area slope position with no statistical analysis.

Utilizing the 2002 reclaimed area data, a composite Shannon–Wiener value was calculated for the 56-cm "mine designated permit" depth treatment only to compare with the combined 15-, 30-, and 56-cm topsoil depth reclaimed treatment data. Because Shannon–Wiener values were calculated from abundance data (i.e., cover estimates), values are dependent on the amount of area that is sampled; therefore, the 2 Shannon–Wiener values were also determined from much different-size areas. This allowed some measure of comparison between the deeper reclaimed topsoil treatment, which is the mandated replacement depth at NARM, as compared to the combined set of reclaimed topsoil treatments. This comparison allowed us to evaluate a mandated homogenous depth to our 3 varied depths. In addition, a reclaimed area at NARM that was seeded in 1991 was also compared to our more recently seeded study area. Life-form cover differences were examined based on in-house cover monitoring by the mine in 1995, 1998, and 2001 as well as production monitoring in 1996, 1999, and 2002.

RESULTS AND DISCUSSION

Climatic conditions were droughtlike for 2000–2002, based on mine records, despite the fact that precipitation was slightly above average for 2001 according to the official NOAA site closest to the study area. The mean annual precipitation for the NARM meteorological station was 254 mm for the period of record 1990–2002, while the Dull Center annual average for the same period of record was 363 mm; NOAA Dull Center average precipitation from 1948 to 2002 was 315 mm. The majority of annual precipitation at NARM occurs from March through June. Although some months were atypical for average precipitation (e.g., July 2001), the majority of months were below average. Highest precipitation at NARM in October 1998 was 140 mm, which is over half the normal annual precipitation. Fall moisture and subsequent subsoil wetting provides a large share of the growing season moisture for annual cover crops or annual forbs and grasses as well as volunteer perennials.

Reclaimed Area

At this early age of the reclaimed area, significant plant parameter differences in reclaimed treatments or between years were limited. Higher values for average number of plant species were determined in the 30-cm reclaimed treatment in all 3 years (Table 2). In the 56-cm reclaimed treatment, 2001 total vegetation canopy cover at 58% was significantly higher than the 15-cm reclaimed treatment value at 42%, while the 30-cm reclaimed treatment value was intermediate to both at 44% but not different from either of the other treatments (Table 2). This reinforces previous research findings that found canopy cover highest on the deepest topsoil reclaimed treatments (Redente and Hargis 1985).

The Shannon–Wiener index for combined reclaimed treatments (i.e., 15, 30, and 56 cm), based on species encountered during cover sampling, was 2.14 versus 1.77 for the 56-cm reclaimed treatment only. Based on species encountered during production sampling, the comparable values were 1.76 for the combined treatments and 1.60 for the 56-cm reclaimed treatment only. In both instances, the combined set produced higher values, which indicates that the use of a mosaic of topsoil replacement depths enhances the overall diversity of a landscape feature. Additional species encountered in the combined cover data set over the single "designated" reclaimed treatment included 2 perennial grasses, 9 perennial forbs, and 1 annual forb, while those enumerated using aboveground production data included 3 perennial grasses, 1 annual grass, 4 perennial forbs, and 3 annual forbs. In most cases, the additional species encountered are considered desirable perennials and valuable from a plant diversity standpoint.

The oldest shrub-grassland reclaimed area at NARM, seeded with the mixture outlined in Table 1, was established in 1991; replacement topsoil depth in this area was 56 cm, but the source of the replacement topsoil was direct hauled, not stockpiled as in the current study. This area was monitored by NARM for vegetative cover in 1995, 1998, and 2001 with production measured in 1996, 1999, and 2002 (NARM, various dates). Annual forbs (AF) and annual grasses (AG) comprised 50% absolute cover in 1995, which dropped off to zero by 2001. Both life-form categories in the current study also experienced a rapid decrease in cover from 2000 to 2002. Cool-season perennial grass (CSPG) absolute cover increased in the older reclaimed area from 1995 to 2001 from 14% to 43%. Perennial forb (PF) absolute cover peaked in 1998 at 20% and dropped off in 2001 to 6%. Warm-season perennial grass (WSPG) absolute cover increased from 1% in 1995 to 8% in 2001. Full shrub (FS) and half-shrub (HS) absolute cover was 1% and 0%, respectively, in 1995 and 4% and 2%, respectively, in 2001.

Cool-season perennial grass production in this older reclaimed area peaked in 1999 at 286 g/m^2 and declined dramatically by 2002 to 106 g/m^2 as a result of drought or other factors such as litter accumulation. The CSPG life-form category accounted for 92% relative production (i.e., percent of total production for a given life-form) in 2002. Warm-season perennial grass production increased from zero in 1996 and 1999 to 9 g/m^2 in 2002. However, WSPG growth in the current reclaimed area was limited because of ongoing drought conditions, lack of timely precipitation conducive to WSPG growth, and overall lack of WSPG individuals. Total production in 2002 for the older reclaimed area was 115 g/m^2 as compared to 60.9 g/m^2 for the reclaimed area in the current study.

Prior research has found that thicker topsoil replacement depths generally result in higher plant cover and/or productivity (Power et al. 1976; McGinnies and Nicholas 1980; Redente et al. 1997; Bowen et al. 2002). Biondini et al. (1985) and Redente and Hargis (1985) also found that forbs and shrubs performed best on 15 cm of topsoil, while total production was higher with deeper topsoil depths. Although the current reclaimed area was only 3 years old, initial results indicated a general trend of higher cover and production values on the deeper reclaimed treatment depth, while the average number of species was greater on the more shallow reclaimed treatments. Limited statistically significant differences between reclaimed treatments within this study may be attributable to the young age of the reclaimed area (Redente et al. 1997; Bowen et al. 2002), and it would be expected that, over time, shallow reclaimed treatment areas would exhibit more diversity.

Barth and Martin (1984) found that 50, 71, and 100 cm of topsoil were necessary on generic, sodic, and acid spoil, respectively, to maximize forage production of crested wheatgrass (*Agropyron cristatum* L. [Gaertn.]), pubescent wheatgrass (*Elymus hispidus* [Opiz] Melderia), green needlegrass (*Stipa viridula* Trin.), thickspike wheatgrass (*Elymus lanceolatus* [Scribn. & Sm.] Gould), and western wheatgrass (*Elymus smithii* [Rydb.] Gould). In the current study, the underlying spoil would be most similar to the Barth and Martin "generic" spoil. In the Barth and Martin study, crested wheatgrass, thickspike wheatgrass, and western wheatgrass productivity appeared to peak at 50-cm topsoil depth and leveled out or declined with increasing topsoil depth on the generic spoil. In the current study, thickspike wheatgrass, riparian wheatgrass (*Elymus lanceolatus* var. *riparius* [Scribn. & Sm.] Dorn), western wheatgrass, and slender wheatgrass (*Elymus trachycaulus* [Link] Gould ex Shinners) formed the dominant CSPG contributing most to absolute cover for all 3 sample years (discussed in a later section) and ultimately relative production throughout all reclaimed treatments but particularly in the 30-cm depth treatments.

Table 3. Comparison of plant parameter means for the reclaimed and native reference (Upland Grass and Breaks Grass) study sites on the North Antelope/Rochelle Mine in northeastern Wyoming.[1]

Location or treatment	2000	2001	2002
Slope position			
		Total cover (%)	
Reclaimed	75.7b	84.6	83.2
Upland Grass	86.7a	88.2	83.6
Breaks Grass	92.1a	87.0	83.8
		Total vegetation cover (%)	
Reclaimed	51.3	48.2b	35.3b
Upland Grass	57.2	68.3a	44.8a
Breaks Grass	54.2	67.4a	47.9a
		Average no. species (no./30 m)	
Reclaimed	4.13b	5.82b	5.58b
Upland Grass	6.85a	7.70a	6.07b
Breaks Grass	6.78a	7.96a	7.15a
		Total no. species (no./replicate)	
Reclaimed	6.89b	11.7	12.1
Upland Grass	10.7a	12.2	10.9
Breaks Grass	10.3a	12.0	12.4
		Production (g/m^2)	
Reclaimed	NA[2]	NA	60.9a
Upland Grass	NA	NA	43.4b
Breaks Grass	NA	NA	40.0b

[1]Means for a parameter between locations in a particular year that are followed by the same letter are not statistically different ($P > 0.05$) based on Tukey's HSD. Data without letters are not significant. Plant parameter values were combined by location over either treatments or reference area slope positions and analyzed using 2-factor analysis of variance. For example, reclaimed production at 60.9 g/m^2 was calculated over all treatments within the reclaimed area only.

[2]NA indicates not available since sampled only in 2002.

Our initial results indicated higher diversity on the shallow reclaimed treatments. Biondini and Redente (1986) found that plant community diversity on a reclaimed area, after 4 years, was also higher at shallow topsoil depths. In an earlier study on a similar area, Biondini et al. (1985) reported that relatively shallow topsoil depths (less than 30 cm) encouraged less aggressive species such as big bluegrass (*Poa juncifolia* Scribn. var. *ampla* [Merr.] Dorn) and winterfat, which enhanced growth of additional desirable species, while deeper soils supported higher amounts of the more aggressive beardless wheatgrass (*Agropyron inerme* [Scribn. and Smith] Rydb.) and western wheatgrass, which tended to suppress encroachment by other species.

Reclaimed and Native Areas

Cover and Production. Total percent cover was significantly lower in the reclaimed than either Upland Grass or Breaks Grass sites in 2000; total percent vegetation cover was significantly lower in the reclaimed sites than either of the 2 native reference areas in 2001 and 2002 (Table 3). Reduced litter, as a result of the young age of the reclaimed sites and lack of effective precipitation from 2000–2002, was also a factor in

Table 4. Significant cover of vegetative life-forms by location and year over all study sites on the North Antelope/Rochelle Mine in northeastern Wyoming.

		Significant category[1]					
Cover type	Life-form	RECA	UG	BG	2000	2001	2002
Absolute	WSPG	0.0b	11.4a	9.5a	9.0a	6.8ab	5.1b
	HS	0.1b	2.4a	1.8a			
Relative	HS	0.2b	4.1a	3.3a			
	FS	0.7b	1.5b	12.5a			

[1]Individual means by life-form between locations that have the same letter are not statistically different ($P > 0.05$) based on Tukey's HSD. Life-form cover values were analyzed by split plot in time analysis on the combined 3-year data set in 1 of 2 ways: by location over treatment or reference area slope position and year and by year over treatment or reference area slope position and location. RECA indicates reclaimed sites; UG, Upland Grass sites; BG, Breaks Grass sites; WSPG, warm-season perennial grass life-form; HS, half shrub life-form; FS, full shrub life-form.

lower total cover on the reclaimed sites. Average number of plant species per transect was statistically lower in the reclaimed than Breaks Grass and Upland Grass sites for all 3 sample years, except in 2002, when reclaimed and Upland Grass were not different. Production in 2002 was significantly higher in the reclaimed area when compared to the native reference areas, which was a result of CSPG growth.

Vegetative life-form differences occurred between the reclaimed and 2 native reference areas (Table 4). The absolute cover of WSPG in both native areas was significantly higher than the reclaimed area, which was zero. Yearly effects were noted in that WSPG cover was significantly higher in 2000 than in 2002. Weather plays a key role in resulting plant communities (Frarck et al. 1992), and lack of WSPG may have resulted from timing of sampling before the atypical 2002 August moisture. Since much of the moisture in the Powder River Basin typically comes during April–June, which is optimum for the growth of CSPG, lack of well-timed summer precipitation limits the growth of WSPG species in favor of CSPG, resulting in reclaimed areas dominated by the latter grasses. Absolute cover of HS in the Upland Grass and Breaks Grass areas was also significantly higher than the reclaimed area. Both the lack of WSPG and desirable HS are a long-term reclamation challenge in this portion of Wyoming. Relative cover of HS was also significantly higher in both native areas than the reclaimed area, while relative FS cover in the Breaks Grass was significantly higher than either the Upland Grass or the reclaimed area.

Species Richness. Average number of plant species per transect and total number of plant species per replicate were significantly lower in the reclaimed area than either of the 2 native reference areas in 2000 (Table 3), indicating greater species richness within the native areas. In 2001 and 2002, 1 or both of the native areas were significantly higher in ASPEC than the reclaimed sites. Although CSPG and AF provided the most absolute cover in the reclaimed area, seeded PF in the 30-cm topsoil reclaimed treatment, such as cicer milkvetch (*Astragalus cicer* L.) and alfalfa (*Medicago sativa* L.), provided the most cover or were most frequently encountered. Within the Upland Grass and Breaks Grass reference areas, CSPG and WSPG provided the most absolute cover, with the exception of AG on the lower slope position in Breaks Grass. Dominant PF in the Upland Grass "middle" included scarlet globemallow (*Sphaeralcea coccinea* [Nutt.] Rydb.) and American vetch (*Vicia americana* Muhl. ex. Willd.). Dominant PF in the Breaks Grass "middle" included Hoods phlox (*Phlox hoodii* Richardson), scurfpea (*Pediomelum argophyllum* [Pursh] Grimes), and fleabane daisy (*Erigeron pumilus* Nutt.).

Table 5. Total number of plant species encountered during cover and production sampling within each treatment or native reference area slope position over all study sites on the North Antelope/Rochelle Mine in northeastern Wyoming.[1]

Year	Type	Treatment or reference area slope position	Total no. based on cover sampling	Total no. based on production sampling
2000	Breaks Grass	Top	20	NA
		Middle	23	NA
		Bottom	17	NA
	Upland Grass	Top	19	NA
		Middle	17	NA
		Bottom	24	NA
	Reclaimed area	15 cm topsoil	20	NA
		30 cm topsoil	23	NA
		56 cm topsoil	15	NA
2001	Breaks Grass	Top	20	NA
		Middle	23	NA
		Bottom	17	NA
	Upland Grass	Top	18	NA
		Middle	17	NA
		Bottom	25	NA
	Reclaimed area	15 cm topsoil	20	NA
		30 cm topsoil	21	NA
		56 cm topsoil	15	NA
2002	Breaks Grass	Top	22	23
		Middle	17	20
		Bottom	18	21
	Upland Grass	Top	13	21
		Middle	16	26
		Bottom	15	27
	Reclaimed area	15 cm topsoil	18	26
		30 cm topsoil	21	32
		56 cm topsoil	16	22

[1]NA indicates not applicable.

Another way to evaluate species richness is to compare the number of different plant species encountered in each reclaimed treatment (Table 5). While the highest number of species per reference area slope position comparison was not consistent from 2000 through 2002, the highest number of species in the reclaimed area was always in the 30-cm reclaimed treatment. The highest number of species based on production sampling was also in the 30-cm reclaimed treatment.

Species Diversity. Shannon–Wiener diversity indices (H′) values increase with increasing diversity and are based on the proportional abundance of species (Magurran 1988). Shannon–Wiener H′ values typically fall between 1 and 3 but may

Table 6. Comparison of Shannon–Wiener H′ means over all study sites and treatments or native reference area slope positions on the North Antelope/Rochelle Mine in northeastern Wyoming.[1]

Location	Treatment or reference area slope position	Index value			
		Absolute total vegetation cover			2002 Production
		2000	2001	2002	
Reclaimed	15 cm topsoil	1.29	1.80ab	1.94	1.85
	30 cm topsoil	1.42	2.17a	2.04	1.96
	56 cm topsoil	1.24	1.62b	1.88	2.02
Upland Grass	Top	1.85	1.86	2.04	2.21
	Middle	2.08	2.02	1.91	2.16
	Bottom	2.00	2.14	1.71	2.06
Breaks Grass	Top	1.90	2.13	1.57	2.04
	Middle	2.05	2.23	1.56	2.05
	Bottom	1.90	2.05	1.55	1.95
Reclaimed	All sites	1.32b	1.86b	1.95a	1.95
Upland Grass	All sites	1.97a	2.01ab	1.89a	2.14
Breaks Grass	All sites	1.95a	2.14a	1.56b	2.01

[1]Means for a parameter between locations or treatments or reference area slope positions in a particular year, based on cover or production data, that are followed by the same letter are not statistically different ($P > 0.05$) based on Tukey's HSD. Data without letters are not significant. H′ values were combined by location over treatments or reference area slope positions or by treatments or reference area slope positions over locations and analyzed using 2-factor analysis of variance.

be as high as 4–5 (E. B. Allen, University of California, Riverside, personal communication, 2003). The values calculated for the current study were within the range of 1–3. Shannon–Wiener H′ values derived by Bowen et al. (2002) on a reclaimed uranium area seeded in 1977 in central Wyoming were in the range of 1.75–2.50, with the highest value on the nontopsoiled treatment, which after 24 years exhibited some soil deposition and organic matter accumulation. Shannon-Wiener H′ values derived by Biondini and Redente (1986), who evaluated a retorted oil shale area reclaimed in 1977 in northwestern Colorado, were 0.6–0.9 with the highest values in the 30-cm topsoil replacement depth. Comparison of H′ values on the 2000 and 2002 absolute total vegetation cover data indicated significant differences between location only, with the 2001 cover data resulting in differences between location, treatment, and their interaction (Table 6). The Breaks Grass site in 2001 had the lowest and highest H′ values in the bottom and middle slope positions, respectively. The reclaimed site displayed a similar pattern of the lowest and highest values in the 56- and 30-cm treatments, respectively. Diversity on the Upland Grass, however, increased from a low in the top slope position to a high on the bottom slope sites. Two of 3 Upland Grass replicates had a slightly greater percent slope at the bottom than the top position, resulting in greater diversity due to more variable topsoil depth within those specific replicates (Schladweiler et al. 2004). The H′ value in the 2000 reclaimed treatments was significantly lower than both Upland Grass and Breaks Grass treatments. Treatment and reference area slope position effects within the 2000 and 2002 data were not significantly different. Although Breaks Grass is usually more diverse, 2002 H′ values for Breaks Grass were significantly lower than for either reclaimed or Upland Grass sites, which may be indicative of lack of timely precipitation and resulting variable plant growth during the drought year.

Table 7. Comparison of derived diversity and similarity indices for 2001 of all study sites at the North Antelope/Rochelle Mine in northeastern Wyoming.[1]

Treatment/slope position[2]	Reclaimed	Upland Grass	Breaks Grass
	McIntosh (% cover)[3]		
15 cm/top	17.85	28.85	26.47
30 cm/middle	16.11	26.75	21.15
56 cm/bottom	27.35	22.27	24.35
	Simpson 1/d (% cover)[3]		
15 cm/top	6.30	6.48	7.91
30 cm/middle	6.83	7.34	10.69
56 cm/bottom	4.71	8.90	9.45
	Berger–Parker (% cover)[3]		
15 cm/top	3.24	3.47	4.00
30 cm/middle	4.60	4.80	5.58
56 cm/bottom	2.70	4.12	5.79
	Shannon–Wiener (no. species)[3]		
15 cm/top	1.80[4]	1.86	2.14
30 cm/middle	2.17[4]	2.02	2.23
56 cm/bottom	1.62[4]	2.14	2.05

[1]For diversity indices, larger numbers indicate more diversity. For example, using McIntosh, the greatest diversity using percent cover for the 15-cm treatment was found in the Upland Grass but was not significant. Only 2001 data were utilized for derivation of diversity values for those indices other than Shannon–Wiener.
[2]Data presented for different treatment depths and native site slope positions.
[3]Data used to derive specific index value.
[4]Interaction present.

Other studies have indicated lower diversity on deeper topsoil compared to shallow depth treatments (Redente et al. 1997; Bowen et al. 2002). This study reinforces those findings in that the 2001 Shannon–Wiener H′ value for the 56-cm topsoil replacement treatment depth is less than the values for the 15- or 30-cm topsoil treatment depths (Table 6). The 30-cm reclaimed treatment, however, has greater diversity indices than the 15- and 56-cm reclaimed treatments, which would suggest that this topsoil depth in the current study resulted in greater plant species diversity.

The diversity indices in Table 7 were summarized collectively by treatment (reference area slope position) because derived values were low and were not statistically analyzed. Based on the 4 evaluated diversity indices, the highest consistent values for diversity appeared to be Breaks Grass reference area slope positions, where 3 out of 4 indices were highest in that vegetation type. The highest values, based on McIntosh, were found in the Upland Grass top and middle slope positions and reclaimed 56-cm treatment. Historically, the highest number of species was found within the Breaks Grass vegetation type (NARM, various dates).

Species Composition. Perennial cool-season grass species such as thickspike wheatgrass, western wheatgrass, and slender wheatgrass tended to increase with time in the reclaimed sites (Table 8), while AF such as Mexican-fireweed (*Kochia scoparia* [L.] Schrad.) decreased. In 2002, drought resulted in reduced cover of most species, likely a result of cumulative drought stress

Table 8. Comparison of individual species percent absolute cover at the NARM reclamation topsoil (15-, 30-, and 56-cm depths) study sites in northeastern Wyoming.

		2000			2001			2002		
Scientific name	Common name	15 cm	30 cm	56 cm	15 cm	30 cm	56 cm	15 cm	30 cm	56 cm
Cool-season perennial grass										
Elymus lanceolatus (Scribn. & Sm.) Gould	Thickspike wheatgrass	2.89	6.22	10.4	5.78	6.22	10.4	8.67	8.22	11.1
Elymus elongatus (Host) Runem var. *ponticus* (Podp.) Dorn	Tall wheatgrass							0.22		
Pseudoroegneria spicata (Pursh) A. Love spp. *inermis* (Scribn. & J.G. Sm.) A. Love	Beardless wheatgrass									0.45
Elymus lanceolatus (Scribn. & J.G. Sm.) Gould var. *riparius* (Scribn. & J.G. Sm.) Dorn	Riparian wheatgrass							7.56	9.11	6.44
Elymus smithii (Rydb.) Gould	Western wheatgrass	4.89	7.33	8.00	4.89	7.33	8.00	5.33	4.67	3.11
Elymus spicatus (Pursh) Gould	Bluebunch wheatgrass		0.22			0.22		0.67	0.44	0.22
Elymus trachycaulus (Link) Gould ex Shinners	Slender wheatgrass	4.49	7.55	10.4	8.89	7.55	10.40	3.11	4.44	4.89
Hordeum jubatum L.	Foxtail barley		0.22			0.22				
Oryzopsis hymenoides (R.&S.) Ricker ex Piper	Indian ricegrass		0.44	0.22		0.44	0.22			
Poa canbyi (Scribn.) Piper	Canby bluegrass[1]								0.22	0.44
Poa secunda Presl	Sandberg bluegrass[1]							1.78	0.45	0.45
Stipa comata Trin. & Rupr.	Needle and thread	0.22		0.22	0.22		0.22			
Stipa viridula Trin.	Green needlegrass	0.22	1.34	0.45	0.22	1.11	0.45	0.89	2.00	1.56
Annual grass										
Bromus japonicus Thunb. ex Murray	Japanese brome	0.22		0.45	0.22		0.45	0.22	0.22	2.00
Bromus tectorum L.	Cheatgrass			0.45			0.45	0.22	0.44	1.33
Hordeum vulgare L.	Common Barley	1.33	0.67	2.89	1.33	0.67	2.89			
Perennial forb										
Ambrosia psilostachya DC.	Cuman ragweed		0.22			0.22				
Ambrosia tomentosa Nutt.	Skeletonleaf ragweed								0.22	
Astragalus cicer L	Cicer milkvetch	1.11	2.00		1.11	2.00		0.89	0.45	
Astragalus spatulatus Sheld.	Tufted milkvetch	0.22			0.22					
Cirsium arvense (L.) Scop.	Canada thistle	0.22			0.22					
Grindelia squarrosa (Pursh) Dunal	Curlytop gumweed		0.67			0.67		0.45	0.45	
Medicago sativa L.	Alfalfa	1.11	1.33		1.11	1.33			1.11	
Penstemon strictus Benth.	Rocky Mountain penstemon		0.22	0.22		0.22	0.22	0.22		
Phaselia hastata Dougl. Ex Lehm.	Silverleaf phacelia	0.22			0.22					
Tragopogon dubius Scop.	Yellow salsify	0.45	0.67		0.45	0.67		0.22		
Vicia americana Muhl. ex Willd	American peavetch	0.22	0.44		0.22	0.44		0.67	0.45	0.22
Annual forb										
Alyssum alyssoides (L.) L.	Pale madwort	0.22	0.44		0.22	0.44				
Camelina microcarpa Andrz. ex DC.	Littlepod falseflax	0.22	0.22	0.22	0.22	0.22	0.22		0.22	0.22
Kochia scoparia (L.) Schrad.	Mexican-fireweed	13.1	9.55	21.3	13.1	9.55	21.3	0.67	1.56	2.89
Lactuca serriola L.	Prickly lettuce	0.89	2.66	0.89	1.33	2.66	0.89	0.22	0.22	0.67
Melilotus officinalis (L.) Pallas	Yellow sweetclover							0.89	0.67	0.67
Polygonum aviculare L.	Prostrate knotweed	0.67	0.89	1.11	0.67	0.89	1.11			0.22
Salsola australis R. Br.	Prickly Russian thistle	1.78	0.89	0.22	1.78	1.33	0.22			
Full shrub										
Artemisia tridentata Nutt. var. *wyomingensis* (Beetle & Young)	Wyoming big sagebrush									0.22

[1]Canby bluegrass and Sandberg bluegrass are combined in Dorn (1992) but are separated for purposes of collection and presentation because both are commercially available seed.

from 3 years of lower-than-normal precipitation. Seeded PF such as cicer milkvetch and Rocky Mountain penstemon (*Penstemon strictus* Benth.) were generally present in the 15- and 30-cm topsoil replacement depths. Volunteer forbs such as tufted milkvetch (*Astragalus spatulatus* Sheld.), silverleaf phacelia (*Phaselia hastata* Dougl. Ex Lehm.), and American peavetch (*Vicia americana* Muhl. ex Willd) were also present in the 15- and 30-cm topsoil replacement depths. The presence of AF and AG species was generally reduced from 2000 to 2002 compared to historical reclaimed sampling of similar-aged sites at NARM (NARM, various dates) and was generally uniform, in presence, over the 3 topsoil replacement treatments. If precipitation patterns had been normal during any portion or the entire time frame of the study, it is likely that AF and AG may have played a greater role. However, lack of precipitation may actually have assisted the PF, HS, and FS in providing more bare ground in less topsoiled areas and less competition from CSPG.

CONCLUSIONS

Higher total vegetation canopy cover and aboveground production was achieved at the deeper topsoil replacement depths, but the deeper depths tended to suppress plant diversity. The highest total number of species encountered based on canopy cover and aboveground production sampling was in the 30-cm reclaimed treatment, many of which were desirable seeded and volunteer PG and PF. Species richness included AF and AG, but these species were reduced in number and abundance because of drought conditions during the study time period. Comparison of the current study area to a 1991 reclaimed area indicated a consistent general pattern of species establishment. Aboveground production was also higher in the reclaimed area when compared to the 2 native reference areas, but total cover and total vegetation canopy cover were lower. Both CSPG and AF canopy cover were dominant in the reclaimed area for 2000–2002. Absolute cover of WSPG and HS as well as relative cover of HS were significantly higher in the native reference areas.

Shannon–Wiener diversity H′ indices for absolute total vegetation canopy cover were between 1 and 3 and differed significantly between the reclaimed, Upland Grass, and Breaks Grass sites in 2000 and 2002. Various other indices were examined, but Shannon–Wiener was the only diversity index statistically evaluated based on 2000–2002 cover and 2002 production data. The generalized Shannon–Wiener index for the combined reclaimed treatments compared to the current permitted topsoil replacement depth treatment of 56 cm was always higher, which indicates that the use of a mosaic of topsoil replacement depths enhances the overall diversity of a landscape feature. A mosaic of different topsoil depths, including the shallow 15- and 30-cm depths and the mandated 56-cm depth, may create the broadest range of vegetation response under a standard regime of revegetation practices.

Every effort should be made to provide opportunity for diversification within a reclaimed plant community as well as between communities and on a landscape scale. Without flexibility in topsoil replacement depths, seedbed preparation, and seeding innovation, aggressive CSPG tend to dominate the landscape, discouraging diversification of life-forms. Historical, standard seeding techniques have given way to multiple seeding dates of CSPG versus shrubs and WSPG, broadcasting of shrubs and warm-season grasses, seeding mosaics, and reduced grass rates in the seed mixtures. The capacity to replace different thicknesses of topsoil should be a reclamation practice available to mine operators.

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