SEED RAIN ON AND NEAR A COAL STRIPMINE IN SOUTHWESTERN WYOMING[1]

by

Neil E. West[2] and Susan Durham[2]

Abstract. Seeds of many native rangeland species are not reliably available, yet regulations for mine rehabilitation in several western states limit seeding to native species. Attainment of plant community diversity approximating the original situation will require eventual migration of seed from adjacent unmined areas. Seed rain patterns on either native or mined rangelands have rarely been studied. We thus investigated seed rain in transects across a coal stripmine and adjacent native areas in southwestern Wyoming between 1982 and 1988. Total seed rain, life forms represented and species composition varied enormously in both space and time. There was a generally positive correlation between total seed rain and the amount of precipitation received the previous water year. Changes in life form and species composition of the seed rain tracked changes in cover, density and production by annuals early in the recovery of the mined area to later dominance by perennials. Total seed rain in the adjacent native area was much less than on the mined area, but greater in diversity. Windward slopes on the mined area received much less total and diverse seed rain than the leeward slopes. Heavy native seeds, especially those without structural adaptations for wind dispersal, will only move slowly onto mined areas. If their presence on the mined area is required for meeting diversity requirements, special efforts should be made to gather and seed them in the original planting mix before a competitive plant cover develops.

Additional Key Words: sagebrush steppe, salt desert shrubs, succession, recovery

Introduction

The Surface Mine Reclamation and Conservation Act (SMCRA, Public Law 95-87) requires that U.S. miners restore original contours, replace topsoil, and establish

> "...a diverse, effective and permanent vegetative cover of the same seasonal variety native to the area of land to be affected and capable of self-regeneration and plant succession at least equal in extent of cover to the natural vegetation of the area."

Furthermore, regulations applied by the State of Wyoming limit the operator to planting only native plant species. Meeting the diversity and self-regeneration criteria are difficult in semi-arid regions largely because of considerable abiotic stresses on seedlings. Many native plant species, especially the appropriate ecotypes, are not commercially grown. Natural seed sources for some species are scarce most years. Even when available, it is often difficult and expensive to gather wild seed. Much of a gathered seed crop may consist of non-viable seed. Many of the native seeds have durable appendages and aren't easily seeded from presently available equipment. Furthermore, conditions for germination and establishment of many native species are unknown.

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[2]Neil E. West is Professor, Department of Range Science, Utah State University, Logan, UT 84322-5230. Susan Durham is Research Associate, Department of Fisheries and Wildlife, Ecology Center, Utah State University, Logan, UT 84322-5235.

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While there is some seed in the replaced topsoil (Johnson and West 1989), because of soil mixing during scraping and replacement operations, much of the inherent seed density is diluted and deposited too deeply for germination to result in seedling establishment. Seed of some of the dominant shrubs of intermountain rangelands (e.g., Artemisia and Chrysothamnus) have no dormancy and begin germinating shortly after falling in the autumn. Therefore, stored soils will usually lack viable seeds of such shrubs. Direct transfer of fresh soil will also lack viable seeds of these species during most of the year. Attaining higher diversity than is possible from artificial reseeding will thus be largely dependent on the inherent ability of native seed to move onto the disturbed area. Therefore it would be useful for managers to know what kind of patterns of seed rain to expect. Very few investigations of seed rain have been undertaken in such environments. We consequently undertook a study to describe the seed rain on transects across a particular mined site undergoing reclamation.

We define seed rain as the number of filled seed arriving at the soil surface over a defined interval (Everett and Sharrow 1983). We use "seed" in a general sense, since the actual dispersal units may be fruits, propagules or diaspores with multiple individual seeds.

Methods

Study Site

The study site is located in southwestern Wyoming, near the town of Kemmerer (41°45'N, 110°35'W), on the Elkol-Sorenson Mine, owned and operated by the Pittsburgh and Midway Coal Mining Co., a division of Chevron Inc. The average elevation of the site is about 2100 m. The climate of the area is temperate semi-arid. The mean long term average (over the past 40 years) precipitation is 22.6 cm/yr. About half of the precipitation input is snow in winter and about half is rain during other seasons. Mid-summer is usually the driest part of the year. Monthly mean temperatures range from -8°C in January to 17°C in July (Parmenter and MacMahon 1983). Winds average ~5 m/sec and are predominantly from the west (Allen et al. 1989). Winds strongly redistribute snow in relation to topography and cause pronounced spatial variation in soil moisture (Allen 1988).

The reclaimed site (known as 12 UC) is dominated by two prominent ridges running in a N-S direction and increasing in elevation from south to north (Fig. 1). The average slope lengths are approximately 50 m and the average slopes are 15%.

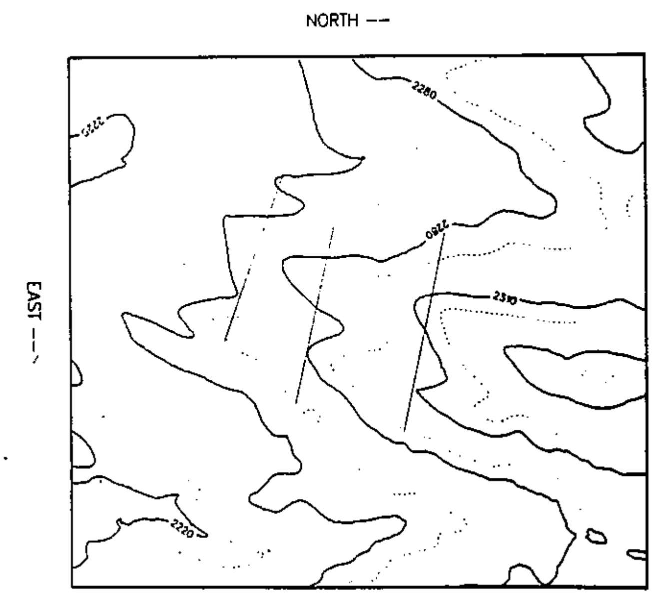

Figure 1. Post-mining elevational contours (meters) and seed trap transect placement at 12 UC.

The original vegetation on the site was a mosaic of sagebrush steppe (West 1983a) where soils were derived from limestone and sandstone and salt desert shrub (West 1983b) where shales outcropped (Bonham 1977).

The site had its topsoil stripped and stored in 1975. Overburden and underlying coal were removed by large shovel and trucks between 1977 and 1979. The site was recontoured in 1980. Topsoil was applied (to an average depth of 15 cm) in the summer-fall of 1981. The majority of the soil applied had been stockpiled, but in some experimental locations fresh topsoil was applied. The original stored topsoils were mainly Moyerson-Rentsac series on the ridgetops. The Moyerson Series is a member of the clayey, montmorillonitic (calcareous), frigid, shallow Ustic Torriorthent Family. The Rentsac Series is a member of the loamy-skeletal mixed (calcareous) frigid, lithic Ustic Torriorthent Family. The side slopes were occupied by a Luhon-Blazon complex. The Luhon Series is a member of the fine-loamy, mixed Borollic Calciorthid Family. The Blazon Series is a member of the loamy, mixed (calcareous) frigid, shallow Ustic Torriorthent Family (unpublished maps provided by Pittsburg & Midway Coal Co.). The fresh topsoil was derived from an adjacent bottomland area occupied by the Trembles and Dempsey Series. The Trembles Series is within the coarse loamy, mixed (calcareous), frigid, typic Ustic Ustifluvent Family. The Dempsey Series is a member of the coarse loamy, mixed, pachic Paleboroll Family.

The unmined area to the west of the minesite, considered the major seed source area because of its windward location, was dominated by several variants of sagebrush steppe (West 1983a). The unmined areas to the east of the minesite were predominantly variants of the salt desert shrub type (West 1983b).

Prior to mining, the site was primarily used for wildlife habitat and livestock grazing. These same uses are also the prescribed post-mining uses (Wyoming Department of Environmental Quality and Pittsburgh & Midway Mining Co., personal communications).

Five plant species were purposefully planted on the mined site at various densities and spatial arrays during early spring of 1982 (Hatton and West 1987). These included three shrubs (as 18 month old tubelings): Artemisia tridentata, ssp. vaseyana, Chrysothamnus viscidiflorus and Atriplex gardneri; one perennial forb, Hedysarum boreale; and one perennial grass, Agropyron smithii var. Roseana. The shrubs (all tubelings) were planted in a wetted (0.5 l water applied) dibble hole. The forb and grass seed were broadcast by hand into a short length of 25 cm diameter plastic pipe (to prevent wind dispersal) centered over the indicated spot. The spot was then hand-raked to lightly cover the seed with soil. No cover crop or mulch was grown or applied prior to planting.

Study Methods

A novel seed trap design was chosen following testing of several alternative traps in a wind tunnel (Johnson and West 1987). The selected trap was a 15 cm length by 15 cm diameter PVC irrigation pipe driven vertically into the soil until its lip was level with the surface and the soil within removed. A string (for wicking moisture away) and cotton ball (to prevent seed from falling through) were placed in the neck of a 15-cm funnel. Each funnel was then filled with pea size (mean diameter of ~1 cm) washed river gravel, a surface texture likely to readily entrap all seeds (Chambers et al. 1991). The filled funnels were then placed in the pipes with their lips flush with the soil surface. This design was found to create very little turbulence in wind tunnel tests (Johnson and West 1987). Wind was considered the major vector for propagule movement on this site. This seed trap design may not account as well for seeds that are moved primarily by water or animals.

Seed traps were placed at 5-m intervals along three parallel transects running west to east, each beginning at least 40 m into the undisturbed native area to the west of the mined site, extending completely through the mined area and into some native areas to the east (Fig. 1). The west-east orientation of the transects roughly parallels the prevailing wind direction (Allen et al. 1989). The three transects were spaced about 100 m apart to typify high, medium and low elevations on the mined site.

A total of 225 seed traps were put in place during the summer of 1982. Once each fall and spring season over six years (Table 1) the funnels were removed and the gravel sieved and shaken (about 30 seconds) over a paper bag. The cotton ball and string were also placed in the bag. Any soil, seed or seedlings adhering to the funnels were also scraped into the bag. A new cotton ball and string was placed in the neck of the funnel and the same gravel replaced. Additional gravel was added, if necessary, to bring the level of gravel back to the surface of the funnel. If frost heaving or erosion had displaced the pipe, it was re-driven in flush with the soil surface. The funnel was then replaced in the pipe for the next collection period.

Table 1. Timing of trap placement and seed trap collections at area 12UC, Pittsburg and Midway Coal Co., near Kemmerer, Wyoming.

9 July	1982 (initial installation)
2 November	1982
20 June	1983
31 October	1983
5 June	1984
29 October	1984
8 May	1985
12 October	1985
3 June	1986
16 October	1986
22 April	1987
9 October	1987
12 April	1988

Autumn collections were timed to accumulate seeds produced and disseminated over the main growing season. Spring collections were made prior to any seed set that year and were designed to collect any seed shattered from late flowering plants (e.g., Chrysothamnus and Artemisia spp.) during late fall and winter when snow usually covered the ground. The paper bags holding all non-gravel materials accumulated in the funnels were kept in cold storage (2°C) to reduce seed shrinkage and germination until seeds could be extracted and identified.

Seeds were extracted from litter and soil by hand sifting through a series of progressively smaller screens (10, 1, 0.3 mm). Debris remaining on each screen was examined by 10X binocular microscope. Material less than 0.3 mm was not searched because the smallest completely filled seed in this area was expected to have a diameter greater than 0.5 mm. Samples from seed traps that contained dried mud were washed in a solution recommended by Malone (1967), then dried and separated as described above.

Intact seeds were identified to the lowest taxonomic rank which was judged consistently reliable. We developed a seed herbarium for the site, collecting seeds from previously identified individuals of all species that flowered and set seed. Additional taxa were identified from sources such as Martin and Barkley (1961), Schopmeyer (1974), and Hitchcock and Cronquist (1973). A few seeds could not be identified from either the herbarium or references available.

Diaspores of plants exhibit morphological features associated with dispersal by particular kinds of vectors, e.g., wings or plumes for wind dispersal. One can thus place diaspores into morphologically determined dispersal categories and calculate dispersal spectra (Willson et al. 1990). The taxa identified in the cumulative seed rain data set were assigned to five dispersal categories (Table 2).

Data Analyses

The study involved a non-randomized design with three blocks (transects) and six categorical locations: 1) west native area, 2) west slope of west ridge, 3) east slope of west ridge, 4) west slope of east ridge, 5) east slope of east ridge, and 6) east native area (except for the lowest elevation transect where a nearby native area was not available, Fig. 1). Use of statistical analysis was constrained by the lack of replication and randomization in this exploratory study. Consequently, various graphical and data summarization techniques were used in conjunction with a limited number of statistical procedures to examine patterns of seed deposition.

Seed rain densities (seeds/m^2/yr) depicted in Figure 2 were computed for each transect area using seed rain collections combined overall traps in that area over both seasons. Seed densities (seeds/m^2), species richness, and species diversity depicted in Figure 6 were computed for each seed trap location in each transect using seed rain collections combined over both seasons and all years. Diversity was measured using Hill's (1973) diversity index number N2, which is equal to the reciprocal of Simpson's (1949) Index of Concentration.

The first null hypothesis tested was that the seed rain at the site was spatially random. That is, there were no differences among transects or among locations with regard to the total number of seeds or species composition through time. The alternative hypothesis was that total seed rain and its species composition was not random in space or time.

A log linear analysis of the seed count data was performed using BMDP (Dixon 1983). This analysis was interpreted cautiously, because the assumptions of the analysis were not strictly met.

The dependence of total seed count on precipitation occurring in the preceding water year, October through September (Sneva and Britton 1983) was analyzed using regression techniques.

The association between the six locations and the five dispersal categories within the cumulative seed rain data was assessed using chi-square analyses of both simple occurrence and count-weighted abundance.

Results

Total seed rain varied enormously over time (Fig. 2) as did climate (Fig. 3). Generally, there was a positive relationship between total seed rain and the amount of precipitation received the preceding water year (Fig. 4). Two exceptions to this pattern were observed, however. First, total seed rain collected for the first year (fall 1982 and spring 1983) was less than total seed rain for any later year (Fig. 2). The vegetation on the mined areas during that time was dominated by mid-summer annuals (largely Salsola kali) (Hatton and West 1987). The fall blooming shrubs also

Table 2. Cumulative seed rain (seeds/m^2 from 1982-86) on various topographic sectors from major taxa. Disperal categories used are W = wind assisted; V = vertebrate assisted; B = ballistic; E = external; N = no special device (Willson et al. 1990). For taxa where species identity cannot be reliably attributed, number of species probably involved is given in the first column to the right of names of taxa.

Dispersal Categories	Growth Form Taxa	No. of spp.	Area W Native	W Wind	W Lee	E Wind	E Lee	E Native
	SHRUBS							
N	*Purshia tridentata*		25					
V	*Rosa woodsii*		4					
W	*Tetradymia canescens*		14		2			
N	*Artemisia* spp.	4	9816	1372	2029	28	12207	8
W	*Chrysothamnus* spp.	3	1078	626	329	21	66	50
W	*Grayia spinosa*			453	33	243	88	8
W	*Sarcobatus vermiculatus*				32	170	7	
W	*Tetradymia nuttallii*				13	5	30	
W	*Atriplex confertifolia*			6	7			68
V	*Amelanchier* spp.	2	135					8
	HALF SHRUBS							
W	*Atriplex gardneri*							63
	PERENNIAL GRASSES							
N	*Koeleria macrantha*		7					
N	*Bromus japonicus*		16	184				
N	*Carex* spp.	2		15	37			8
N	*Bromus* spp.	2	33	368	171	160	28	
N	*Festuca idahoensis*		32		522	4	142	
N	*Agropyron* spp.	7	3104	7856	10585	9681	8335	1033
N	*Elymus cinereus*		134	1935	2399	3558	1459	95
E	*Hordeum* spp.	2	76	2437	20184	4788	10220	321
N	*Poa* spp.	5	23241	2073	1641	93	126	5372
E	*Sitanion hystrix*		211	409	737		1202	111
E	*Stipa* spp.	4	709	102	383	4	911	11
N	*Oryzopsis* spp.	2	225	201	427	21	580	2344
N	*Melica bulbosa*		283				4	16
	ANNUAL GRASSES							
E	*Avena fatua*		18					
E	*Bromus tectorum*		262	3351	21664	799	24047	2117
	PERENNIAL FORBS							
W	*Agoseris glauca*		4					
N	*Castilleja chromosa*		24					
W	*Cirsium undulatum*		16					
E	*Geranium viscosissimum*		18					
W	*Haplopappus acaulis*		11					
N	*Linum lewisii*		4					
N	*Lithospermum ruderale*		198					
W	*Lomatium macrocarpum*		4					
B	*Oxytropis sericea*		4					
W	*Senecio integerrimus*		42					
N	*Trifolium gymnocarpon*		9					
N	*Allium geyeri*		4					
W	*Antennaria dimorpha*		57					
B	*Astragalus lentiginosus*		12					
B	*Astragalus spatulatus*		120					
N	*Delphinium nuttallianum*		7	28				
B	*Stanleya viridiflora*		21					

Table 2. (Continued).

N	*Cryptantha flavoculata*		57	28				
N	*Viola purpurea*		11	11				
N	*Zygadenus paniculatus*		7	3				
B	*Lupinus sericeus*			3				
N	*Potentilla glandulosa*			3				
W	*Antennaria microphylla*			3				
B	*Arabis holboellii*			3	42			
N	*Arenaria hookeri*		18		10			
N	*Eriogonum ovalifolium*		4		12			
W	*Chaenactis douglasii*				16			
W	*Machaeranthera grindeloides*		160	9	5			71
W	*Microseris nutans*				22			
N	*Oenothera caespitosa*				4			
N	*Phlox longifolia*		59		319			36
N	*Sedum lanceolatum*		11		3			45
N	*Sphaeralcea coccinea*			13	7			
N	*Achillea millefolium*		5			4		
B	*Arabis drummondii*		105		4		7	
N	*Arenaria congesta*		316		7		3	45
W	*Cirsium arvense*			903	12		8	
N	*Eriogonum heracleoides*		4	4	15	52		
N	*Eriogonum umbellatum*		4		2			156
N	*Phlox hoodii*		11	3	25	4		
N	*Penstemon* spp.	7		251			8	
N	*Mertensia viridis*		164		2	4		
W	*Senecio multilobatus*		4		25		7	
W	*Taraxacum officinale*		137	52	153	13	265	
W	*Machaeranthera canescens*		74	19	318	5	24	
N	*Eriogonum brevicaule*		69	9	178	25	1714	236
N	*Eriogonum microthecum*		1040	3	20	26	130	299
W	*Rumex salicifolius*		164	316	4475	11219	2709	475
W	*Epilobium paniculatum*		819	376	1397	16	47	16
W	*Aster glaucodes*			79	421	2262	57	16
W	*Erigeron* spp.	3		9	2	48	18	22
W	*Carduus nutans*				114	12	79	14
W	*Cirsium subniveum*				45	4		14
E	*Heuchera parviflora*				12			14
N	*Sidalcea oregana*						8	
N	*Sphaeralcea munroana*						13	8
	ANNUAL FORBS							
N	*Plagiobothrys scouleri*		4					
N	*Polygonum sawatchense*		195	13				
N	*Veronica biloba*		57		160	91	3	25
N	*Androsace septentrionalis*		21	66	2			8
E	*Bassia hyssopifolia*		8				3	14
N	*Nicotiana attenuata*		25			42		
N	*Orthocarpus* spp.	2	4		8			
N	*Phacelia ivesana*				256	22		
E	*Lappula myosotis*			9	130		192	
N	*Chenopodium album*		357	325	378	49	34	
N	*Collinsia parviflora*		2908	234	1418	4	26	
W	*Atriplex rosea*		79	3488	484	382	754	530
B	*Descurainia sophia*		514	40758	35735	6881	111249	7413
N	*Gilia tweedii*		42	3	406	9	110	38
W	*Halogeton glomeratus*		74	6256	604	1819	557	309
W	*Lactuca serriola*		82	510	19717	2155	22049	287
E	*Lappula redowskii*		513	877	959	36	153	197
N	*Monolepis nuttalliana*		170	83	215	137	126	5142
N	*Polygonum aviculare*		820	1624	60485	32309	73495	9926
N	*Polygonum douglasii*		655	239	945	466	237	232
W	*Salsola kali*		454	37435	8395	22026	28098	2665
B	*Thlaspi arvense*		26	2203	1489	30	8934	1764
N	*Iva axillaris*							11
	MINOR SPECIES & UNKNOWNS	22	472	581	404	1064	1487	438
	TOTALS	159	50943	117968	201056	100791	312056	42104

produced less seed in 1982 (Carpenter and West 1988) and thus a low seed rain was recorded the following spring. The second exception was the large seed rain collected during the spring of 1984. This pulse is probably due to the unusually mild, wet preceding winter. Ignoring the data for the 1982-83 period, the relationship between total seed rain combined over both seasons and precipitation is linear and positive (r = .926, p = .006).

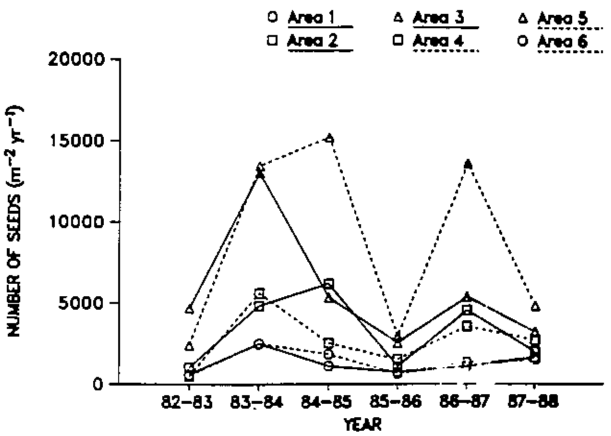

Figure 2. Mean annual seed rain (seeds/m^2/yr) at the six locations. 1 = west native area, 2 = west slope of west ridge, 3 = east slope of west ridge, 4 = west slope of east ridge, 5 = east slope of east ridge, and 6 = east native area.

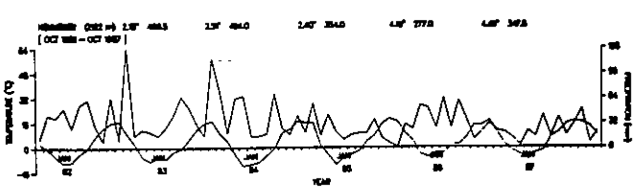

Figure 3. Trends in mean monthly precipitation and temperature at 12 UC during the study period.

The bulk of the seed rain was observed from the early fall collections (Fig. 4). On average, there was 3.8 times as much seed falling during the growing season compared to that taking place over winter. The range of the growing season to overwinter seed rain ratio was 2.3 to 6.7.

Life form contributions to the total seed rain varied enormously between years (Fig. 5), tracking the changes in cover, density and phytomass dominance by annuals early in the recovery of the mined area to a greater preponderance by perennials in later years (Hatton and West 1987).

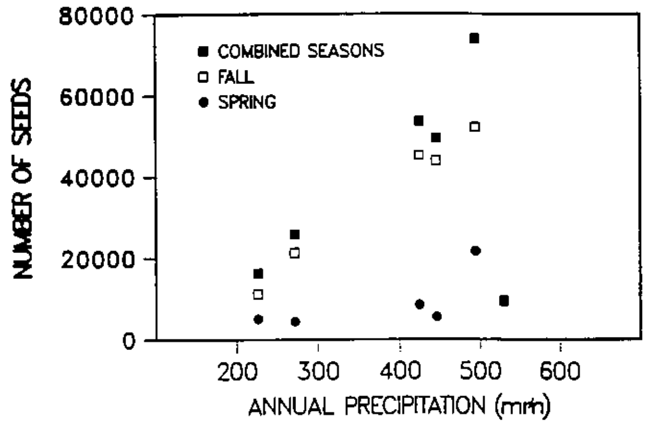

Figure 4. Relationship of seasonal seed rain to total precipitation during the previous crop-year.

Total seed rain was generally less in the native vegetation (areas 1 and 6) than on mined area (Fig. 2). The preponderance of short-lived herbaceous species on the mined area (areas 2-5) naturally led to greater seed production there. The diminishment of annuals over time allowed an increasing proportion of seeds produced by longer-lived species (Fig. 5). The effect of successional differences is confounded, however, with topography. The native areas are relatively flat, whereas the mined areas are inclined either windward or leeward (Fig. 6). Lee slopes to the prevailing wind (areas 3 and 5) usually had greater seed rain than windward ones (areas 2 and 4).

The only apparent difference in seed rain densities between transects is on the easternmost-portion of the upper transect (Fig. 6). This part of the transect is near the portion of 12 UC where the mining firm used complete seeding with a drill. The remainder of 12 UC was experimentally planted by hand, at various densities and spatial patterns described in Hatton and West (1987). This area drill-seeded by the mining firm attained more complete but less diverse plant cover earlier (Hatton and West 1987). Thus, more seed rain is likely available nearby. Furthermore, the stronger winds encountered on the upper parts of the slope apparently leads to greater seed accumulation on the lee slope of the upper easternmost ridge.

Richness of species represented in the seed rain is generally higher in the native "source area" directly west of 12UC, regardless of elevation (Fig. 6). Species richness in seed rain is also consistently greater in traps in the native vegetation to the east of the mined area. Note that native

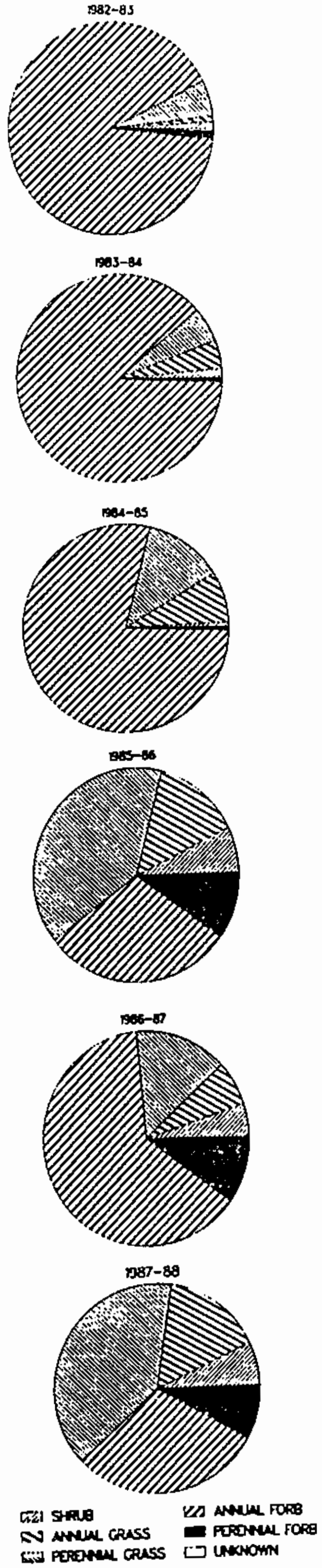

Figure 5. Pie charts of life-form contributions to seed rain during different years.

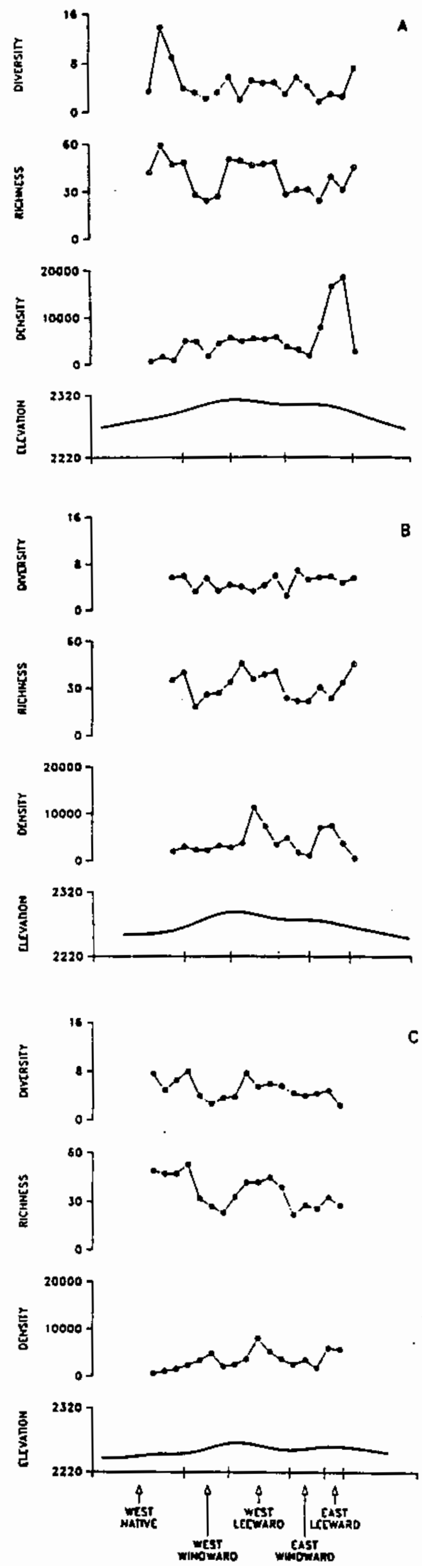

Figure 6. Seed rain diversity, richness and density in relation to topographic position along the three transects. A - north transect, B = middle transect, C = south transect.

vegetation wasn't available in the easternmost part of the lowest elevation transect. Diversity concentration showed greatest sharing of dominance of species in the seed rain of the native "source area" on the highest elevation transect. All transects showed depressions of both species richness and sharing of dominance on the windward slopes of the mined area, whereas the leeward slopes had relatively higher richness and more equitable dominance concentration.

In addition to turbulence patterns that cause greater deposition of particulate matter on lee slopes compared to other locales on or near the mined site (Allen 1988), there was also increased deposition of snow there which led to greater soil moisture, less evaporative losses and consequently greater plant density, cover, and production.

The null hypothesis of no spatial difference in dispersal spectra was not rejected. However, residual analysis suggests that there may be an under-representation of seeds with wind assisted dispersal in the west native area. Qualitative examination of Table 2 shows the west native area is the only locale where there are appreciable numbers of large, structurally unmodified seeds of shrubs and legumes, e.g., Purshia, Prunus, Astragalus, Lupinus.

General Conclusions

Total seed rain over this six year study showed consistently greater total input but lower diversity seed rain on the mined area than at adjacent undisturbed sites. Life form and species contributions to this seed rain varied enormously in both space and time. Annual forbs dominated the seed rain during early recovery whereas perennials generally increased their proportions within the total seed rain with time, except during drier years. Windward slopes on the mined area received much less total and diverse seed rain than the leeward slopes. Heavy native seeds, especially those without structural adaptations for wind dispersal, were only rarely found in seed traps on the mined area. If those species are required to enhance diversity, special efforts should be made to either gather from the wild or contract with growers so as to have them available for the original seeding mix or plant tubelings before a competitive plant cover develops.

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Literature Cited

Allen, M.F. 1988. Belowground structure: a key to reconstructing a productive arid ecosystem. pp. 113-135 in E.B. Allen (ed.). The Reconstruction of Disturbed Arid Lands. Westview Press, Boulder, Co.

Allen, M.F., Hipps, L.E. and Wooldridge, G.L. 1989. Wind dispersal and subsequent establishment of VA mycorrhizal fungi across a successional arid landscape. Landscape Ecology 2:165-171.
http://dx.doi.org/10.1007/BF00126016

Bonham, C. 1977. Vegetation Inventory. South Block, Report to Kemmerer Coal Co.

Carpenter, A.T. and West, N.E. 1988. Reproductive allocation in Artemisia tridentata ssp. vaseyana: effects of dispersion patterns, nitrogen and water. Bull. Torrey Bot. Club 115:161-167.
http://dx.doi.org/10.2307/2995953

Chambers, J.C., MacMahon, J.A. and Haefner, J.H. 1991. Seed entrapment in disturbed alpine ecosystems: effects of soil particle size and diaspore morphology. Ecology 72 (in press). http://dx.doi.org/10.2307/1940966

Dixon, W.J. 1983. BMDP Statistical Software. Univ. Calif. Press, Berkeley.

Everett, R.L. and Sharrow, S.H. 1983. Understory seed rain on tree-harvested and unharvested pinyon-juniper sites. Environmental Management 17:349-358.

Hatton, T.J. and West, N.E. 1987. Early seral trends in plant community diversity on a recontoured surface mine. Vegetatio 73:21-29. http://dx.doi.org/10.1007/BF00031848

Hill, M.D. 1973. Diversity and eveness: A unifying notation and its consequences. Ecology 54:427-432.
http://dx.doi.org/10.2307/1934352

Hitchcock, C.L. and Cronquist, A. 1973. Flora of the Pacific Northwest: an illustrated manual. University of Washington Press, Seattle.

Johnson, C.K. and West, N.E. 1987. Laboratory comparisons of five seed-trap designs for dry, windy environments. Canadian Journal of Botany 66:346-348. http://dx.doi.org/10.1139/b88-055

Johnson, C.K. and West, N.E. 1989. Seed reserves in stock-piled topsoil on a coal stripmine near Kemmerer, Wyoming. Landscape & Urban Planning 17:169-173. http://dx.doi.org/10.1016/0169-2046(89)90024-8

Malone, C.K. 1967. A rapid method for enumeration of viable seed in soil. Weeds. 15:381-382. http://dx.doi.org/10.2307/4041016

Martin, A.C. and Barkley, W.D. 1961. Seed Identification Manual. Univ. Calif. Press, Berkeley.

Parmenter, R.R. and MacMahon, J.A. 1983. Factors determining the abundance and distribution of rodents in a shrub-steppe ecosystem: the role of shrubs. Oecologia 59:145-156. http://dx.doi.org/10.1007/BF00378831

Schopmeyer, C.S. 1974. Seeds of woody plants in the United States. U.S. Dep. Agric. Handb. 450.

Simpson, E.H. 1949. Measurement of diversity. Nature 163-688. http://dx.doi.org/10.1038/163688a0

Sneva, F. and Britton, C.M. 1983. Adjusting and forecasting herbage yields in the Intermountain Big Sagebrush Region of the Steppe Province. Sta. Bul.. 659, Oregon Agric. Expt. Sta., Corvallis.

West, N.E. 1983a. Western Intermountain Sagebrush Steppe. pp. 351-374 in N.E. West (ed.) Temperate Deserts and Semi-deserts. Vol. 5, Ecosystems of the World. Elsevier Science Publishing Company, Amsterdam.

West, N.E. 1983b. Intermountain salt-desert shrubland. pp. 375-397 in N.E. West (ed.). Temperate Deserts and Semi-deserts. Vol. 5, Ecosystems of the World. Elsevier Science Publishing, Company, Amsterdam.

Willson, M.F., Rice, B.L. and Westoby, M. 1990. Seed dispersal spectra: a comparison of temperate plant communities. Journal of Vegetation Science 1:547-562. http://dx.doi.org/10.2307/3235789