PRE- AND POSTMINE DIVERSITY REVISITED

by

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Baseline vegetation inventories from the premine condition contain information that can be used to develop seed mixes and to subsequently set reclamation standards. Such inventories are usually developed as premine floristic surveys and later as inventories conducted prior to mine expansion. Two species lists were compiled from the premine baseline and postmine inventories of the reclaimed acreages at eight surface coal mines in New Mexico. Plant species listed from premine inventories, seed mixes, and postmine inventories were categorized by life form (tree, shrub, semi-shrub, grass, forb, succulent). These tabulations were then compared and examined for differences and commonalities. Sorensen's and Jaccard's indices (Magurran 1988) were also calculated from the premine inventories, seed mixes and postmine (reclamation) lists. The results of these comparisons suggest that premine species richness, species area relationships, richness and composition of seed mixes and subsequent reclamation practices influence postmine species richness.

Additional Key Words: New Mexico, life form, species richness, Jaccard's index, Sorenson's index.

Introduction

Biological diversity (biodiversity) on reclaimed mined lands is an increasingly important issue among mining industry, regulatory agencies, and environmental groups. The Surface Mining Control and Reclamation Act of 1977 (SMCRA) requires that "a diverse and permanent vegetative cover capable of self-regeneration and plant succession" be established on all regraded and affected lands. From a regulatory point of view, this has been typically, but not consistently interpreted to mean a number of native species comprising simple synthetic vegetation types (Call and Roundy 1991) as opposed to more structurally and functionally complex vegetation communities. Attention in recent years has also shifted from managing for high levels of production to reseeding more diverse species mixes for sustained geochemical and ecosystem processes (West 1993).

It is generally acknowledged that besides the legal requirement for diversity on reclaimed coal surface minelands, a diverse vegetation provides biophysical benefits such as: 1) greater protection against erosion, 2) insurance against loss of vegetation cover with the loss of one or a few dominant species due to disease, fire, or climatic extremes, and 3) greater integrity of nutrient cycles. Greater diversity of plant species is related to heterogeneity of environments, number of species used in reclamation seed mixes, landform diversity, shape of boundaries, and distances to species source populations (Dzwonko and Loster 1992, Wade and Thompson 1993). Plant diversity on disturbed lands has also been related to increased biomass production and ecosystem stability (Tilman and Downing 1994, Tilman 1996), although the reverse has not proved to be universally true (Zimmer 1996). Finally, plant diversity on reclaimed lands has been shown to lead to higher diversity of insects (Parmenter and MacMahon 1992), other invertebrates, mammals, (Hingtgen and Clark 1984 Rumble 1989), birds, and some herptofauna (Ireland *et al.* 1990).

Much of the preceding work was carried out on disturbed lands not reclaimed to the standards set forth in SMCRA or on minelands reclaimed under interim or prelaw standards. While there have not been large scale evaluations of how premine diversity and seed mix diversity affect reclamation success, these components clearly influence how regulators and operators view mineland diversity and how we subsequently establish reclamation success standards for diversity. This is especially true of the large coal surface mines in the western United States. Mines in New Mexico, for

[1]Paper presented at the 1998 National Meeting of the American Society for Surface Mining and Reclamation, St Louis, Missouri. May 17-22, 1998. Publication in these proceedings does not preclude authors from publishing their manuscripts, whole or in part in other publication outlets.

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Proceedings America Society of Mining and Reclamation, 1998 pp 564-571
DOI: 10.21000/JASMR98010564
https://doi.org/10.21000/JASMR98010664

example, have been reclaimed to different standards for diversity using seed mixes of varying compositions Yet, diversity appears to be most related to fluctuations in time and receipt of annual precipitation (Call and Roundy 1991), and to microsite and landscape heterogeneity (Tierney, unpubl. data) -- two features that typify the arid Southwest.

The purpose of this paper is to illustrate some of the relationships between premine vegetation inventories, seed mixes used in reclamation, and the subsequent postmine diversity on the reclaimed coal surface mine lands of northwestern New Mexico. Wade and Tritton (1997) proposed that discussions of biodiversity define the type of diversity, the scales to which the discussion is limited, and the social stakes and stakeholders. Here, we confine our discussion to the inventory-based diversity of vascular plant species at the scale of pre- and postmine mine reclamation units. The social stakes are reclamation success and productivity for the postmining land use of livestock grazing and the stakeholders are land owners/ managers, mining companies, and state and federal regulatory agencies.

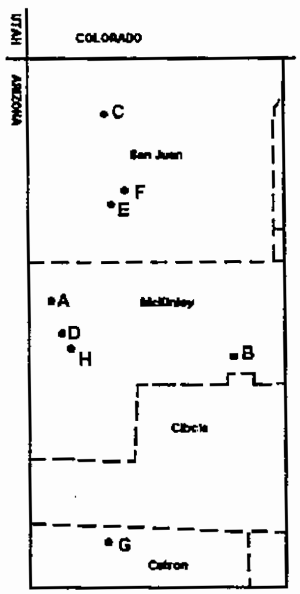

Figure 1. Location of this study's eight mines in the counties of northwestern New Mexico.

Methods

Premine baseline inventories, revegetation seed mixes, and postmine vegetation inventories were compiled and entered into an electronic database from the current permits of eight coal surface mines in New Mexico. The mines were selected for their location within the San Juan Coal field and their floristic similarities. A map identifying the location of each mine is presented in Figure 1.

Lists were developed from the premine vegetation inventories described in each mine's permit. Sources of information for the reclamation seed mixes included descriptions of seed mixes contained in mine permits, annual reports and correspondences. Additional plantings, including interseedings and plantings of tree and shrub seedlings were also listed as part of the revegetation seed mix. Information on species occurrence for the postmining condition was developed from annual reports, field observations, and vegetation measurements (New Mexico Mining and Minerals Division 1997).

Prior to entry into the database, each species was checked for nomenclature and synonomy (Kartesz 1994) and growth form using standard regional floras (Allred 1993, Kearney and Peebles 1951, Martin and Hutchins 1980, Welsh *et al.* 1987) and taxonomic monographs (Wagner and Aldon 1978). Species identified in each permit or annual report to the level of genus were included in the database. Subspecies and varieties were listed at the species level. Species occurrences by year of inventory, areal extent of the inventory, growth habit, and family were sorted and tabulated for each mine. The results of these tabulations were then compared and examined for commonalities and differences. Sorensen's and Jaccard's indices (Magurran 1988) were also calculated from premine and postmine (reclamation) lists.

Results

Mine A conducted three premine vegetation inventories in 1980, 1984 and 1987 (Table 1). The total number of species from these inventories of premine areas included 28 graminoid (grasslike) species, 194 forb, 10 succulent, 5 semi-shrub, 27 shrub species, and 3 tree species. Seed mixes used at this mine contained 36 graminoid, 20 forb, 3 semi-shrub, and 14 shrub species. Postmine species composition included 29 graminoid, 40 forb, 4 semi-shrub, 13 shrub species, and 3 tree species.

Vegetation surveys were conducted from 1981 through 1987 and again in 1989 at Mine B (Table 1). The cumulative number of species from these surveys include 26 grasses, 73 forbs, 7 succulents, 7 semi-

Table 1. Current areal extent of 8 mines, vegetation inventories, and reclaimed lands in northwestern New Mexico.

Mine	Current Permit Area (ha)	Year of Survey or Inventory	Areal Extent of Surveys and Inventories (ha)	Total Hectares Reclaimed
A	5,581 [1]	1980	9,848	1,761
		1984	4,589	
		1987	3,289	
B	3,856	1981 - 1987	3,714	847
		1989	1,093	
C	3,256	1983 - present	664	877
D	775	1976, 1981 - 1983	2,692	90
		1986	87	
E	332	1980	2,349	69
		1981	518	
F	243	1980 - 1981	243	58
G	202	1986	202	49
		1992	8,801	
H	82	1981	269	124
		1984	207	

[1] Current Permit area under New Mexico Mining and Minerals Division jurisdiction.

shrubs, 8 shrub species and 2 tree species. This mine's seed mixes included 6 grass during the summer of 1997 bv the New Mexico Minerals Division (NMMMD) produced a postmining total of 10 grasses, 17 forbs, 3 semi-shrub, and 5 shrubs.

Twenty-nine grasses, 7 succulents, 120 forbs, 10 semi-shrub, and 17 shrubs were collected at Mine C from 1983 through present at a large reference area (Table 1). This information formed the basis for establishing a historical-based reference standards at this mine and in this study was used to establish the premine condition of Mine C. The seed mixes used at this mine included 8 grass species, 5 forb species, 2 semi-shrub species, and 4 shrub species. Postmining data indicated that there were 13 graminoid, 17 forb, 6 semi-shrub, and 6 shrub species on the reclaimed acreages of this mine.

A compilation of the species observed in the premine condition at Mine D produced 80 forb, grass, succulent, semi-shrub, and shrub species. The seed mix for Mine D was comprised of 14 grass species, 5 forb species, and 10 shrub species. Surveys conducted for Mine E produced 74 grass, forb, succulent, semi-shrub, and shrub species.

Vegetation baseline inventories conducted in 1986 and 1992 were used to identify species in the premine condition at Mine F (Table 1). Twenty-five grass species, 105 forb species, 5 succulent species, 5 semi-shrub species, 15 shrub species, and 2 tree species were counted in the premine area. The seed mix for this mine included 9 grass species, 9 forb species, 1 semi-shrub species and 2 shrub species. Two postmining surveys of the mine conducted by NMMMD in 1995 and 1997, identified 9 graminoid species, 17 forbs species, 2 semi-shrub species, and 6 shrub species on the reclaimed lands.

Similar inventories of three combined reference areas at Mine G produced 55 grass, forb, semi-shrub and shrub species. The seed mix for Mine G contained 5 graminoid and 6 shrub species. Premine inventories for Mine H produced 139 grass, forb, succulent, semi-shrub, and shrub species (Table 2). Here, the reclamation seed mixes contained 11 graminoid, 5 forb, and 6 shrub species.

Although total species richness was greatly reduced in all of the seed mixes used at these mines, the mixes generally contained the dominant perennial life

Table 2. Known species richness of 8 reclaimed mines and their reference areas, number of species in common, and Jaccard's and Sorenson's Indices of Similarity.

Mine	Reference Area Type	Reference Richness	Postmine Richness[1]	Species in Common	IS_j	IS_s
A	3 Combined Premine Inventories	256	86	58	0.20	0.34
B	3 Combined Premine Inventories	114	35	33	0.28	0.44
C	Reference Area Survey 1983 - 1997	176	42	29	0.15	0.27
D	1981 - 1983 Survey 1986 Survey	80 41	11 11	6 5	0.07 0.11	0.13 0.19
E	Reference Area 1 Reference Area 2	74 51	14 14	12 14	0.16 0.23	0.27 0.37
F	2 Combined Premine Inventories	150	34	29	0.19	0.32
G	3 Combined Reference Areas	55	16	10	0.16	0.28
H	Reference Area Premine Inventory	139 53	13 13	5 5	0.03 0.08	0.07 0.15
				Mean	**0.17**	**0.28**

[1] Based on inventories conducted in 1997

forms and species found in the premine inventories or on the reference areas (Table 3). Dominant native shrub species identified in premine inventories were included in nearly all of the seed mixes or planted as seedlings and transplants. Most of the seeded grasses and shrubs have established and persisted on all of the mines. Tree, forb, succulent, and some semi-shrub species, however, were consistently under-represented or absent in all of the seed mixes. The number of seeded species contained in reclamation mixes ranged from 10 to 73 and contained an average of 13 percent of the species and 25 percent of the species richness found in the corresponding reference areas. When the similarities between seed mix and reclamation flora were determined, the mean Jaccard's index, $IS_j = 0.44$ and mean Sorenson's index, $IS_s = 0.58$.

Richness of the seed mix (S) appears to have had a significant and positive influence on the richness of the postmining flora (F) of mines A, B, C, and G:

$$F = 7.7 + 9.94S \quad r^2 = 0.61 \quad P = 0.95 \qquad (1)$$

There was also a highly significant positive correlation ($P = 0.99$) among the areal extent of the reference areas or premine inventories, their concommitant flora richness and postmining flora richness of reclaimed areas which reflects the well-known species-area relationship.

Postmining species richness was about 25 percent of that found in reference areas or mined areas surveyed before mining. About 18 percent of the reference area or premine floras were found in the reclaimed areas (Table 2). Of the species found in the eight reclaimed areas, 69 percent of them were also found in the reference or unmined inventory areas. The mean Jaccard's index of similarity (IS_j) of the floras of unmined and reclaimed lands was 0.17, and the mean Sorenson's index of similarity (IS_s) was 0.28.

Discussion

Known plant species richness is difficult to compare among the eight mines used in this study because the mines are of different sizes (Table 1). That larger areas have a greater number of species is one of the oldest axioms in ecology (Rosenzweig 1995). Certainly, in this study there appears to be a strong relationship between the size of the area surveyed, the number of times an area was surveyed, and the cumulative number of species counted. Here, we limit our discussion of species richness to comparisons between reference and reclaimed areas.

Table 3. Similarity of reclamation seed mixes to pre- and postmining floras on 8 mines in New Mexico.

Mine	Life Form	Seed Mix Richness	Common to Reference Area	IS_J	IS_s	Common to Reclaimed Area	IS_J	IS_s
A	grasslike	36	5	0.08	0.16	25	0.63	0.77
	forbs	20	12	0.06	0.11	20	0.50	0.67
	semi-shrubs	3	2	0.33	0.50	2	0.40	0.57
	shrubs	14	10	0.30	0.61	12	0.80	0.89
	total	**73**	**29**	**0.10**	**0.21**	**59**	**0.59**	**0.74**
B	grasslike	6	6	0.23	0.38	6	0.60	0.75
	forbs	2	1	0.01	0.03	2	0.12	0.21
	semi-shrubs	1	1	0.14	0.25	0	0.00	0.00
	shrubs	3	3	0.38	0.55	3	0.60	0.75
	total	**12**	**11**	**0.10**	**0.18**	**11**	**0.30**	**0.47**
C	grasslike	8	7	0.23	0.38	6	0.40	0.57
	forbs	5	3	0.02	0.05	4	0.22	0.36
	semi-shrubs	2	2	0.20	0.33	2	0.33	0.50
	shrubs	4	4	0.14	0.38	4	0.66	0.80
	total	**19**	**16**	**0.09**	**0.16**	**16**	**0.36**	**0.53**
D	grasslike	14	7	0.35	0.52	7	0.35	0.52
	forbs	5	1	0.06	0.11	0	0.00	0.00
	semi-shrubs	0	0	—	—	0	—	—
	shrubs	10	4	0.17	0.29	0	0.00	0.00
	total	**34**	**14**	**0.19**	**0.31**	**7**	**0.14**	**0.25**
E	grasslike	7	5	0.31	0.48	7	0.78	0.88
	forbs	0	0	—	—	0	—	—
	semi-shrubs	0	0	—	—	0	—	—
	shrubs	3	3	0.10	0.18	3	0.60	0.75
	total	**10**	**8**	**0.10**	**0.18**	**10**	**0.71**	**0.83**
F	grasslike	9	6	0.21	0.35	8	0.80	0.89
	forbs	9	5	0.05	0.10	8	0.44	0.62
	semi-shrubs	1	1	0.20	0.33	1	0.50	0.67
	shrubs	2	1	0.11	0.12	2	0.33	0.50
	total	**21**	**13**	**0.08**	**0.15**	**18**	**0.53**	**0.69**
G	grasslike	5	4	0.36	0.53	5	0.63	0.77
	forbs	0	0	—	—	0	—	—
	semi-shrubs	0	0	—	—	0	—	—
	shrubs	6	6	0.29	0.44	4	0.44	0.62
	total	**11**	**10**	**0.18**	**0.30**	**9**	**0.50**	**0.67**
H	grasslike	11	6	0.30	0.46	7	0.44	0.61
	forbs	5	0	0.00	0.00	0	0.00	0.00
	semi-shrubs	0	0	—	—	0	—	—
	shrubs	6	3	0.09	0.16	1	0.17	0.29
	total	**22**	**9**	**0.08**	**0.15**	**8**	**0.35**	**0.46**
			Mean	**0.12**	**0.21**		**0.44**	**0.58**

Given the overall floristic diversity of New Mexico's Four Corners region, the known species richness of the reclaimed lands at the eight mines is rather low. Even considering the differences in areal extent between premine and reclaimed lands, age of reclaimed lands, and the number of surveys conducted at each mine (Table 1), all of the reclaimed areas have a low species richness. In contrast, using species-area curves derived from the Mixed and Western Mesophytic Forest Regions of Braun (1950), Wade and Thompson (1995) found partially reclaimed (pre-SMCRA) eastern mines had species richness only 2-12 percent below what was expected on unmined areas of the same size. There are several factors that may account for the low richness observed on these New Mexico mines:

1) Most of the postmine surveys used in this study were conducted on lands reclaimed under the standards of SMCRA. These permanent program lands appear to have a lower diversity than prelaw or interim lands -- possibly because of approximate original contour (AOC) design and construction and more prescriptive use of topdressing materials. The ensuing loss of meso- and microhabitat diversity may preclude establishment of some species commonly found in the premine condition.

2) Current reclamation practices and reclamation seed mixes favor rapid establishment of late successional vegetative species. Once established, these species may inhibit colonization and invasion of new species more than facilitating establishment. The absence of husbandry practices such as grazing and burning that simulate natural patterns of disturbance may also preclude establishment of species requiring unique environmental conditions for germination.

3) Most of these mines were inventoried by transect or production plot sampling methods and some species lists were supplemented with additional species noted on site but observed outside sample areas. Further, all of these inventories were conducted in late summer and not throughout an entire growing season. In fact, several of the permits note that many of the predominant spring-flowering species were expected to be missed in subsequent surveys.

Ecologists and botanists frequently use diversity similarity indices, and there are many available (Magurran 1988). Species richness is the most basic of diversity indices and is widely used as a reclamation success standard. Jaccard's (IS_j) and Sorenson's (IS_s) indices are most frequently used for similarity comparisons when presence-absence data are analyzed. When comparing two areas, an IS_j value indicates what proportion of the total flora is common to both. An IS_s value indicates the mean proportion of the flora in each area that is found in the other. The differences in meaning are subtle, and we present both for those readers who may have slightly different interests in floristic similarities. Values for IS_s change linearly as floras change in similarity, while IS_j values have a nonlinear response to change. Jaccard's index has a lower value than Sorenson's index.

When we make numerical comparisons between the floristic compositions of two areas, it is also useful to place these differences in the context of normal variation. In our data, IS_j ranges approximately 0.45 to 0.65 among reference areas and community types on the same mine, while IS_s ranges from approximately 0.60 to 0.80 for the same data. Large differences in the richness of floras will produce low IS_j and IS_s values. For example, 69 percent of the species found in the reclaimed areas were also found in the reference or inventory areas, but because premine areas were much richer, their mean indices of similarity are low with $IS_j = 0.17$ and $IS_s = 0.28$.

Both species-rich seed mixtures and species-rich reference areas are positively correlated with the species richness on reclaimed lands. The larger mine reference or inventory areas and seed mixes were also richer. Seed mix composition appears to contribute the most to rapid development of vegetative cover on the reclaimed lands. In general, composition of each seed mix was similar to the composition of the respective reference areas or inventories with 66 percent of seeded species being present in the reference areas. On average, 73 percent of the seed mix species persisted on the eight mines. The influence of the seed mix is most likely responsible for the high proportion of reclamation species being common to reference areas. Although there was an increase in the number of annual species encountered on the reclaimed lands, the overall low species richness of the postmine floras is responsible for low similarity indices between reclaimed and reference areas.

These results raise two major questions. Are mined and reclaimed areas truly depauperate in plant species richness? Are current sampling and inventory methods for pre- and postmining lands adequate to the task of determining true post-mining biodiversity? While it is unlikely that the postmine plant species richness is as depauperate as it appears in Table 3, examination of the data has convinced us that inventory and reporting methods have a significant impact on how mined land diversity is evaluated. Much of the data for this study was derived from sample-based studies using transects and plots of varying sizes and sample densities. Such sampling studies, even those using stratified methods, fail to capture 20 - 70 percent of the total species richness of an area (Wade, unpublished data). Rare and infrequent species are often missed, and the majority of the flora of both reference and reclaimed areas may fall into these abundance classes.

Additional monitoring and survey work conducted in intervening years between premine inventory and final bond release appears to be inconsistent. This work, however, is vitally important in establishing realistic and achievable reclamation standards for diversity. We also believe that more complete floristic inventory work both in unmined and reclaimed areas is necessary to answer some part of the questions posed above as well as others. For example, much of the emphasis in revegetation success continues to be placed on establishment of perennial grass and shrub species without giving consideration to the forb or annual species that may comprise the largest part of a native flora on undisturbed lands. When we checked the database against regional floras (Allred 1993, Kearney and Peebles 1951, Martin and Hutchins 1980, Welsh *et al.* 1987), it became apparent that there is very little consistency in how species are reported as perennials, biennials, annuals, scapose forbs, semi-shrubs, or shrubs. This presents something of a challenge as to how we categorize plant species. It also reinforces the idea that vegetation inventories should follow some guidelines such as those presented by Palmer *et al.* (1995) and should be conducted when plants are actually growing.

Conclusion

Application and interpretation of current reclamation laws, and regulations do not address these issues. Future studies of mined land vegetation and floras should be designed to identify species other than those seeded or planted that successfully colonize reclaimed lands. Ideally, the requisite annual monitoring of reclaimed lands would complimented by less frequent but more intensive complete floristic inventories to fully document plant species invasion and establishment. Standardized methods should be developed for annual surveys and metadata base establishment. Surveys should include greater focus on boundaries between reclaimed and undisturbed lands, determination on how to treat inclusions of undisturbed vegetation contained within reclaimed units, and consistent recording of the life forms found in both mined and reference areas.

Such standardized methods would produce data that could be easily integrated into regional databases that would also serve two other purposes. First, the effectiveness of different reclamation techniques with respect to the expression of different species contained in reclamation seed mixes could be more systematically evaluated. Second, these data would provide a more comprehensive, and perhaps more biologically significant documentation of real biodiversity for final bond release.

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