Faunal Community Development on Disturbed Lands: An Indicator of Reclamation Success

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Abstract

The contemporary approach to reclamation of disturbed lands usually follows an "agricultural" strategy which often results in the development of spatially homogeneous flora dominated by a small number of species. In addition, the planting of alien or "native-but-not-resident" species creates unique floral communities that historically have not existed on the site or in the region. As a result, initial colonization by animals is accomplished by only a small subset of the potential species pool, and may result in dramatic population increases of certain opportunistic species that have been released from resource limitation or competitive and predatory pressures. In many cases, the faunal community structure of reclaimed sites bears little resemblance to those of pre-disturbance or nearby undisturbed faunas. In view of the importance of invertebrate and vertebrate wildlife to ecosystem function (e.g., pollination, herbivory, soil aeration, litter decomposition, seed predation, and dispersal), we suggest that an analysis of the faunal community development (incorporating trophic organization, species dominance hierarchies, guild apportionments, population demographics, and species turnover rates) can be used as an evaluation method for successful reclamation. We further suggest that deliberate inclusion of both horizontal and vertical heterogeneity in vegetation architecture, at various spatial scales (micro-, meso-, and macro-scale), will result in a landscape mosaic more conducive to the development of a highly diverse, self-perpetuating faunal community.

Introduction

To a large extent, reclamation "success" is more a human perception than an ecological reality. "Successful" reconstruction of a disturbed ecosystem depends on the attainment of certain anthropogenic, predetermined goals, such as the development of a prescribed flora and fauna, or the replacement of the original, pre-disturbance biotic community. In reality, of course, some form of biological assemblage will develop on all but the most severely disturbed sites, regardless of the reclamation effort. The question then becomes, "Is the resulting community a reasonable facsimile of the desired community (both in structure and function), and will it persist through time to become self-perpetuating?"

Clearly, one of the prerequisites for determining the degree of reclamation success is a model community with which to compare the reclaimed community. If the reclamation goal is to restore the original biotic system, then the model community can be either the pre-disturbance community of the site, or a nearby undisturbed community of similar type. If the reclamation goal is to create a different type of ecosystem from the pre-disturbance one, then one has two options: (1) a comparison can be made to similarly reclaimed sites that have been declared "successful;" or (2) if no such comparison sites exist, then biological surveys and long-term monitoring efforts can be implemented to evaluate the structure, functioning and persistence of the reclaimed site's community. Such studies would provide the data from which a judgement of "success" would eventually be made.

The purpose of this symposium is to address a number of ecological considerations in evaluating reclamation success. These considerations can provide the framework for assessing the degree to which a reclaimed site has developed a suitably complex and stable biotic community. The subject of this paper is the use of data on faunal assemblages as a means of measuring reclamation success. Animals (both vertebrates and invertebrates) can be useful indicators of ecosystem development, because, as with plants, their life cycles integrate a wide variety of abiotic and biotic variables. However, animals contribute additional layers of ecological complexity to ecosystem structure and functioning, and may themselves influence the development of a reclaimed site. Hence, inclusion in site evaluations of at least some animal species has long been recognized as an important component of reclamation success (Majer 1989).

In this paper, we first briefly discuss the properties and processes of biotic systems in which animals are important participants, and identify those components that ecologists might use to measure, compare, and evaluate different undisturbed and reclaimed communities. We will then provide an example data set from studies performed on the

faunal communities of a shrub-steppe, surface coal-mine site in western Wyoming. Next, we will report on preliminary results of a long-term experiment designed to accelerate successional processes following reclamation of the Wyoming site, and discuss the implications for faunal community development. Finally, we will delineate future research needs and techniques for evaluating reclamation success with an integrated approach using both faunal and floral community data.

Properties of Biotic Systems

In the context of evaluating reclaimed ecosystems, the faunal component of the ecosystem both influences and responds to a number of biotic system properties. First, animals require a suite of habitat resources, that provide food, shelter and reproduction sites. A major component of an animal's habitat is the architectural structure of the vegetation. This includes both vertical architecture (grass vs. shrub vs. tree) and horizontal architecture (patch size and spatial distribution of vegetation types). Because animal species vary tremendously in their vagility and movement patterns, horizontal vegetation architecture is an important resource factor at a number of scales, ranging from landscapes (km^2) through stands (m^2) to individual plants (cm^2).

Animals also impart a trophic structure to the ecosystem. Through their feeding activities, animals influence the plant community in a number of ways (e.g., herbivory, granivory, pollination, and seed dispersal). In addition, animals can transport spores of beneficial mycorrhizal fungi (Rothwell and Holt 1978; Ponder 1980; Warner et al. 1987). Animal trophic interactions also influence nutrient cycling and energy flows; numerous invertebrate species (e.g., earthworms) are detritivores and play important roles in decomposition and soil development (Abbott 1989; Hutson 1989)

Faunal diversity (species richness and evenness) and biomass are additional properties of ecosystems that can be measured and used to compare various sites. Species richness and diversity are ecologically significant attributes of an ecosystem, as they can be a measure of the amount of redundancy in functional groups and trophic guilds. High levels of species redundancy may promote a greater stability of ecosystem functioning (e.g., numerous species of detritivores may increase decomposition rates and efficiencies, enhancing nutrient availability to vegetation). Animal biomass will, to some degree, determine the amount of herbivore pressure on the floral assemblage, and may ultimately influence the dispersion and species composition of the plant community.

Successional Processes

Succession is perhaps the most important ecological process influencing the outcome of a reclamation effort. While numerous models of successional processes have been developed (see MacMahon 1981), in this paper we will use Clements' (1916) classic succession model as a conceptual framework in which to discuss ecosytem development on reclaimed lands. In Clements' scheme (which applies to both flora and fauna), the ecosystem sustains a disturbance ("nudation") that reduces or eliminates resident populations. Surviving species ("residuals") undergo the process of establishment ("ecesis"), during which some species that are unable to cope with the new environment are eliminated. Through time, newly colonizing species ("migrants") join the residuals. Species that successfully establish alter the abiotic environment ("reaction"), thereby influencing the potential establishment of future migrants and the survivorship of the offspring of both residuals and past migrants. Biotic interactions ("coactions," e.g., competition, predation, parasitism) also influence the species compositions of the community. These successional processes continue until an equilibrium ("stabilization") is attained among the extant species and the environment. This state is often termed the "climax."

In the following section, we present a summary of faunal successional studies conducted on reclaimed surface coal mines in southwestern Wyoming. Many of our data can be interpreted using Clements' successional model outlined above. In addition, we will emphasize the relationships among the developing faunal and floral communities, and provide interpretations and implications for different management strategies.

Faunal Community Development In Shrub-Steppe Ecosystem

In 1979, a multi-disciplinary group of scientists (of which we were a part) at Utah State University began an NSF-funded long-term study of successional patterns on reclaimed surface coal mines in southwestern Wyoming. During the initial period of the project, we examined a number of reclaimed mine sites of varying ages in an attempt to describe the early successional patterns of the floral and faunal communities, given the conventional regime of reclamation efforts.

We conducted our studies on seven reclaimed surface coal mines, and an adjacent, undisturbed site, on the Pittsburg and Midway Coal Mining Company's Kemmerer Mine near Kemmerer, Wyoming. The region is characterized by rolling hills covered with a mosaic pattern of shrub-steppe vegetation (Fig. 1). Precipitation, mostly snow, averages 226 mm/yr, and is highly variable. Mean monthly temperatures in this high elevation site (2,200 m) range from -8°C in January to 17°C in July.

Vegetation in the region was shrub-steppe (West 1983), and was composed of two physiognomically distinct plant associations (Fig. 1). The first, a "tall shrub" association (with shrubs greater than 30 cm high) was dominated by big sagebrush (*Artemisia tridentata*), antelope bitterbrush *(Purshia tridentata)*, and Utah serviceberry *(Amelanchier*

utahensis). Shrub density was approximately 16,000 shrubs/ha (Parmenter et al. 1987). Understory vegetation was composed or forbs and grasses. This association of plants was patchily distributed throughout the region, but occurred most frequently in moister areas (e.g., along ephemeral stream courses and the leeward side of hills and ridges where deep winter snowpacks accumulate). These "islands" of tall shrubs were surrounded by areas of much shorter vegetation (less than 30 cm high), dominated by the diminutive low sagebrush *(Artemisia arbuscula),* rabbitbrush *(Chrysothamnus viscidiflorus),* and a variety of cushion plants, forbs and grasses.

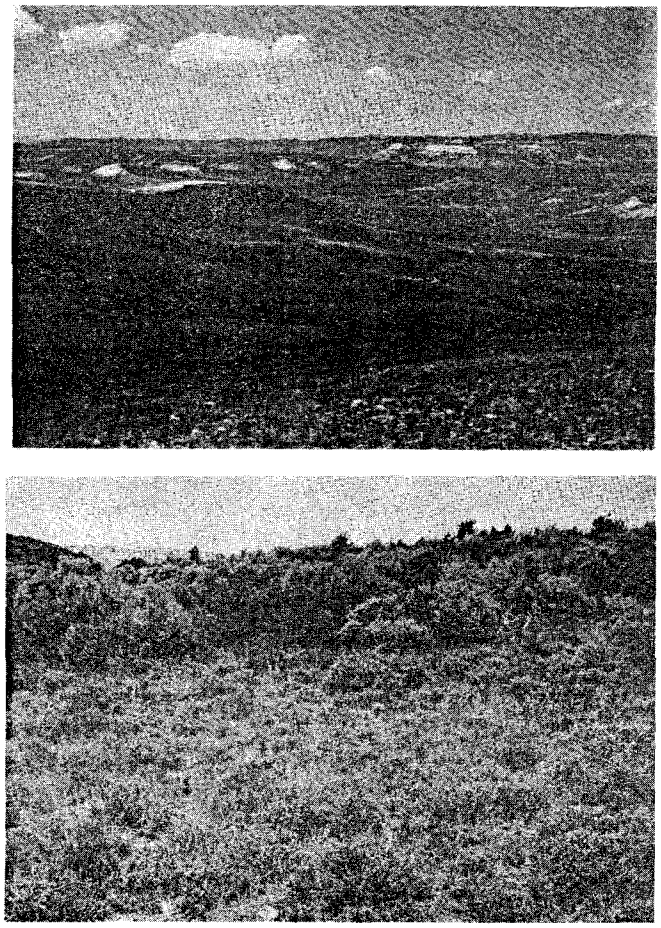

Figure 1.—Shrub-steppe vegetation near Kemmerer, Wyoming. Top: View of undisturbed area west of surface coal mines. Note landscape mosaic patterns of tall and short shrub associations. Bottom: Tall shrub association in background, short shrub association in foreground.

The primary goal of the reclamation effort at the Kemmerer Mine was to establish a shrub-steppe ecosystem that would be used both for wildlife habitat and livestock grazing (sheep and cattle). The seven reclaimed sites on the Kemmerer Mine had been sequentially revegetated at one year intervals beginning in 1977. The mines had been excavated by drag-lines, and the coal removed by truck-and-shovel procedures. Pit sizes ranged from 8 to 67 ha. Following coal extraction, the pits were recontoured with overburden materials (shales and sandstone). The mine pits revegetated from 1977 to 1979 received no topsoil, as they were not included in the Federal Government's 1977 Surface Mining Control and Reclamation Act (P.L. 95-87). The sites reclaimed from 1980 to 1983 received approximately 10 cm of stored topsoil. All sites were drill-seeded with a mixture of four-wing saltbrush *(Atriplex canescens)* and several wheatgrasses (western wheatgrass *[Pascopyrum smithii],* beardless wheatgrass *[Pseudoroegneria spicata],* thickspike wheatgrass *[Elymus lanceolatus],* and slender wheatgrass *[Elymus trachycaulus])* (Fig. 2). Fertilizer and irrigation were applied during the first or second years to facilitate plant establishment. At the time of revegetation, each site was contiguous with undisturbed vegetation; however, as new, adjacent mines were developed, older mine sites became surrounded by newer ones. Details of each mine site's reclamation history can be found in Parmenter et al. (1985).

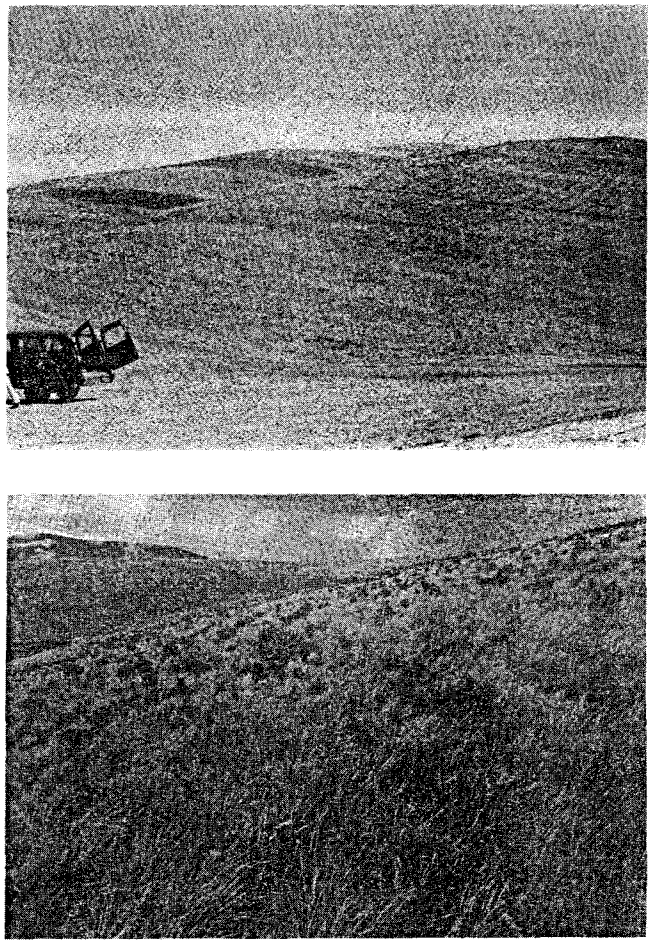

Figure 2.—Top: Recontoured surface coal mine pit on the Kemmerer Mine, Wyoming, following initial seeding and shrub planting. Bottom: Reclaimed mine site 6 years after revegetation with drill-seeded saltbush and wheatgrass seed-mix.

At the time of our sampling, the sites represented a series of plots containing various successional stages of plant

communities, ranging from a newly seeded site (0 yr old) dominated by annual forbs, through young sites (1-2 yr old) with mixed forb/grass vegetation, to older sites (3-6 yr old) with established stands of bunchgrasses and saltbush. Unfortunately, no replicate (i.e., similarly aged) mine sites were available in the region; hence, we could not estimate the degree of faunal or floral variation that may have existed within each successional stage. In addition, these sites may not have represented a strict, temporally-linear successional sequence, due to variation in weather conditions (e.g., precipiation amounts) that existed on the sites at the time of their revegetation. However, the successional sequences and time-frames that we observed on these sites were comparable to those reported for other grassland mine sites in western states (e.g., Iverson and Wali 1982).

We sampled the flora and fauna of the seven mine sites and the undisturbed area in 1983. Sampling methods for vegetation and vertebrate wildlife are described in Parmenter et al. (1985), and methods for invertebrate sampling are given in Parmenter and MacMahon (1987) and Parmenter et al. (1990). Briefly, (1) vegetation was sampled on a series of 0.5m² quadrats, (2) rodent population densities were estimated from mark-recapture data, (3) large mammal, reptile and amphibian presence/absence data were collected from general surveys, (4) bird presence/absence data were collected from line transects, and (5) anthropod data were collected from pitfall traps (ground-dwelling species) and barrier traps (flying species).

The vegetation data from the mine sites showed a pattern of increasing dominance by grasses (Fig. 3, Table 1). Floral diversity was greatest on the one-year-old site, due to the large number of annual forbs that had colonized this site. As grasses became dominant, however, diversity decreased. Some shrubs (virtually all four-wing saltbush) eventually became established (see Figure 2, bottom). Although conspicuous in appearance, shrubs did not achieve very high densities or percentage cover (Table 1). The floral communities on the site bore little similarity to the undisturbed site's vegetation (Fig. 4). This was due to the absence of the seeded mineland plants in the undisturbed area; while four-wing saltbush and various wheatgrasses occur patchily in western Wyoming, they are generally restricted to locally favorable sites (e.g., alkali soils for the saltbush, and disturbed sites for the wheatgrasses). As a result, the shrub-steppe ecosystem initiated by the mine company was very different from the surrounding, undisturbed shrub-steppe.

Surveys of vertebrate wildlife on the sites produced 24 species of mammals, 35 birds, 3 reptiles and 3 amphibians (Parmenter et al. 1985). The undisturbed area contained more species of mammals, birds, and reptiles than any of the mine sites; on mine sites with extant ponds, the amphibian species were generally common.

The early colonizing species of mammals on the reclaimed mines included shrews *(Sorex* spp.), deermice *(Peromyscus maniculatus)*, sage voles *(Lagurus curtatus)*, montane voles *(microtus montanus)*, and jackrabbits *(Lepus townsendi)*. Larger carnivores (coyotes *[Canis latrans]* and foxes *[Vulpes fulva])* and ungulates (mule deer *[Odocoileus hemionus]* and pronghorn antelope *[Antiolocapra americana])* were observed traversing and foraging on the mine sites, but did not appear to be permanent residents; these animals had home ranges that were much larger than any of our mine sites. Dominant birds on the mine sites were vesper sparrows *(Pooecetes gramineus)* and horned larks *(Eremophila alpestris)*, both of which prefer grassland habitats. No reptiles were ever observed on any reclaimed mine site.

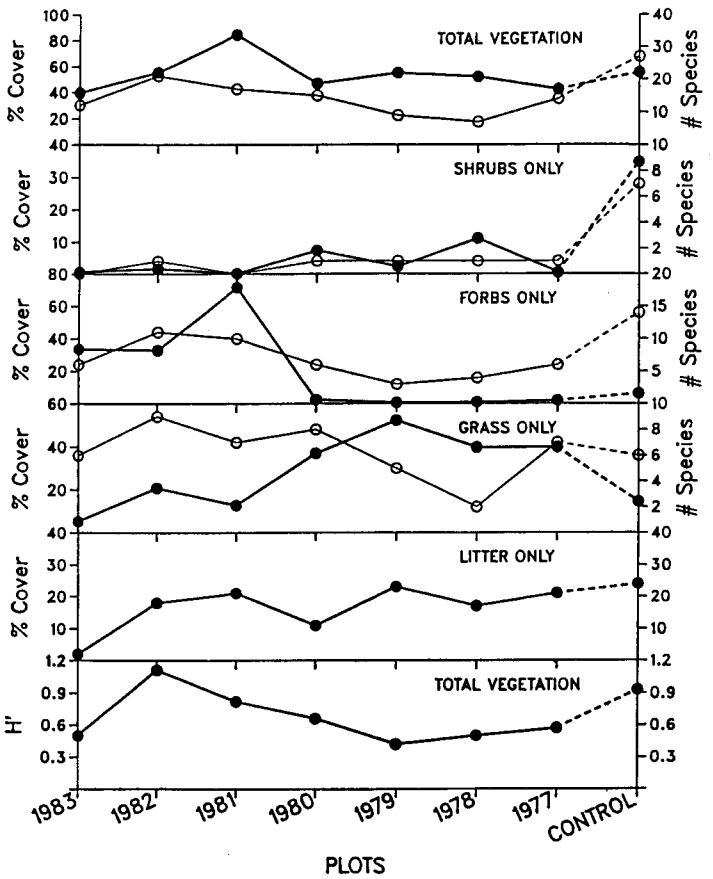

Figure 3.—Early succession trends in vegetation of reclaimed surface mine sites on the Kemmerer Mine, Wyoming. Plots are listed by year of vegetation seeding. Solid circles with heavy lines are percentage cover or diversity. Open circles with light lines are number of species. H'=Shannon-Weiner Index (Margalef 1957) (from Parmenter et al. 1985, with permission).

In analyzing the floral and faunal data from these sites, we first tested the hypothesis that faunal recolonization was independent of time since revegetation. This analysis (linear and non-linear regressions) failed to reject the hypothesis, indicating that time alone was not a significant factor in faunal re-establishment. We then tested a series of 63 potential relationships among floral and faunal community variables. The floral variables included species

COMMON SPECIES	PERCENT SIMILARITY: CONTROL	1977	1978	1979	1980	1981	1982	1983
CONTROL		9	7	7	7	7	10	6
1977	4		50	62	62	18	15	10
1978	2	5		81	75	14	9	6
1979	3	4	5		76	14	9	7
1980	3	6	6	8		16	16	8
1981	4	11	6	5	8		31	28
1982	4	11	5	6	9	13		32
1983	3	7	4	5	7	9	10	

Figure 4.—Schoener's (1968) percent similarity indices (upper right triangle) and number of "mutually common" species (lower left triangle) from inter-plot comparisons of vegetation on reclaimed mine sites on the Kemmerer Mine, Wyoming. Plots are listed by year of vegetation seeding (from Parmenter et al. 1985, with permission).

Table 1.—Vegetation characteristics of undisturbed and reclaimed mine plots near Kemmerer, Wyoming, 1983, reclaimed mine plots are labeled by year of revegetation (values compiled from Parmenter et al. (1985).

		No topsoil plots			Topsoil plots			
Parameter	**Undisturbed**	**1977**	**1978**	**1979**	**1980**	**1981**	**1982**	**1983**
No. Species:								
Shrubs	7	1	1	1	1	0	1	0
Forbs	14	6	4	3	6	10	11	6
Grasses	6	7	2	5	8	7	9	6
Total	27	14	7	9	15	17	21	12
Percent Cover:								
Shrubs	35	<1	11	2	7	0	1	0
Forbs	6	2	1	1	2	72	33	34
Grasses	15	40	40	52	38	12	21	5
Total plants	56	42	52	55	47	84	55	39
Litter	24	2	19	21	11	23	19	22
Diversity (H')	0.93	0.57	0.51	0.42	0.66	0.82	1.10	0.50

richness and percentage cover for the total plant community, for grasses, forbs, and shrubs (separately), and for percentage cover of litter. Faunal variables included species richness for both resident and non-resident mammals, birds, total vertebrates, and deermouse densities (the only rodent species with sufficiently large sample sizes). Of these regression analyses, only one significant relationship consistently emerged: as the shrub component increased in the floral community, vertebrate species richness increased (Fig. 5). Similarly, deermouse densities were positively correlated to shrub cover (Fig. 6).

Few of the vertebrate species present on the reclaimed mine sites fed extensively on four-wing saltbush; hence, the importance of this shrub to the recolonizing vertebrate fauna was probably not food-related. Rather, we suggest that the scattered shrubs on the older mine sites contributed to architectural heterogeneity of the vegetation, providing small patches of shelter (for small mammals and birds in particular), as well as sources of alternative foods (e.g., concentrated seed clumps and insect populations). However, the density of shrubs was still below the threshold needed to support many species of vertebrates. For examples, shrub-dwelling species of rodents (such as long-tailed voles *[Microtus longicaudus]*, least chipmunks *[Eutamias minimus]*, and Uinta ground-squirrels *[Spermophilus armatus])* and birds (such as Brewer's sparrows *[Spizella breweri]*, sage thrashers *[Oreoscoptes montanus]*, and green-tailed towhees *[Pipilo chlorurus])* failed to successfully colonize the mine sites. Addition of these species into the mineland fauna will likely occur if and when shrub densities increase; however, this may take many decades to accomplish without additional reclamation efforts.

From the perspective of Clements' successional model, we can not only interpret our Wyoming results but also contrast

succession in the shrub-steppe ecosystem with succession in more mesic, forested ecosystem. In terms of vertebrates, mining operations ("nudation") effectively leave no surviving "residual" species; hence, the initial vertebrate fauna is composed of "migrants." As forb and grassland vegetation develop, providing food and shelter resources, vertebrates (generally omnivores) become established ("ecesis"). As shrub vegetation becomes more dominant and begins to modify the architecture of the site ("reaction"), more vertebrate species may be added to the community. As the animal diversity and biomass increases, predators (weasels, badgers, hawks, snakes) can move in and exploit the prey populations ("coactions").

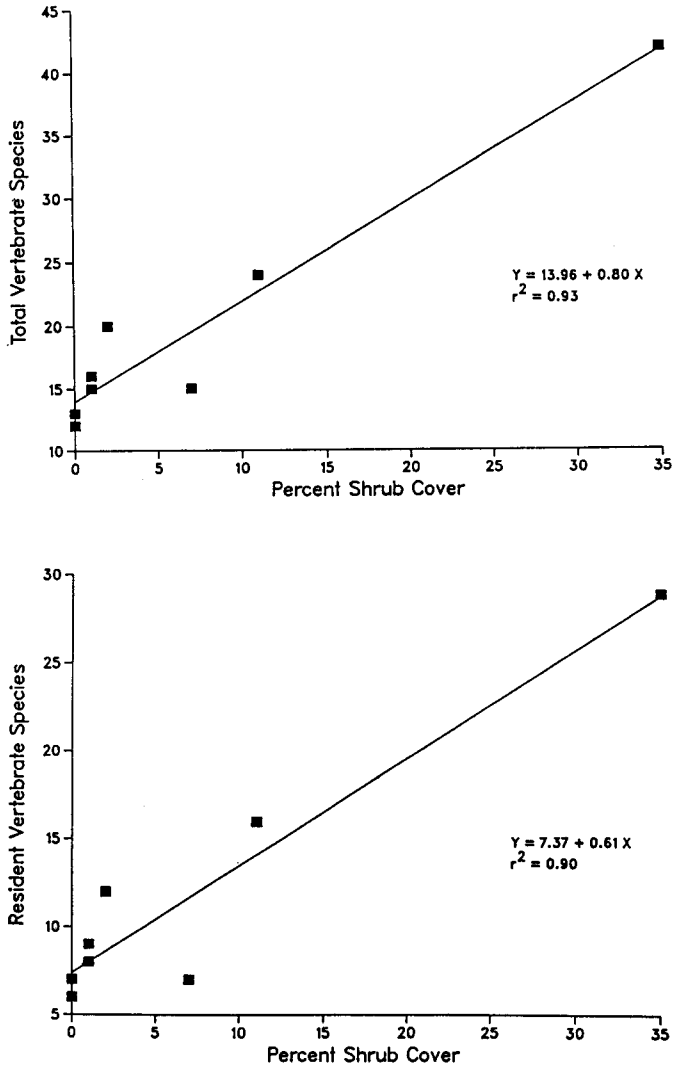

Figure 5.—The relationship between percentage cover of shrubs and vertebrate species richness on reclaimed mine sites on the Kemmerer Mine, Wyoming. Top: Total vertebrate species (includes residents, non-residents, and amphibians). Bottom: Resident species only (does not include amphibians) (from Parmenter et al. 1985, with permission).

In the shrub-steppe, as in other arid and semi-arid ecosystems, the successional process can be viewed as a simple accumulation of species, in which plants and animals are sequentially added to the community without extensive losses or replacement (species turnover). This is because arid lands generally do not progress beyond shrub-dominated vegetation patterns. This type of succession, based predominantly on the initial species list, can be termed auto-succession. In contrast, mine land succession in more mesic, forested regions follows a pattern of distinct species turnover (or relay succession) as a site goes from a forb/grassland system through shrubland into forest. Such patterns have been well documented for small mammals (Yeager 1942; Verts 1957; Kirkland 1976; Sly 1976; Hansen and Warnock 1978) and birds (Karr 1968; Chapman et al. 1978; Crawford et al. 1978; Bejcek and Tyrner 1980; Krementz and Sauer 1982; Schaid et al. 1983).

While general analyses of vertebrate community structure on reclaimed mine lands can yield insights into the complexities of successional processes, such studies often suffer from the logistical difficulties of obtaining large, statistically suitable sample sizes. Field population sizes of many rodents or shrews, for example, may be too small to sample adequately, and in many cases fluctuate dramatically from year to year. Home ranges of larger vertebrates may extend across multiple mine sites and unmined areas, making data interpretation difficult. In addition, detailed statistical comparisons using various indices of vertebrate assemblages (e.g., species diversity, richness, evenness, similarity), when based on small numbers of species and/or individuals per plot, can be virtually meaningless. In contrast, studies of invertebrates (principally arthropods) can yield more extensive data sets from which to evaluate successional trajectories and reclamation success.

Unfortunately, only a few studies have examined arthropod community development on reclaimed mine sites (e.g., Neumann 1971; Usher 1979; Hawkins and Cross 1982; Majer et al. 1982; Urbanek 1982; Schrock 1983; Majer 1985; Nichols and Burrows 1985; Parmenter and MacMahon 1987; Sieg et al. 1987; Parmenter et al. 1991; see also references in Majer 1989). Given the importance of insect pollinators, herbivores, predators, and detritivores to ecosystem funtioning, and the potential for economic impact on reclamation efforts, knowledge of insect recolonization and successional patterns would be useful to ecologists and land managers in their attempts to develop successful strategies of reconstructing disturbed ecosystems.

Studies of the successional development of insect communities on disturbed sites have shown that initial colonization and dominance is generally accomplished by scavenging and omnivorous species, and that the herbivore assemblage changes as a function of vegetation diversity and abundance (Bulan and Barrett 1971; Teraguchi et al. 1977; Southwood et al. 1979; Butt et al. 1980; Force 1981; Hawkins and Cross 1982; Majer et al. 1982; Brown and

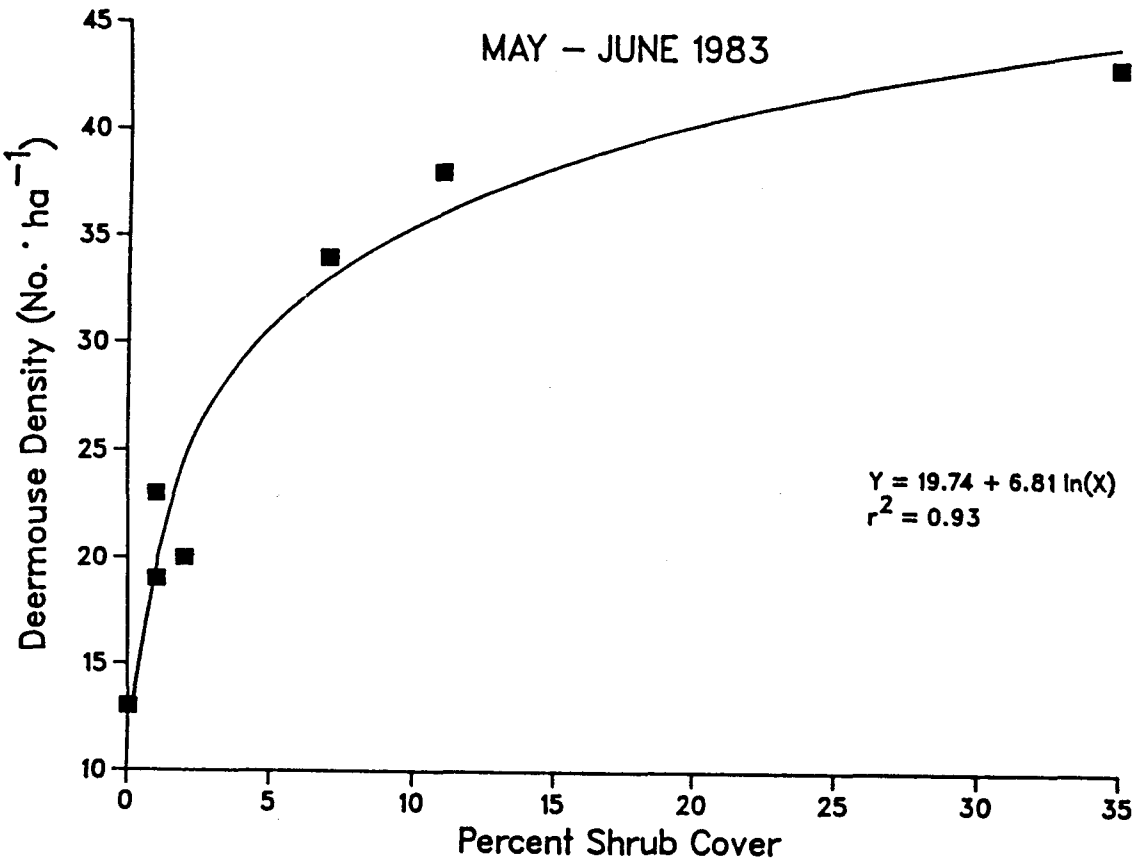

Figure 6.—The relationship between percentage cover of shrubs and deermouse densities on reclaimed mine sites on the Kemmerer Mine, Wyoming (from Parmenter et al. 1985, with permission).

Southwood 1983; Majer 1985; Parmenter and MacMahon 1987; Parmenter et al. 1991). In addition, numerically dominant species in post-disturbance environments are oftentimes exceedingly rare in the undisturbed community; such opportunistic "pioneer" species typically exhibit large and rapid population increases following a disturbance. These successful colonizers benefit not only from a suite of newly available food resources, but also from a combination of changes in the abiotic (e.g., temperature and moisture regimes) and biotic environments (e.g., predation and competition pressures).

On the Kemmerer Mine, we selected two groups of insects as representative taxa for examining trends in faunal community development: beetles (Coleoptera) and grasshoppers/crickets (Orthoptera). Grasshoppers represented an important and abundant group of herbivores/omnivores that should respond to floral community development. Beetles constituted a highly diverse order, with representatives of a wide range of trophic groups (e.g., predators, herbivores, omnivores, fungivores, granivores, palenivores, parasitoids, detritivores, and carrion feeders). As such, beetle assemblages had the potential to illustrate overall trends in the development of the faunal community.

During our field study, we trapped 12,196 beetles, belonging to 98 species in 19 families (Parmenter and MacMahon 1987), and 7,125 orthopterans, belonging to 26 species in 3 families (Parmenter et al. 1991). Summary statistics for the beetle and grasshopper assemblages on the reclaimed mines and undisturbed areas are presented in Tables 2-5. Analysis of beetles species-dominance curves (Fig. 7) showed approximately similar structural patterns, although the reclaimed sites tended to have more rarer species. However, cluster analysis revealed that the beetle assemblages on the reclaimed mines were considerably different from that of the undisturbed site (Fig. 8). A similar pattern was recorded for the orthopteran fauna (Fig. 9). In addition, the beetle faunas on older, grass-dominated sites appeared similar to one another, indicating that successional changes had slowed. We also noted lower beetle species richness and diversity indices on older mine sites (Fig. 10).

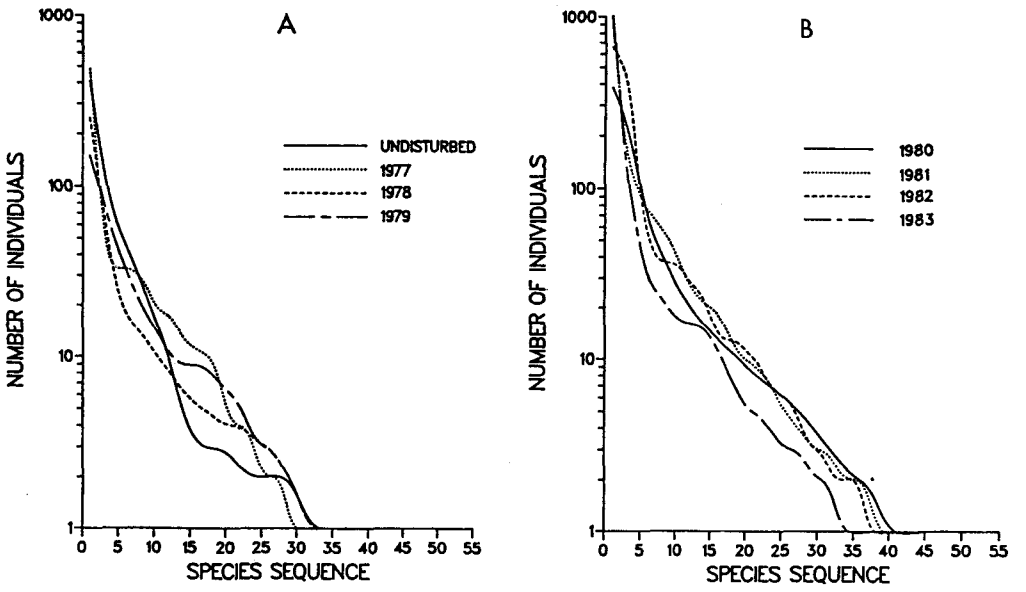

Figure 7.—Species-dominance curves of beetle assemblages on (A) undisturbed and non-topsoiled reclaimed mine sites, and (B) topsoiled reclaimed mine sites (Kemmerer Mine, Wyoming) (from Parmenter and MacMahon 1987, with permission).

Table 2.—Taxonomic and community parameters of beetle assemblages on undisturbed and reclaimed surface coal mines near Kemmerer, Wyoming, 1983; reclaimed mine plots are designated by the year in which they were revegetated (diversity computed using Shannon-Wiener (H') index)

	Plot							
Parameter	**Undisturbed**	**1977**	**1978**	**1979**	**1980**	**1981**	**1982**	**1983**
No. Families	15	13	13	14	14	13	13	13
No. Species	45	35	37	39	52	48	46	44
No. Individuals	1189	1072	684	686	1651	2503	2461	1950
Diversity (H')	0.91	0.94	1.00	1.18	1.12	0.89	0.99	0.77
Evenness (J')	0.55	0.60	0.64	0.74	0.65	0.53	0.60	0.47

Table 3.—Numbers of individuals of beetles in trophic groups found on undisturbed and reclaimed surface mine plots near Kemmerer, Wyoming, 1983

	Plot							
Trophic group	**Undisturbed**	**1977**	**1978**	**1979**	**1980**	**1981**	**1982**	**1983**
Herbivores	241	52	50	74	103	89	90	154
Predators	277	141	90	130	195	264	242	139
Omnivores	643	340	348	252	1123	722	1551	200
Fungivores	3	12	18	21	38	137	66	419
Dung feeders	5	1	0	0	0	0	1	0
Carrion feeders:								
on vertebrates	17	36	25	104	13	2	2	5
on insects	1	490	153	105	179	1289	508	1033

Table 4.—Numbers of species of beetles in trophic groups found on undisturbed and reclaimed surface mine plots near Kemmerer, Wyoming, 1983

Trophic group	Plots							
	Undisturbed	1977	1978	1979	1980	1981	1982	1983
Herbivores	11	6	7	7	9	10	9	8
Predators	14	11	10	14	16	18	17	18
Omnivores	10	12	11	11	17	14	12	11
Fungivores	3	2	5	4	6	4	4	5
Dung Feeders	2	1	0	0	0	0	1	0
Carrion feeders:								
on vertebrates	4	2	3	2	4	1	2	1
on insects	1	1	1	1	1	1	1	1

Table 5.—Species and numbers of Orthopetera collected from undisturbed sagebrush-steppe site and seven reclaimed mine sites near Kemmerer, Wyoming, summary computations of diversity and evenness based on Shannon-Wiener function, H' (Margalef 1957)

Taxon	Undisturbed sagebrush-steppe	Reclaimed mine sites (No. years since revegetation)						
		0	1	2	3	4	5	6
ACRIDIDAE								
Gomphocerinae								
Aeropedellus clavatus	0	0	4	3	28	2	3	3
Amphitornus coloradus	0	0	0	0	1	1	0	20
Aulocara elliotti	4	2	76	5	11	2	3	20
Psoloessa delicatula	139	0	2	1	0	0	0	1
Melanoplinae								
Melanoplus bivitattus	1	0	0	0	1	0	0	0
Melanoplus complanatipes	5	1	0	0	0	1	0	0
Melanoplus infantilis	25	1	10	1	7	0	0	5
Melanoplus sanguinipes	3	1	362	7	25	64	32	48
Oedipodinae								
Arphia conspersa	12	0	0	0	0	1	0	0
Arphia pseudonietana	1	0	4	0	0	0	0	0
Camnula pellucida	4	0	160	22	6	96	69	229
Circotettix carlinianus	1	1	9	9	0	0	0	1
Circotettix rabula	0	0	0	0	0	0	1	0
Cratypedes neglectus	3	0	10	17	3	0	3	16
Trimerotropis gracilis	2	0	0	0	1	0	0	0
Trimerotropis pallidipennis	11	0	11	8	4	5	0	9
Trimerotropis sparsa	1	0	0	0	1	0	0	0
Trimerotropis strenua	1	0	0	0	0	0	0	0
Xanthippus corallipes	3	0	1	10	0	3	2	6
GRYLLACRIDIDAE								
Rhaphidophorinae								
Ceuthophilus caudelli	48	219	270	133	1031	1023	1948	699
Stenopelmatinae								
Stenopelmatus fuscus	23	0	0	1	1	0	0	1
TETTIGONIIDAE								
Decticinae								
Anabrus simplex	0	0	7	5	1	1	0	3
Steiroxys pallidipalpus	3	0	9	0	0	0	1	10
Total individuals	290	225	935	222	1121	1199	2062	1071
Species richness, (R)	19	6	14	13	14	11	9	15
Diversity, (H')	0.79	0.07	0.68	0.67	0.19	0.25	0.12	0.50
Evenness, (J')	0.62	0.09	0.60	0.60	0.16	0.24	0.13	0.42

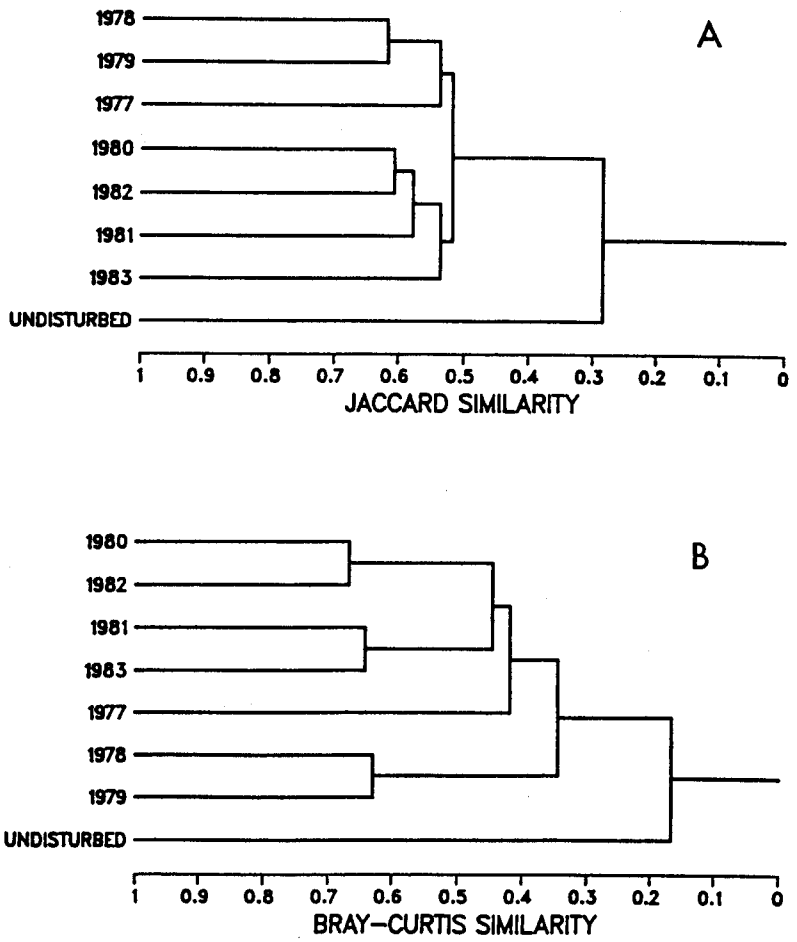

Figure 8.—Dendrograms of similarity clusters from hierarchical cluster analysis of beetle assemblages on undisturbed and reclaimed mine sites of the Kemmerer Mine, Wyoming. (A) Community similarities based on species presence/absence data (Jaccard's [1908] Similarity Coefficient). (B) Community similarities based on both species and numbers of individuals per species (Bray-Curtis [1957] Similarity Coefficient) (from Parmenter and MacMahon 1987, with permission).

The beetle and grasshopper assemblages on the sites proved to be reasonable indicators of vegetation development. Both herbivorous beetles and grasshoppers showed significant correlations between insect and plant species richness (Figs. 11 and 12). Grasshopper diversity also was correlated to plant diversity, although herbivorous beetle diversity was not. In addition, we observed no significant correlation between the total beetle fauna and any floral variable; this was not unexpected, as many of the beetles were predators, omnivores, fungivores, and carrion feeders, and should not be highly sensitive to differences in vegetation. However, some species require shrubs as an architectural resource that ameliorates temperature and moisture extremes (Parmenter et al. 1989a,b). For example, in the undisturbed area, darkling beetles (Tenebrionidae) partition their microhabitats based on the presence/absence of tall shrub cover (Fig. 13). As with vertebrates, shrub architecture can have a significant influence on invertebrate recolonization of reclaimed sites; we found that the two shrub-dwelling species illustrated in Figure 13 *(Eleodes pimelioides and E. constrictus)* had failed to establish populations on the mine sites.

One interesting aspect of the beetle faunal succession was the general decline in the number of fungivores on the reclaimed mines (Fig. 14). As stored topsoil is respread on the mine sites, organic debris (leaves, branches, and small animal carcasses that had been swept up with the topsoil) is suddenly made available to saprophytic fungi. Large numbers of fungivorous organisms can exploit this resource, as evidenced by the abundance of fungivore beetles. However, as this resource (actually, the detrital substrate) is depleted through time, fungivore numbers decline toward the normal background level.

In summary, our studies of the Kemmerer Mine faunal and floral communities, taken together, have shown clearly that

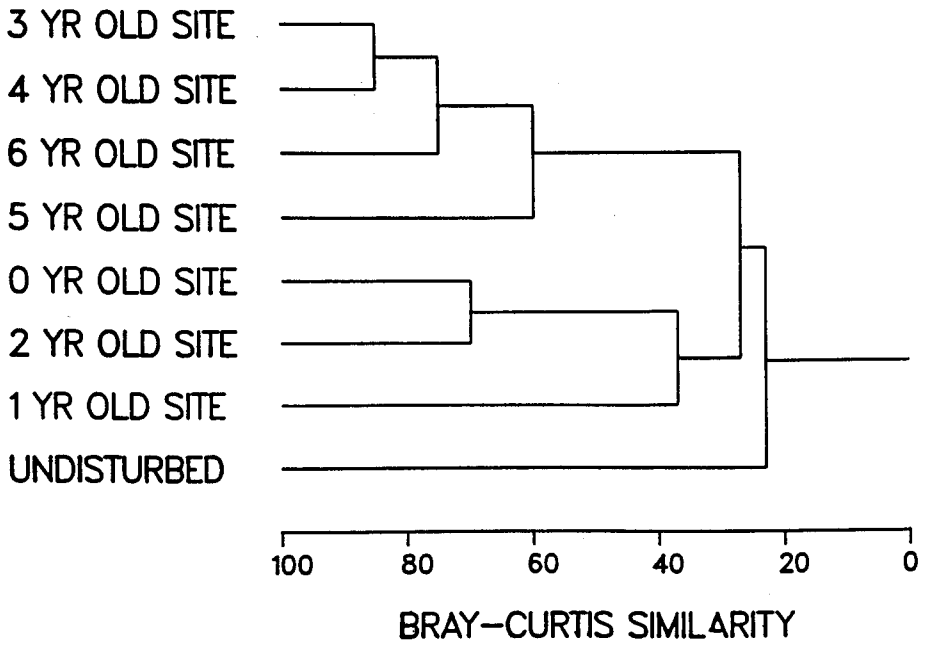

Figure 9.—Dendrogram of orthopteran faunal similarity clusters from hierarchical cluster analysis. Faunas of the disturbed mine sites are listed by the number of years since revegetation. Analyses based on Bray-Curtis (1957) similarity coefficients (from Parmenter et al. 1991, with permission).

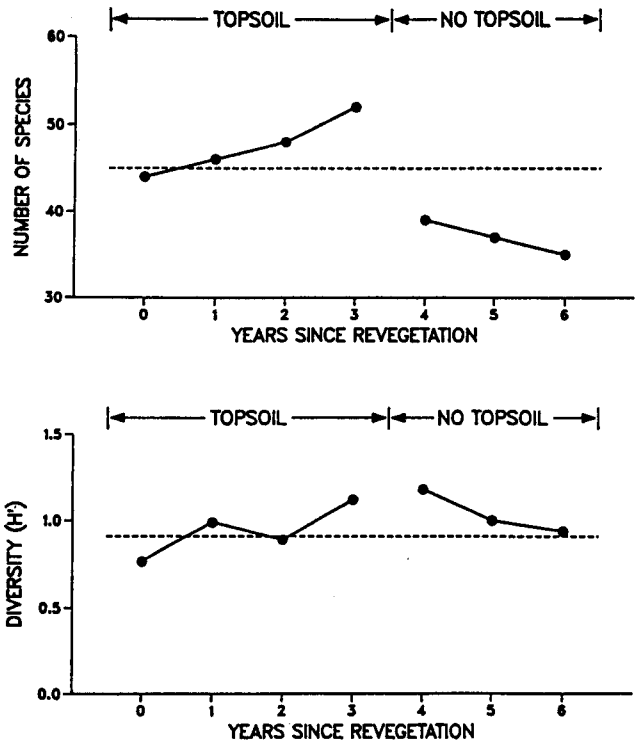

Figure 10.—Early successional trends in the beetle fauna (number of species and diversity) on reclaimed mine sites at the Kemmerer Mine, Wyoming. Dashed horizontal lines indicate undisturbed site values. Diversity was computed using the Shannon-Wiener function (Margalef 1957) (from Parmenter and MacMahon 1987, with permission).

the shrub-steppe ecosystem on the reclaimed sites bears little resemblance to the native, undisturbed shrub-steppe ecosystem. This outcome can be attributed to the use of "native-but-not-resident" shrubs and grasses during the reclamation effort. As a result, the use of an undisturbed area of shrub-steppe as a comparative "model community" is invalid for our study sites. Rather, in the absence of comparable saltbush/wheatgrass communities in the region, we should continue to monitor the successional progress of these sites to determine if they are indeed self-perpetuating and sustainable.

Accelerated Reclamation: An Experimental Approach

In arid and semi-arid environments, one of the most difficult successional stages for shrub vegetation is the "ecesis," or establishment, phase. Shrubs often require several consecutive "good" precipitation years to germinate and establish root systems of sufficient depth to survive drought periods. As a result, shrub populations in arid lands often consist of a few discreet cohorts, rather than a wide variety of differently aged individuals. This constraint on shrub establishment suggests that the formulation of a successful reclamation plan for a disturbed shrub-steppe ecosystem should include a management strategy that circumvents the "bottleneck" of shrub establishment.

With this in mind, and an appreciation for the value of landscape heterogeneity involving shrub vegetation, we began a large-scale experiment on the Kemmerer Mine to

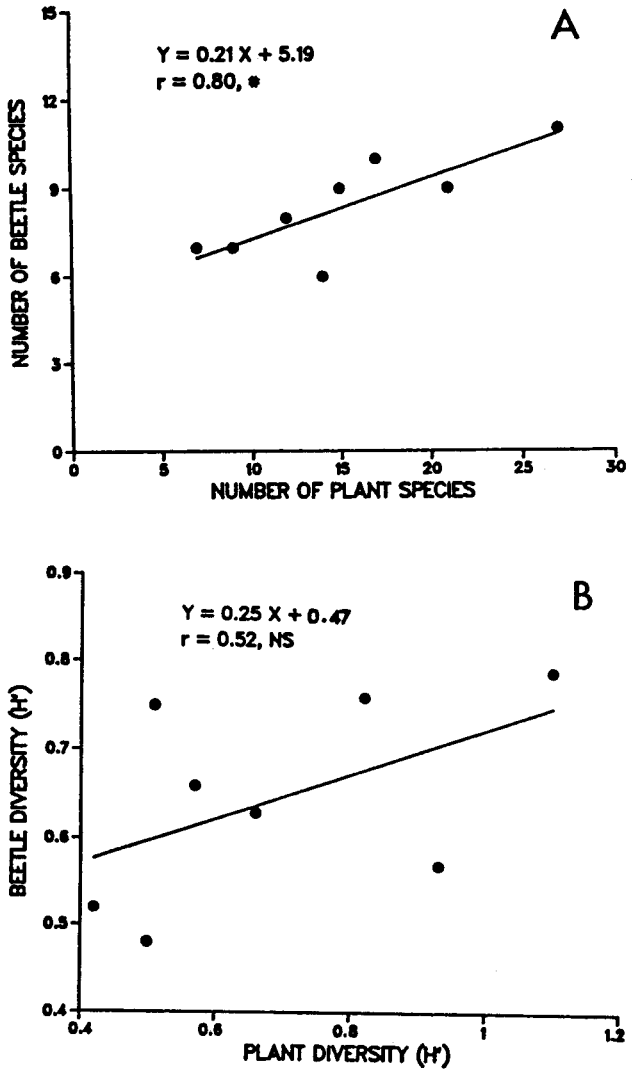

Figure 11.—Linear regression analyses of the relationship between (A) herbivorous beetle species richness and plant species richness, and (B) beetle and plant diversity indices (Shannon-Wiener function) on undisturbed and reclaimed mine sites on the Kemmerer Mine, Wyoming. (*=Significant correlation, *P*<0.05; NS=Not Significant) (from Parmenter and MacMahon 1987, with permission).

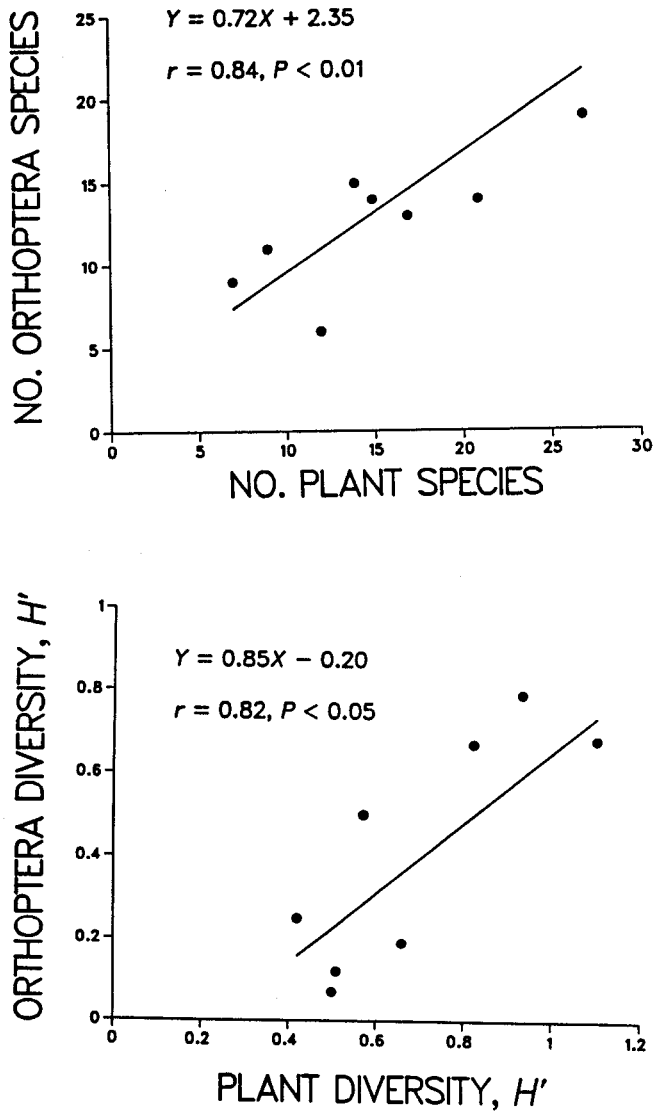

Figure 12.—Linear regressions showing the relationships between orthopteran community attributes and vegetation attributes on reclaimed mine sites near Kemmerer, Wyoming. Top: Species richness; Bottom; Diversity (from Parmenter et al. 1990, with permission).

evaluate successional processes under a variety of management conditions, paying particular attention to both floral and faunal components. The major portion of the research focused on a comparison of two reclamation "strategies." The first was the conventional "agricultural" approach, wherein the mining company utilized farm equipment to drill-seed prescribed plant species in a spatially homogeneous pattern across re-topsoiled mine sites. The second, alternative approach was based on our ecological knowledge of succession in semi-arid, shrub-steppe ecosystems. We hypothesized that young native shrubs, grown in greenhouses for a year and transplanted onto the mine sites in varying densities and spatial patterns, would provide a large number of "islands of fertility." These "islands" of shrubs would act as foci for wind-blown seeds, organic matter, fungi spores, and animal activity, and would eventually expand and coalesce, thereby greatly accelerating the successional process. The use of greenhouse-grown plants would allow the shrubs to avoid the critical germination and establishment period experienced by seeds. While the initial planting of the shrubs would be more expensive than simply drill-seeding the site, we hypotheized that the accelerated development of the biota would shorten the time span required to achieve certification as "successfully revegetated," thereby facilitating the early release of the bond posted by the mine company.

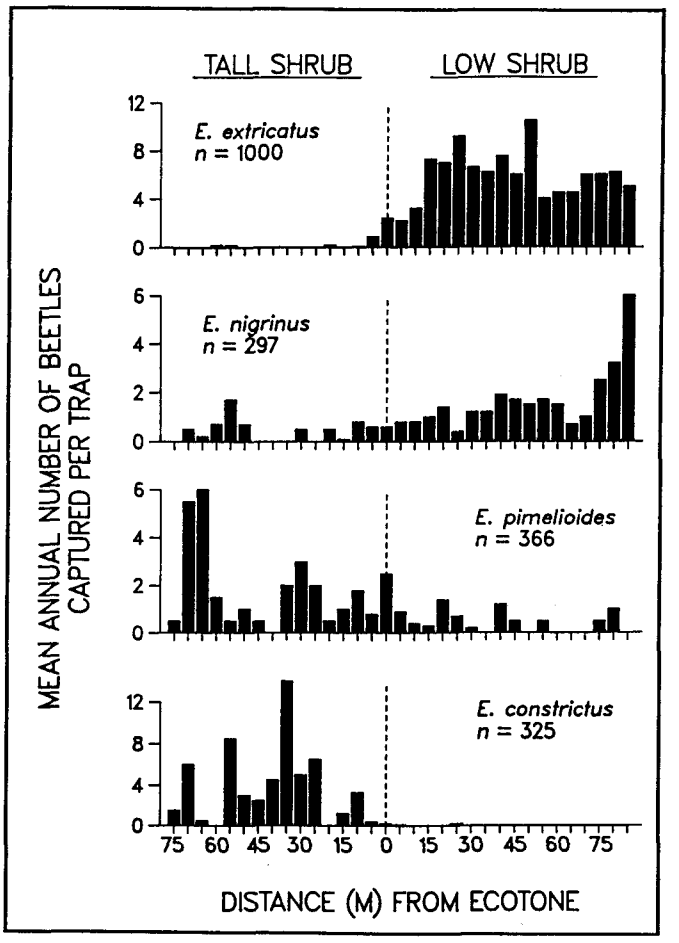

Figure 13.—Spatial distributions of captures of darkling beetles, *Eleodes* spp., in two adjacent habitat types in the undisturbed shrub-steppe site on the Kemmerer Mine, Wyoming. Total sample sizes *(n)* represent pooled data from 1983 to 1986. The ecotone was the interface between stands of tall and low shrubs (from Parmenter et al. 1989a, with permission).

The overall design of the experiment was an incomplete, replicated factorial in which the treatments were (1) soil type (no topsoil, stored topsoil and fresh topsoil, (2) shrub density (normal [16,000/ha], high [2X normal], medium [0.6X normal], and low [0.2X normal]), (3) shrub dispersion pattern (regular or clumped), and (4) shrub species (big sagebrush, Gardner's saltbush, and rabbitbrush). Additional treatments included controls and "conventional" reclamation plots (plots that were revegetated by the mine company using standard practices and seed mixes). Each treatment was replicated 3 times on plots ranging in size from 0.06 to 0.22 ha. Vegetation and animals were sampled annually on all plots from 1982 through 1987. Periodic sampling (at 5 to 10 year time intervals) is planned for the future.

Shrub establishment on the sites was very successful (Fig. 15), with high rates of survival and establishment of big sagebrush and rabbitbrush. Mortality of Gardner's saltbush was about 70% in the first year, but because it was a relatively small shrub, it's loss did not have a significant influence on vegetation architecture of the plots. For forbs and grasses, results to date indicate that the herbaceous communities on the plots are converging to a common (cover-weighted) diversity (Hatton and West 1987), regardless of topographic position, planting density, or freshness of topsoil. The shrub-planted plots also have produced consistently greater numbers of species and higher percentage cover of vegetation than the unplanted controls or the plots seeded by the mine company.

Results of the animal studies have thus far been consistent with our previous successional studies in that during the early stages of succession, the colonizing species and community structure are similar among all treatments. However, as the shrub vegetation has developed, we have observed colonization by shrub-dwelling species, such as least chipmunks, Brewer's sparrows, and the darkling beetles (*Eleodes* spp.) discussed above. Hence, the deliberate inclusion of patches of shrubs for the purpose of diversifying the vertical and horizontal vegetation architecture on reclaimed mines has led to predictable increases in recolonizing animal species.

Summary and Future Needs

From our research experiences on the Kenmerer Mine, we have concluded that faunal analyses can successfully distinguish communities in disturbed and undisturbed ecosystems and among various seral stages of ecosystem succession. Comparative model communities, when appropriate, can be used to test whether a community on a reclaimed site is statistically similar. These test results, in turn, can be used to evaluate the success of the reclamation effort. Faunal assemblages worldwide have been shown to be sensitive to changes in floristics and abiotic variables, and can therefore be expected to reliably perform as indicator variables of successional status in disturbed ecosystems. We would emphasize that an ecologically based, holistic approach to the evaluation of reclamation success, incorporating both abiotic and biotic variables, will have the greatest probability of accurately determining the degree to which a disturbed site has been reclaimed. We also suggest that in future monitoring and research activities, more attention be paid to landscape-scale heterogeneity of vegetation. We predict that landscape heterogeneity, if incorporated into reclamation plans, will increase both floral and faunal richness and diversity. Finally, we recommend that more resources be devoted to the examination of invertebrate assemblages, as these faunas are likely to have extremely important influences on, and responses to, the various successional trajectories of disturbed ecosystems.

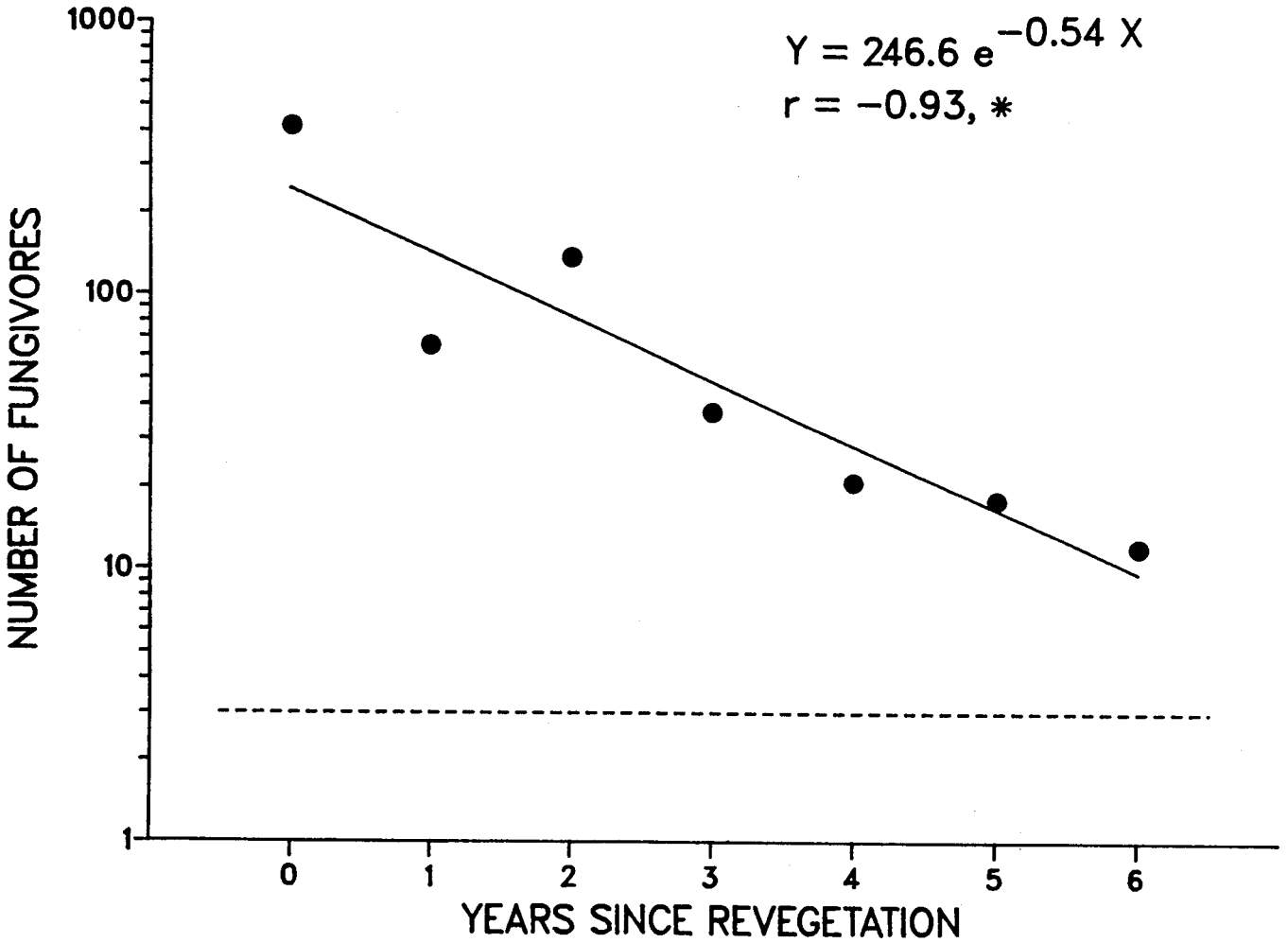

Figure 14.—Temporal changes in fungivorous beetle abundances on reclaimed mine sites on the Kemmerer Mine, Wyoming. The dashed, horizontal line represents the undisturbed site's value (from Parmenter and MacMahon 1987, with permission).

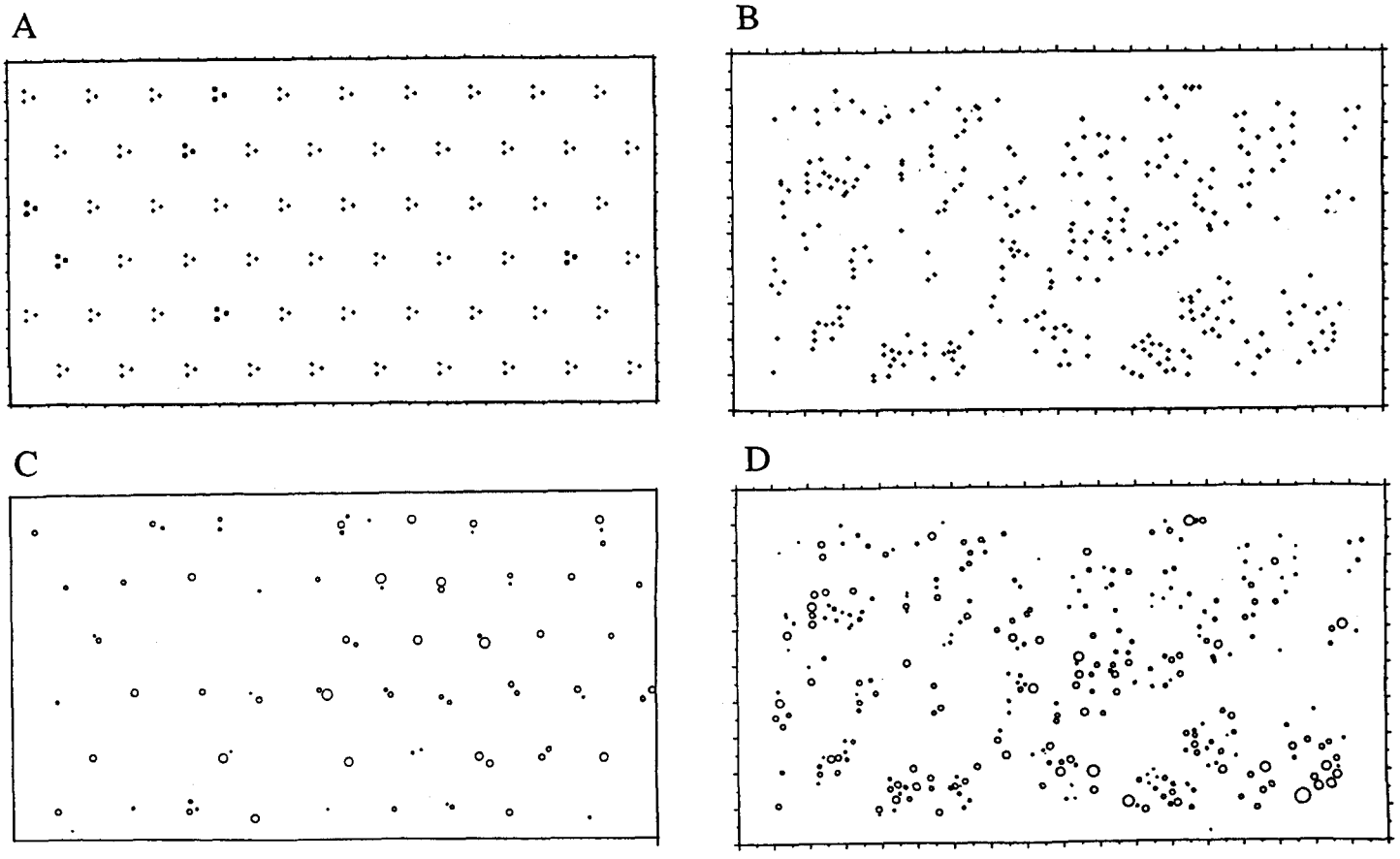

Figure 15.—Examples of distribution maps of shrub dispersion patterns from the Kemmerer Mine reclamation experiment. A,B: Original shrub planting distributions at the start of the experiment in 1982. C,D: Surviving shrub distributions 5 years later (1987); sizes of circles corresponds to diameters of individual shrubs. A,C: The low-density, regular treatment pattern. B,D: The high-density, clumped treatment pattern. Plot sizes are 20x36m.

Acknowledgment

We wish to thank the Pittsburg and Midway Coal Mining Company (CHEVRON, USA) for their cooperation and the use of their lands for the field research. J. Chambers and C. Sieg contributed thoughtful critiques of the manuscript. Funding for this research was provided by the National Science Foundation (Grants DEB81-01827 and BSR 83-17358). Support for manuscript preparation was provided by the University of New Mexico, Sevilleta Long-Term Ecological Research Program (NSF Grant BSR-8811906).

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