SPATIAL PATTERNING AND SOIL SAPROPHYTIC MICROBIOTA:

IMPACT OF STRIP MINING, IMPORTANCE AND MANAGEMENT STRATGIES

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INTRODUCTION

Management of disturbed ecosystems has been an area of growing interest among both applied and theoretical scientists (e.g. BioScience, 1985). Due to the reclamation laws of the late 1960's and 1970's and the awareness of the mining industry itself, studies on reclamation of coal strip mines have promoted both the management techniques and the theoretical framework on which to base those techniques. Treatises on the manipulation and roles of animals, plants and mutualistic organisms in these systems are commonplace and continually increasing (e.g. Ehrlich and Mooney, 1983; E. Allen, 1984; Elkins et al., 1984; Gessaman and MacMahon, 1984; Williams and Allen, 1984). There have also been several recent discussions of general ecosystem properties and their responses to disturbance (e.g. Mooney and Godron, 1983; BioScience, 1985). However, a major gap in our understanding of disturbance effects and management strategies is the nature of and processes catabolized by saprophytic microbiota. As a functioning group, these organisms represent the second largest component of all terrestrial ecosystems. Moreover, the processes they regulate are major factors determining reclamation success and long-term stability: nutrient retention and release, organic matter levels, and soil stabilization.

Nutrient dynamics and organic matter accumulation have been shown for several decades as major mechanisms regulating the succession pathway (Fig.]). General reclamation practices such as fertilization and mulching are all based around these processes and constitute major points of debate among managers and theorists. However, due to the microscopic size and extremely high diversity of the microorganisms, they are virtually always ignored in management schemes. The research studies themselves rarely attempt to understand the organisms; they use some arbitrary inaccurate index of activity (e.g. soil enzymes) on a scale irrelevant to both the organisms and the processes of interest. Attempts to describe large-scale nutrient dynamics or regulate use of treatments such as mulching without understanding the organisms involved and the spatial scales (vertical and horizontal) at which these processes are occuring are virtually useless. In this paper, I will attempt to describe some of our observations of the effects of coal strip-mine disturbance in southwestern Wyoming on saprophytic microbiota and

suggest some strategies which we are testing that might be useful for managing these systems to maximize recovery. I will limit the discussion to use as my example a topsoiled site which has been reapplied to the shaped overburden. This limit is created based on our existing knowledge of this essential role of topsoil in providing mutualistic organisms (E. Allen, 1984), as an important rooting medium (McGinnies and Nicholas, 1980), a crucial source of initial saprobe inoculum and organic matter (Allen and MacMahon, 1985), and because it is generally required by law (Public Law 95-87-sec. 515).
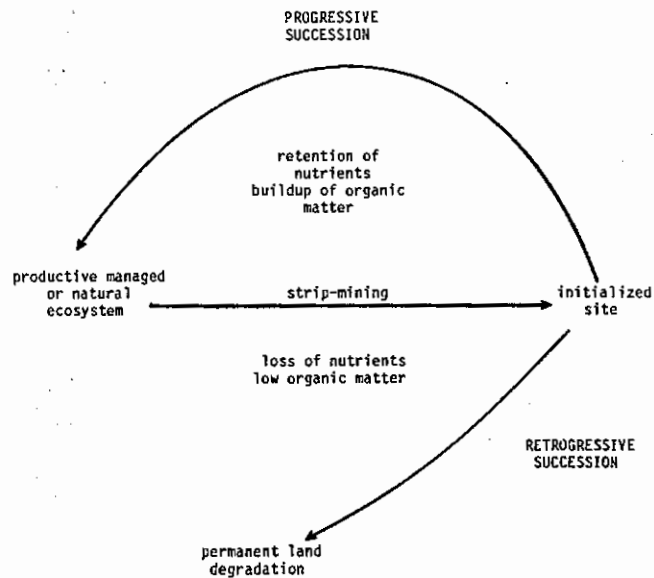

Figure 1.--Potential outcomes and regulatory mechanisms of strip mine regulation.

CONSEQUENCES OF DISTURBANCE

Microbial composition and dispersion are a function of both present and past conditions. The rates and kinds of processes in soil are dictated by the species and structure of the microorganisms present. Thus, in order to describe and manage the processes regulated by the organisms present, we must necessarily understand the effects of strip mining and revegetation on mass, diversity, and structure of those organisms.

Of the three parameters needed to characterize saprophytic microbes, mass is probably the easiest but is rarely reported. Use of some of the more

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recent techniques (see Jenkinson and Ladd, 1981) would allow more comparisons among ecosystems and treatments; this cannot be done at present. Our estimates indicate that using fungal hyphal length (Allen and MacMahon, 1985) modified by fluorescence microscopy (Söderström, 1977) provide relatively similar estimates with the chloroform-fumigation technique (Voroney and Paul, 1984).

Our major, initial response of microbes to disturbance was a significant drop in mass. Upon respreading of topsoil stored 7 years, microbial carbon was 30 µg per g soil compared with 85 µg in the adjacent undisturbed area. This was due to a major change in the distribution of fungal mass (Fig. 2). Even after shrub planting and three years of plant growth, microbial C still ranged from 20 to 40 µg C, not significantly different from initial values. Soil organic matter also dropped with topsoil storage (Allen and MacMahon, 1985) and remained level after 3 years from initiation of the site (unpublished data).
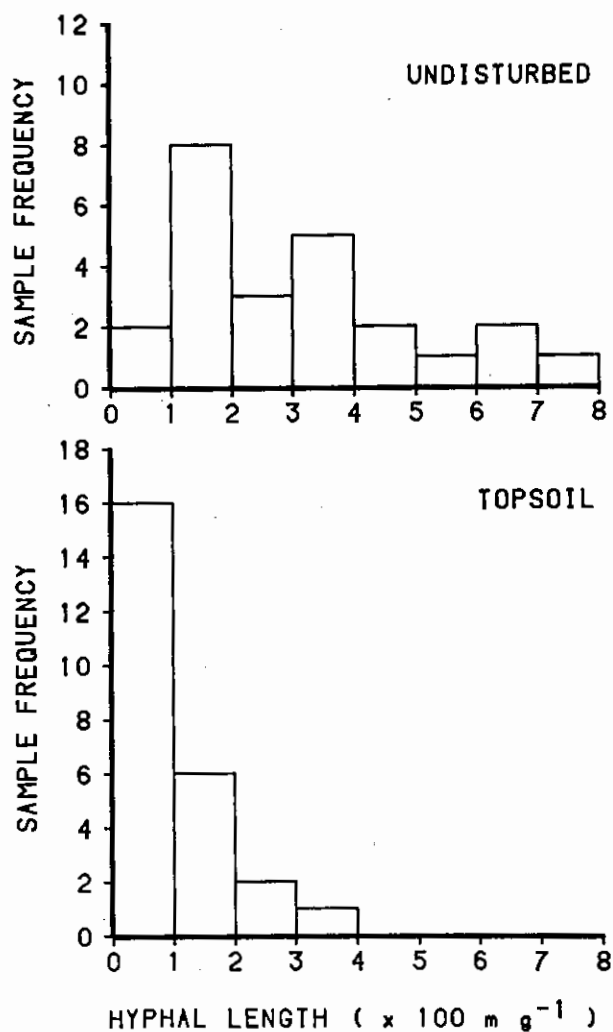
high hyphal length are from undershrubs (see Allen and MacMahon, 1985).

Diversity is often discussed in descriptions of reclaimed systems. Because of the existing taxonomic problems and the tremendous numbers of organisms present, measuring diversity is probably the most difficult problem in microbial community ecology. Many of the problems are described in recent reviews (Atlas, 1984; Christensen, 1981). There are several diversity indices available but prior to their use, a "species-area curve" should be generated. We found that in looking at the fungal component alone, 375 isolates from each site was a minimum to begin to describe differences (Fig. 3) and Christensen (1981) noted that 750 isolates were necessary for the curve to begin levelling. These indicies also are often based on a log scale. In communities with a high number of single isolates, which is the case in most microbial communities, log $1 = 0$. Thus, the vast contribution of richness to diversity is never incorporated.

Figure 2.--Distribution of total fungal hyphal length from topsoiled reclamation site and an adjacent undisturbed site. The samples with
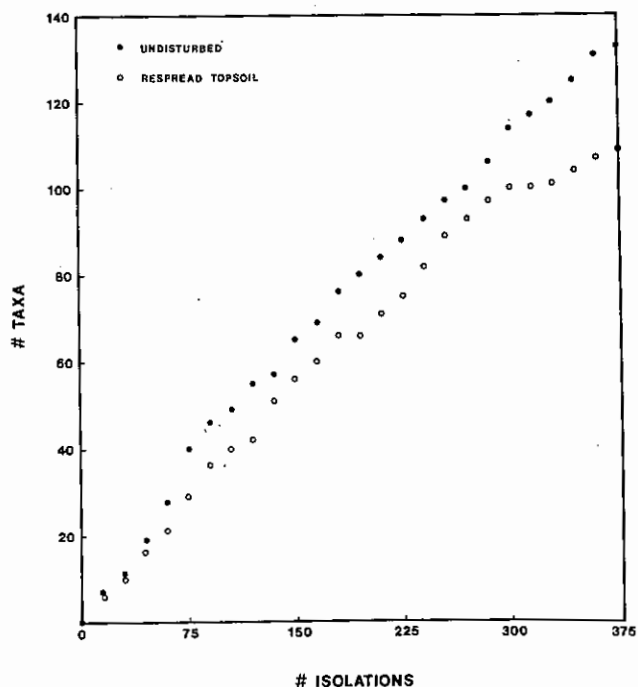

Figure 3.--"Species area curve" of isolations of saprophytic fungi from a topsoiled reclamation site and an adjacent undisturbed area in southwestern Wyoming.

MacMahon et al. (1978) have argued that use of an organism-centered approach might yield a better understanding of ecosystem functioning. As an effort in this direction, we identified the dominant fungi in a topsoiled and adjacent undisturbed area (Allen and MacMahon, 1985). We observed that in the undisturbed area, the dominant fungi were tundra-tiaga forms whereas desert-grassland fungi dominated the disturbed area; the stripping and storage of topsoil resulted in a complete loss of the dominant fungi, which perhaps are remnants from earlier climatic periods (Fig. 4). To confirm these patterns in

laboratory experiments we found that those fungi from the undisturbed site grew better at 5°C than those from the adjacent disturbed site but the pattern was reversed at 45°C. Organic matter inoculated with soil from the undisturbed soil decayed more rapidly at 5°C than when inoculated with disturbed soil and was also reversed at 45°C (Allen, unpublished data). These results strongly suggest that the diversity per se is of lesser importance. There was a high diversity in both soils (Fig. 3). But, the types of species present could have dramatic effects on decomposition, thus immobilization/mineralization of nutrients.

Strip-mining

TUNDRA-TIAGA

Penicillium rubrum
P. simplicissimum
Cylindrocarpon spp.
Chrysosporium pannorum
C. asperatum

Trichoderma konigii
T. harzianum
Fusarium oxysporum
Cladosporium cladosporioides
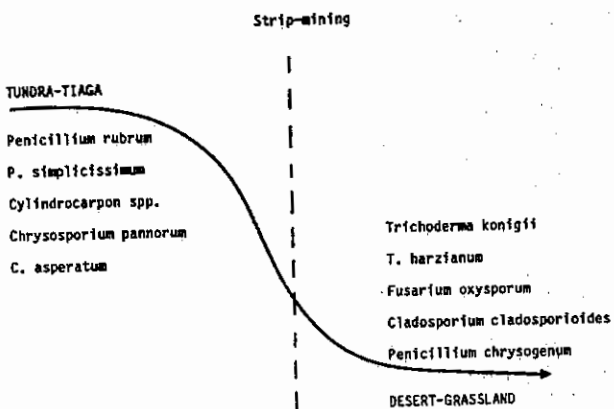Penicillium chrysogenum

DESERT-GRASSLAND

Figure 4.--Dominant saprophytic taxa of an undisturbed cold desert shrub land (left) and a respread topsoil (right). Strip mining may be the event initiating an irreversible shift in the fungal communities (see Allen and MacMahon, 1985).

Of the three parameters, quantification of mass and densities are often at least attempted. We have suggested, however, that structural characteristics may be as important as the others but are generally ignored (Allen and MacMahon, 1985). Vertical structure has been studied in forested ecosystems for some time. For example, the classic studies of Kendrick and Burgess (1962) demonstrated clear differentiation of the fungal species and densities through the litter layers in forested soils. Often overlooked but probably as important are the horizontal characteristics determining microbial activity (e.g. R. Boerner, pers. comm.). Distinctive horizontal and vertical differentiation of nutrients and organic matter in conjunction with soil microbiota are well-known from arid habitats (Skujins, 1981; Allen and MacMahon, 1985).

Following strip mining and soil replacement, microbial mass and diversity may or may not be seriously impacted; structure always is. Horizontal structure is totally destroyed as topsoils and subsoils individually are mixed before respreading. At our site, fungal organization changed from microcommunities tightly organized around plants to a diffuse macrocommunity (Allen and MacMahon, 1985). New types of vertical structures are formed. The topsoil and subsoil fractions are generally different in texture and any organic horizon is

mixed with the topsoil or eliminated. The buried subsoil generally has little microbial activity and organic matter (Allen and MacMahon, 1985). The textural differences alone can regulate saprophytic activities (Griffin, 1972; Sorensen, 1981).

In summary, strip mining appears to affect all three parameters of soil saprophytic activity. However, adequate data for comparative studies do not exist in the literature. The use of better techniques for estimating mass, an individualistic approach to types or organisms rather than general diversity estimates, and special attention to structural characteristics would enhance our understanding of microbial responses to strip mining considerably.

FUNCTIONING OF SOIL SAPROPHYTES AND MANAGEMENT STRATEGIES

Ultimately, the goal of land managers involved in strip mine reclamation is not the reestablishment of either the original mass or diversity of saprophytic microflora; it is the reestablishment of the types of processes and the appropriate rates necessary to maintain the desired ecosystem and land use. Thus, the goal is to provide the environmental characters necessary for establishment of appropriate microbiota.

Ehrlich and Mooney (1983) argued that each species has important roles in ecosystems which cannot be duplicated by others. Following this logic, it would be necessary to replace original species. Alternatively, Fowler and MacMahon (1982) suggested that extinction within communities or ecosystems is common and may regulate attributes of the structure and functioning of ecosystems. Moreover, newly initiated reclamation sites do not represent fully mature ecosystems and should not sustain equal process rates or an equivalent species composition. For example, if decomposition rates in the reclamation site were initially as high as the adjacent undisturbed site, there would be less or no organic matter build-up, a process critical to progressive succession (Vitousek and Reiners, 1975). Thus, reports of lowered mean decomposition rates on reclaimed strip mines than native areas should be assumed to be appropriate, not a detrimental factor (e.g. Wieder et al., 1983). We would suggest that masses and species of microbiota should not be equal in a newly reclaimed and a native site.

An optimum set of microbiota should be present in order for desirable vegetation to establish in a long-term sense. On different areas, we have observed the two extremes wherein the soil microbiota activity resulted in serious negative imparts on the ecosystem. In the first, more common in the east under high precipiation, the microbiota are too active resulting in little to no organic matter and severe nutrient loss via leaching. In the second, more common in lower precipitation areas, initially overproductive species (e.g. crested wheatgrass) resulted in a high standing dead coupled with low microbial activity and the binding of most nutrients into dead organic matter. Few nutrients were available for new plant growth. Both of these two extremes can be treated; the first by a combination

of mulching and fertilizing, the second by burning
or grazing. However, lack of attention to the
structural characteristics of the site (mixing
the mulch with soil and soil-applied fertilizers)
and intensity of treatment (e.g. overgrazing) can
easily result in the site shifting to the other
extreme. Again, we have seen both processes.
Obviously, the optimum approach would be to
balance nutrient release and organic matter
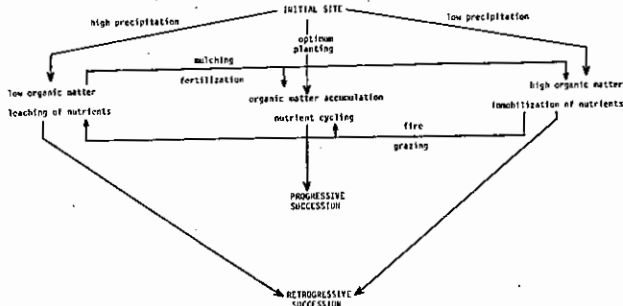accumulation (Fig. 5).

Figure 5.--Management treatments and outcomes of
those treatments during strip mine reclamation.

Our attempt has been to utilize rather than
overcome natural successional processes to optimize
restoration rates. MacMahon and colleagues
(MacMahon, 1981) have shown that architecture is
clearly more important to the organization and
structure of animal communities than is the presence
or absence of individual plant species. Litter
redistribution via wind action is common even in
low wind environments (Orndoff and Lang, 1981) and
we (unpublished data) have shown that wind barriers
such as slope pattern and shrubs can affect snow and
particle desposition. We previously suggested
(M. Allen, 1986) that utilization of shrub "islands
of fertility" should enhance plant and VAM develop-
ment. Concomitantly, planting clumps of vegetation
utilizing a range of sizes and shapes should also
enhance (several factors improving) organic matter
accumulation and nutrient cycling. Having plants
in patches reduces total seed required and reduces
over-production and nutrient immobilization.
Patches also allow for maximum diversity by having
shaded and non-shaded areas; a range of temperature
and moisture conditions for differing microbiota.
Shrubs and trees alter turbulence patterns of a
site (Allen and Hipps, 1985) thereby not only
catching more wind-borne litter and microbes but
also retaining those already there (unpublished
observations). Just as above-ground architecture
regulates aboveground organic and mineral dynamics,
belowground roots of a mixture of grasses, shrubs
and trees provide deep organic matter and hold soil;
critical parameters for establishing the complex
organic matter and nutrient dynamics necessary for
revegetation. Patches are also easier to manage,
i.e. fire, grazing, mulching, than are large
landscape units thereby allowing greater manage-
control. Finally, managing for patches should
optimize plant production and nutrient cycling
retaining available nutrients without leaching.

Although this approach requires a much more
comprehensive understanding of ecosystem dynamics
than simple row plantings, coupled with mulching
and/or fertilization our preliminary results
suggest that greater site productivity and diversity
results. As training for reclamation personnel
includes more ecology, application of succession
theory such as we have proposed should substantially
enhance reclamation success.

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