

## RESTORATION OF NATURAL ECOSYSTEMS ON SURFACE COAL MINE LANDS IN THE NORTHEASTERN UNITED STATES

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### ABSTRACT

Surface mining currently accounts for 50 percent of the coal mined in the United States and will probably increase in the future because of the lower operating cost and increased production/man-day when compared with deep mining. In the past, reclamation of these sites consisted of partial regrading and planting of grasses and trees, often with only partial success. These past as well as current reclamation practices did not adequately restore natural vegetative communities and, for the most part, lacked the diverse plant communities that existed on the sites prior to mining. Of the 66 species of grasses, legumes and forbs currently recommended for reclamation, only 6 are native to the northeastern United States, whereas 44 of the 52 trees and 14 of the 31 shrub species are native to the region. Natural succession is essential to the development of diverse and stable flora and fauna communities on these lands. The restoration of natural ecosystem cannot be accomplished without restoring the organic and moisture retention as well as the microflora of the spoil since these components are essential to restoration of natural grassland and forested ecosystems.

### 1. INTRODUCTION

Coal was first mined in the United States in 1701, along the James River near Richmond, Virginia, but commercial mining did not begin until 1745 (1). Coal was discovered in Kentucky in 1752, and in Ohio three years later. Shortly thereafter coal was discovered throughout the Appalachian Mountains and as far west as Illinois. The early mining operations could be classified as surface or strip mining. Exposed coal layers along river banks were mined with pick and shovel and, in some cases, shallow coal seams were exposed with hand tools. Mechanized mining began around 1825 when mule-drawn scrapers were introduced into the coal field fields. This enabled the removal of additional overburden to expose the caprock over the coal. By the use of explosives, caprocks were fractured and removed by horse and wagon. The Otis steam shovel was introduced into the mining industry in 1877 near Pittsburg, Kansas. These early surface mines were still relatively small since the largest shovels only removed a few cubic meters of overburden.

Following the Second World War, the development of larger drag-

lines made it feasible to remove between 9 - 21 m (30-70 feet) of overburden. By 1968, 27 m (90 feet) of overburden could be exposed in high quality coal seams. Geologists once considered that coals below 30 m (100 ft) could not be recovered by surface mining but today coal as deep as 60 m (200 ft) is routinely included in the calculation of minable reserves. The amount of overburden that can be removed is basically a question of economics. The quality, depth and thickness of the coal seam determines the amount of overburden that can be removed economically. In 1946, the average amount of overburden removed per m coal was 6:1. By 1955, this ratio increased to 8.5:1 (2) and by today, this ratio varies between 20-30:1 in the northeastern coal fields.

The amount of coal mined by stripping was one percent in 1917, increasing to 34 percent by 1968 while today surface mining accounts for over 50 percent of the total United States coal production. The primary reasons for the increase in surface mining are: (1) greater output per man/day (30 tons for surface mining compared to 12 tons for deep mining), (2) lower median operating costs (\$18.00/ton in strip mining and \$37.00/ton in deep mining), (3) greater rate of recovery (90 percent in strip mining to 50 percent in deep mining), and (4) the rate of fatalities is five times lower in surface mining than it is for deep mining (0.606/million tons)(3). Surface mining for coal will continue to increase as the United States moves toward energy independence (4). In 1982, coal accounted for 22.1 percent of the United States energy supply compared to 17.3 percent in 1972, with the use of coal increasing during the next two decades (4). The proven coal reserves of the United States is in excess of 280 billion tons, of which about 75 percent of the surface minable coal is west of the Mississippi. Most of the western coal, however, is classified as subbituminous with a heating value of 5600 Kcal/Kg compared to 6100-7800 Kcal/Kg for eastern coals. Based on caloric value, about 55 percent of the total reserves of coal are east of the Mississippi. The sulfur content of eastern coals, on the other hand, may exceed 6 percent, but the usual range is between 2.5-3.5 percent. It is conceivable, therefore, that stricter air quality regulations may result in less demand for high sulfur eastern coals. In the foreseeable future, however, the demand for eastern surface minable coal should remain constant or increase with a corresponding decrease in deep mine production.

In the past, surface mining caused the destruction of land resources, pollution of streams, contamination of ground water aquifers and other environmental problems. For over 40 years, the lack of regulations and concern for the environment by both the government and industry have left thousands of hectares of unreclaimed mined lands throughout the northeastern coal fields. Acid and heavy metal discharges from abandoned surface mines have caused the degradation of aquatic life in receiving streams(5-13). An increase in the sediment load as a result of improperly reclaimed surface mines is also detrimental to aquatic life (14) as well as increasing the flooding potential in mountainous watersheds (15). Ehrlich and Ehrlich (16) stated that only war caused more destruction to the environment than surface mining. In view of current reclamation practices and the advances in the restoration of abandoned mine lands, this may not be an objective evaluation of the surface mining industry. In this paper, past and

current reclamation practices are evaluated as to their effectiveness in restoring natural ecosystems in the northeastern United States.

## 2. PRE-MINING SURVEYS

A reclamation plan for mined land should begin with a pre-mining geological and ecological survey of the proposed mine site. The basic geological data should include the contour of the site, ground water aquifers and surface drainage patterns. The overburden should be analyzed for pH, acid-base balance and heavy metals, especially iron (Fe), manganese (Mn) and aluminum (Al) to identify potential problem strata (17,18). Once these strata are identified, they should be handled to prevent seepage from the site upon completion of the mine operation. Moreover, an overburden analysis will allow for a more accurate prediction of the spoil characteristics (19), thereby enabling a better selection of the species to be used in re-vegetating the site.

The ecological evaluation of the site should include the principle vegetative associations, chemical and biological characteristics of streams, and wetlands. All critical, sensitive or endangered species either on the site or that might be impacted by mining should be identified and precautions made to protect or re-establish these habitats. This basic ecological information will be an asset in the re-establishment of a natural ecosystem on the site once mining is completed.

## 3. SITE PREPARATION

For over 40 years, only minimum reclamation and partial back filling occurred on much of the surface mine lands in the Appalachian coal fields. These abandoned sites are characterized by a series of short steep slopes, exposed highwalls, often with water at their base and the spoil as a mixture of all horizons, accounting for the variations that exist both within and between mine sites (20-22).

Current state and federal regulations require that the horizons be segregated and replaced in the same order as removed during mining. The affected land has to be returned to the approximate original contour (AOC) unless site conditions or other circumstances do not permit this type of re-grading. Then an alternative reclamation plan is agreed upon by the mine operator, regulatory agencies and the property owner.

These regulations, however, do not ensure adequate reclamation and, in some circumstances, may be detrimental. The use of heavy earth moving equipment often results in compaction, increasing soil density and causing a decline in available moisture, at least for a short duration. Regrading to AOC often results in long slopes that may accelerate erosion. The amount of soil movement on a site devoid of vegetation is more directly related to the length of the slope than it is to the degree of the slope. Soil loss in tons per acre (A) may be calculated by the equation:

$$A = R K L S C P ,$$

where R is the rainfall and runoff factor, K is the soil erodability factor, L is slope length, S is degree of slope, C is the cover and management factor and P is the support factor. In general, soil loss will be less with a series of short steep slopes than with a long gentle slope. The installation of water diversions across the slopes (21) or inverted terraces will aid in reducing soil loss (20). Other factors that affect the final reclamation of a site may be a lack of bonding between soil horizons, replacing top soil during excessively wet or dry conditions and a change in the biological and chemical properties of the top soil due to extended storage.

Although reclamation is a small part of the total mining operation, it is an extremely important part in terms of future land use. The cost of reclamation has been estimated at between \$4000 and \$7000 per acre (23,24) and the majority of the cost is involved with backfilling and regrading the site. These figures may be excessive, however, since backfilling and regrading are part of the continuous mining operation and special equipment is not brought to the site for this purpose. For this reason, as well as the amount of variation from site to site, it is difficult to obtain an exact estimate of the cost of backfilling, regrading and preparation of the site for seeding.

#### 4. RESTORATION OF THE MINE ECOSYSTEM

Current federal and many state regulations require that the productivity of the land be returned to the pre-mining conditions. According to these regulations, if the site has been designated as prime farm land by the U.S. Soil Conservation Service, then the land must be reclaimed as hay, pasture or row crops according to existing agricultural practices. Based on the reclamation cost of \$4000 to \$7000 per acre and a return of \$325 per acre from farming (23), it would take from 12-22 years for the income from this land to equal or exceed the cost of reclamation.

These regulations also state that the natural vegetative communities that existed on the site prior to mining must be re-established on the site. In many areas of the northeastern United States, however, the restoration of woodlands is discouraged by both the industry and the regulatory agencies. This occurs even though woodlands existed on the site prior to mining. The property owner often is encouraged to sign a waiver indicating that the land be reclaimed as grassland rather than woodlands.

According to Braun (25), the majority of the natural climax vegetation communities throughout the northeast were comprised of oak (*Quercus*)-chestnut (*Castanea dentata*) associations with local distribution of maples (*Acer* spp.), beech (*Fagus grandifolia*), hemlocks (*Tsuga canadensis*) or mixed mesophic forest. Lumbering, disease, agriculture and other land use changes over the past centuries has altered these natural communities. A natural community at the time of mining, therefore, may be an old field, shrub or second growth forest community, often composed of a mixture of exotic and native species. Many of these exotic species may have existed in the region since the region was first cleared for agriculture and may now be part of the natural flora. The term natur-

community may not, therefore, be synonymous with native plant communities.

Regardless of the type of plant community to be established on the land after mining, the organic content and moisture retention capacity of the spoil will determine the success of these reclamation efforts since both parameters are significantly correlated with biomass production (Table 1)(20-22,26). The relationship between the organic content and moisture is especially important during periods of reduced rainfall and even excessive rainfall often will percolate through the spoil (6,14,15) or run off, depending on the regrading procedures (26). Initial reclamation effects often fail due to drought and/or high temperatures, even in the humid northeastern United States.

The chemical characteristics are also important in determining the microbial composition of mine spoils (Table 2). These microorganisms are important not only in determining the success of initial reclamation but also the rate and pattern of natural succession. In addition, to their role in mineral and nutrient cycling, microorganisms are involved in the decomposition of organic material, thereby increasing the organic content and providing media for seed germination of both established and invading species. Fungi mycorrhiza provides plants with a larger physiologically active surface area for nutrient and ionic absorption as well as increasing their resistance to high temperatures, toxins and extremes of pH (27). The inoculation of trees with fungi prior to planting has been shown to increase their survival on surface mines (28,29). Likewise, the field inoculation of established plants by either spores (30), soil (31), or vegetative mycella (32) has been shown to increase tree survival. Mycorrhiza also are important in determining the pattern of natural succession (33) since over 125 species of plants have been shown to be associated with specific types of mycorrhiza (34). The pattern of natural succession may to some degree be determined by the previous land use since fungi spores are either disseminated by wind or the replacement of the top soil during reclamation.

Domestic sewage sludge has been recommended as a procedure to increase the organic and nitrogen content of surface coal mines. The addition of sludge has been shown to increase the establishment and growth of both herbaceous and woody vegetation (26). The use of sludge should, however, be carefully monitored for heavy metals that may be detrimental to both plants (35-37) and animals

Table 1. Correlation coefficients between soil parameters and total biomass on 82 surface coal mine sites in Pennsylvania.

Parameters	pH	Organic Matter	Moisture Capacity	Biomass g/m <sup>2</sup>
pH	1.000	0.791	0.894	0.319
Organic Matter	0.791	1.000	0.870	0.654
Moisture Capacity	0.894	0.870	1.000	0.745
Biomass	0.319	0.654	0.745	1.000

Table 2. Correlation coefficients between three spoil parameters and micro-organisms on 82 surface coal mines in Pennsylvania.

Bacteria	pH	Organic Content	Moisture Capacity
Nitrogen-Fixing Bacteria	0.60	0.58	0.77
Iron Bacteria	0.75	0.73	0.94
Sulfur Bacteria	0.77	0.75	0.50
Carbohydrate-Digesting Bacteria	0.50	0.40	0.69
Carbohydrate-Digesting Fungi	0.42	0.59	0.66

(38,39). A single application of sludge is generally sufficient to establish vegetation (20) and will prevent the concentration of heavy metal in the food chain. Spoil pH should be maintained at 6.5 or greater to prevent the uptake of heavy metals by plants.

#### 5. CURRENT RE-VEGETATION PRACTICES

Abandoned and active mine sites as well as refuse piles are visible throughout the Appalachian coal fields. The establishment of vegetation on many of these sites is difficult because of low pH, lack of organic matter, coarse rock fragments and other adverse biological and chemical factors. A variety of trees and shrubs have been planted on these sites with varying success. These species include red pine (Pinus resinosa)(30,31,40), white pine (P. strobus), Jack pine (P. banksiana), pitch pine (P. rigida), Virginia pine (P. virginia), yellow pine (P. echinata), white spruce (Picea glauca), eastern red cedar (Juniperus virginiana)(41,42), white birch (Betula papyrifera), black cherry (Prunus serotina), bur oak (Quercus macrocarpa), green ash (Fraxinus pennsylvanicus), sycamore (Platanus occidentalis), black walnut (Robina pseudoacacia)(43-46) and indigo bush (Amorpha fruticosa)(22). In addition, exotic species such as European larch (Larix decidua), Japanese larch (L. leptolepis), Scotch pine (P. sylvestris), ponderosa pine (P. ponderosa), Austrian pine (P. nigra), loblolly pine (P. taeda)(41-43), autumn olive (Elaeagnus umbellata) and amur honeysuckle (Lonicera maachii)(47). Of the 52 species of trees recommended for planting on surface coal mine sites, 41 are native to the eastern United States whereas only 14 of the 31 shrub species are native to the region (Table 3). Bristle locust (Robina fertilis), a species native to the southern Appalachian region, has been used extensively for mine reclamation in the northeast because of its ability to become established under harsh conditions and nitrogen fixation.

Although the majority of the tree species and approximately 45 percent of the shrubs recommended for surface mine reclamation are native to the eastern United States (47), this has not been the case with grasses and legumes. Of the 66 species of grasses, legumes and forbs currently used in surface mine reclamation,

Table 3. Origin of grasses, legumes and forbs commonly used in surface mine reclamation in the northeastern United States.

Species	East. U.S.	Cent.-West. U.S.	Cent. & S. Amer.	Eurasia	Total
Grasses	4	9	3	21	37
Legumes	2	1	0	22	25
Forbs	0	2	0	2	4
Conifers	12	3	0	4	19
Hardwoods	29	2	0	2	33
Shrubs	<u>14</u>	<u>4</u>	<u>0</u>	<u>15</u>	<u>31</u>
Total	61	19	3	66	149

only 6 are native to the northeast (Table 3) (47). Species such as crown vetch (Coronilla varia) (48), birdsfoot trefoil (Lotus corniculata), lespedeza (Lespedeza spp.), clovers (Trifolium spp.), tall fescue K-31 (Festuca arundinacea), and perennial rye grass (Lolium perenne) have been used successfully throughout the northeastern United States. Generally, the reclamation of surface coal mines as grasslands consists of seeding one or several species of grasses and legumes, none of which are part of the native flora.

## 6. NATURAL SUCCESSION AND MINE RECLAMATION

### 6.1 Grasslands

Natural succession of both native and exotic species is an important component in the development of a diverse and stable ecosystem on mined lands (220). Although opportunistic species such as the ox-eye daisy (Chrysanthemum leucanthemum), coltsfoot (Tussilago farfara) and foxtail (Setaria italica) were introduced from Europe into North America, localized populations or demes may be genetically distinct and, therefore, might be considered native to the region.

In Pennsylvania, of the total of 28 species found on 82 mine sites, 82.1 percent were volunteer species and 80.0 percent of these were native to the region (22). The importance value of each of the 28 species was calculated on the basis of their percentage of total biomass, chlorophyll a concentration and persistence on the site from year to year with a maximum importance value for a single species being 300. Volunteer species comprised from 0.5 to approximately 82 percent of the biomass from year to year, whereas the overall importance of volunteer species varied from 31 to 93 percent. The volunteer species that provided the greatest contribution to these communities included these native species - goldenrod (Solidago spp.), ragweed (Ambrosia artemisiifolia), and dwarf-red raspberry (Rubus pubescens) as well as the exotic ox-eye daisy and sweet clover (Melilotus alba and M. Officinalis). The amount of volunteer species but not the total spe-

cies occurring on the sites was significantly correlated with the total biomass ( $r = 0.58$ ,  $P < 0.05$ ) indicating the importance of natural selection to mine reclamation (22).

If the ultimate objective of reclamation is to create a diverse and stable ecosystem, then initial reclamation should be designed to stabilize the site while providing a suitable habitat for natural succession. For example, the number of volunteer species (12,141 plants) on a site was 50 percent greater when sorghum (Sorghum vulgare) was used as a cover crop rather than oats (Avena sativa) or perennial ryegrass (Lolium perenne) (49). The development of small terraces along the outer slopes during regrading and backfilling will provide ledges for holding seeds and fertilizer during the initial reclamation (50) as well as retain moisture and organic matter, thereby providing a seedbed for invading species (49).

Natural succession not only provides a greater degree of diversity and stability to mined lands, but these plants have also been shown to have a greater food and cover value for wildlife (51,54). It would appear, therefore, that efforts should be undertaken to encourage the research and development of procedures to encourage the use of native species in mine land reclamation. In addition, data should be compiled as to whether these lands could be reclaimed in a manner that would support rare and endangered plant and animal species (55).

## 6.2 Woodlands

The development of a diverse forest community is similar in many respects to that of grasslands. Deciduous species volunteers on mine sites provide diversity to what otherwise would be a coniferous or grassland community. Botkin and Miller (55) and Botkin et al. (57) indicated that the relationship ( $d^2h = R1a(1-dh_{\max} - h_{\max})$ ) between the diameter (d), height (h) and leaf area (1a) ultimately determines the importance of a species to the forest community. A combination of relative dominance (basal area/ha), relative density (stems/ha), contribution to canopy height and the R value of the Botkin equation may be a better indication of the importance of a species to community structure (20-22).

Of the 34 tree species identified on 82 sites in Pennsylvania, 22 were native species that occurred on the sites as a result of natural succession. Native species comprised 50 percent of both the relative density and dominance and 63 percent of canopy height but when all four factors were combined, the contribution of the native species and those used in reclamation were approximately equal. In another study of 19 sites 45-60 years of age in northeastern, Pennsylvania, conifers produced an average of 5290 board ft/acre compared to 599 board ft/acre for deciduous species (58). Generally in the years following mining, the importance of native deciduous trees in the community increase with a corresponding decrease in coniferous species. Opportunistic species such as aspens (Populus spp.), red maple (Acer rubrum) and black cherry (Prunus serotina) invade these sites within 1-3 years following mining followed by oaks (Quercus spp.) and hickories (Carya spp.) and other hardwoods. Brenner (22) reported that the annual growth

rate was similar for 8 deciduous species. Hence, the importance of a given species is largely a function of the time of invasion and the age of the site. Both deciduous (59) and conifers (60) can be established on mine sites by direct seeding. This should be done, however, during initial reclamation since a dense herbaceous community inhibits the establishment of tree species either by natural succession or by direct seeding (22).

Natural succession of trees and shrubs on surface mines also provides food and cover for wildlife. In both Pennsylvania (61) and West Virginia (62), surface mines supported abundant ruffed grouse (Bonasa umbellus) populations. Throughout the range of this species, preferred food species such as aspens, dogwoods (Cornus spp.), crabapple (Pyrus coronaria), hawthornes (Crataegus spp.) and greenbrier (Smilax spp.) volunteer on surface mines, thereby enhancing these areas as ruffed grouse habitat. Likewise, in Pennsylvania, white-tailed deer (Odocoileus virginianus) fed on red maple, aspens, hawthornes and crabapple to a greater degree than they did on other native species or those used in the initial reclamation (63). The planting of trees and shrubs as food and cover for wildlife along the contours, water diversions, and terraces as hedgerows between strips of grasses and legumes would enhance these areas for wildlife without increasing the cost of reclamation (22).

## 7. WETLANDS

The development of both shallow and deep water habitats on surface coal mines should be encouraged by regulatory agencies. These areas have been shown to provide habitat for both migratory and nesting waterfowl (45, 64,65) and the placement of artificial nesting structures (64) and the planting of food species along the shorelines (45) will enhance the wildlife benefits of these areas. These wetlands also support furbearer populations as well as a variety of shorebirds (45).

Over 99 different phytoplankton and zooplankton taxa have been identified in surface mine lakes (21) and these deep mine lakes also support populations of sunfish (Lepomis spp.), yellow perch (Perca flavescens), largemouth bass (Micropterus salmonides), wall-eye pike (Stizostedion vitreum), northern pike (Esox lucius) and tiger muskellunge (E. musquinongy X E. lucius)(21). In addition to the wildlife and fishery benefits, these wetlands also function as sediment traps, allow for the recharge and release of ground water and provide a basis for future water supplies and recreation (66). Wetlands, if constructed properly, should be developed on mined lands wherever site conditions, property owner and water quality permit their inclusion in the reclamation of the site.

## 8. CONCLUSIONS AND RECOMMENDATIONS

Surface mining for coal will continue to increase in the future as the United States moves toward energy independence. Current reclamation practices on these lands include backfilling, re-grading to the approximate original contour (AOC), replacement of top soil, and seeding with a mixture of grasses and legumes.

These procedures, however, do not insure adequate reclamation nor do they restore a diverse and stable ecosystem. Current regulations require that if a site is not being reclaimed for agriculture, that the natural plant community that existed on the site prior to mining be restored. In practice, however, generally grasses and legumes that are not part of the native flora of the region are seeded during reclamation. Moreover, there is little effort to establish tree and shrub species that are beneficial as food and cover for wildlife.

Natural succession is a vital force in the establishment of a diverse and stable ecosystem. Reclamation should be designed to increase the organic and moisture content of the spoil, develop a microbial community as well as stabilize the site and encourage natural succession. Whenever possible, water diversions and small terraces should be installed for erosion control and retention of moisture and organic matter, thereby serving as seed beds for invading species. The planting of trees and shrubs along diversions and terraces or contours will provide hedgerows for wildlife. The construction of both shallow and deep water wetlands should be encouraged by the regulatory agencies. In addition to the ecological benefits of these wetlands, they also function as sediment traps, allow for the recharge and release of ground water and as sites for future water supplies and recreation. Future reclamation should be designed to restore diverse natural ecosystems rather than create grassland monocultures throughout the north-eastern United States.

#### REFERENCES

1. Burrows, H.L. ARS Research on strip mine reclamation. Unpub. Report. 28 pp.
2. Averitt, P. Stripping coal resources of the United States. U.S. Geol. Survey Bull. 1970, 1322. 34 pp.
3. Nephew, E.A. The challenge and promise of coal. Technol. Review. Dec. 1973. pp. 21-29.
4. Perry, H. Coal in the United States: A Status Report. Science, 1983, 222: 377-384.
5. Brenner, F.J., R. Shertzer, S. Corbett and J. Centafoni. Partial correlation analysis of some chemical and biological parameters of two streams receiving mine drainage. PA Acad. Sci. 1978, 51:125-130.
6. Curtis, W.R. Strip mining increases flood potential of mountain watersheds. Proc. Nat. Sym. Watersheds in Transition, 1972, p. 357-368.
7. Dyer, K.L. and W.R. Curtis. Effects of strip mining on water quality in small watersheds in Eastern Kentucky-1967-1975-1977. USDA Forest Service Research Paper, NE-372, 13 pp.
8. Gang, M.W. and G. Langmuir. Control of heavy metals in surface and ground water affected by coal mine drainage: Clarion River

- Redback Creek Watershed, Pennsylvania. 1974, 5th Sym. Coal Mine Drainage, p. 39-69.
9. Parsons, J. The effects of acid mine effluents on the ecology of a stream. Arch. Hydro. Biol. 1980, 65: 25-50.
  10. Werner, R.W. Acid coal mine drainage effects on aquatic life. In R.J. Hutnik and G. Davis (eds.), Ecology and Reclamation of Devastated Lands, Gordon and Breach. 1973, Vol. 1, pp. 227-239.
  11. Werner, M.J., L.L. Osborne, W. Kodrich and D.L. Wood. Effects of coal strip mining on the structure of benthic macroinvertebrate communities in Town Run. PA Acad. Sci. 1981, 55: 142-146.
  12. Wood, C.E. and C.W. Rutschky. Benthic macroinvertebrate community structure in a stream receiving acid mine drainage. Proc. PA Acad. Sci. 1981, 45: 41-46.
  13. Kimmel, W.G. The impact of acid mine drainage on the stream ecosystem. In S.K. Majumdar and E. W. Miller (eds.) Pennsylvania Coal: Resources, Technology and Utilization. 1983, pp. 426-437.
  14. Curtis, W.R. Sediment yield from strip-mined watershed in Eastern Kentucky. 2nd App. Technol. Symp. in Mine Land Reclam. 1979, pp. 88-100.
  15. \_\_\_\_\_. Effects of strip mining on the hydrology of small mountain watersheds in Appalachia. In R.J. Hutnik and G. Davis (eds.), Ecology and Reclamation of Devastated Lands, Gordon and Breach. 1973, pp. 143-157.
  16. Ehrlich, P. and A. Ehrlich. Extinction, Ballantine Books, N.Y. 1981, 384 pp.
  17. Despard, F.L. Avoid problems spoils through overburden analysis. USDA Forest Service General Technol. Report. 1974, NE-10, 4 pp.
  18. Sturey, C.S., J.R. Freeman, T.A. Keeney, and J.W. Sturm. Overburden analysis by acid-base accounting and simulated weathering studies as a means of determining the probable hydrological consequences of mining and reclamation. Sym. Surface Mining Hydrology, Sedimentology and Reclamation, Univ. Kentucky. 1982, pp. 163-179.
  19. Krause, R.R. Predicting mined-land soil. In R.J. Hutnick and G. Davis (eds.), Ecology and Reclamation of Devastated Lands, Gordon and Breach. 1973, pp. 121-134.
  20. Brenner, F.J. Surface coal mine reclamation - need for re-evaluation. In S.K. Majumdar (ed.), Energy, Environment and the Economy. PA Acad. Sci., pp. 81-92.
  21. \_\_\_\_\_. Environmental aspects of coal production in Pennsylvania and a guide to reclamation. In S.K. Majumdar and E.W.

- Miller (eds.), Pennsylvania Coal : Resources, Technology and Utilization. PA. Acad. Sci. 1983, pp. 405-424.
22. \_\_\_\_\_ . Ecosystem development and natural succession in surface coal mine reclamation. Minerals and the Environment. 1984, 6:10-22.
  23. Forster, D.L. Economics: research on the hydrology and water quality of watersheds subjected to surface mining. USDI Bureau of Mines Mining Contract Report. 1982, 9 pp.
  24. Misiolak, W.S. Analysis of bituminous coal production costs in the Warrior coal field: Economic analysis of the 1977 reclamation law, Univ. Alabama. 1980, 104 pp.
  25. Braun, E.L. The deciduous forests of eastern North America. Blakiston Co., Inc., Philadelphia. 1950, 596 pp.
  26. Brenner, F.J. Soil and plant characteristics as determining factors in site selection for surface coal mine reclamation. Minerals and the Environment. 1979, 1: 37-44.
  27. Medve, R.J. Mycorrhiza: a common form of mutualism. Amer. Biol. Teacher. 1978, 40: 414-418.
  28. Marx, D. Mycorrhizae and establishment of trees on strip mine land. Ohio J. Sci. 1975, 75: 288-297.
  29. Wolf, C.H., C.E. Cordell and S.M. Keller. Fungus seeds speeds mine reclamation. Coal Age. September, 1982, 4 pp.
  30. Theodore, S. and G. Bowen. Inoculation of seeds and soil with basidiospores of mycorrhizae fungi. Soil. Biol. Biochem. 1973, 5: 765.
  31. Vozzo, J. and E. Hackskazo. Inoculation of Pinus caribaea with ectomycorrhizal fungi in Puerto Rico. Forest Science. 1971, 17: 239.
  32. Medve, R., F. Hoffman and T. Gaither. The effects of mycorrhizae on the survival and growth of trees planted on strip mine spoils. 4th Sym. Surface Mine Reclamation. 1976, 4:184.
  33. Riley, R.K. and M.L. Brown. The natural succession of wildlife food and cover species onto bituminous coal spoil. In D.E. Samiel, J.R. Stauffer, C.H. Hocutt and W.F. Mason, Jr. (eds.), Surface Mining and Fish/Wildlife Needs in the Eastern United States. FWS/OBS, 1978, pp. 376-380.
  34. Rothwell, F.M. and W.G. Vogel. Mycorrhizae of planted and volunteer vegetation on surface-mined sites. USDA Forest Service General Technical Report, NE-66. 1982., 12 pp.
  35. Berg, W.A. and W.G. Vogel. Manganese toxicity of legumes seeded in Kentucky strip-mine spoils. USDA Forest Service Research Paper, NE-14. 1968, 12 pp.

36.                     . Toxicity of acid coal mine spoils to plants. In R.J. Hutnick and G. Davis (eds.). Ecology and Reclamation of Devastated Lands. Gordon and Breach, N.Y. 1973, pp. 57-68.
37. Goodman, G.T., E.E.R. Putcairo and R.P. Germmell. Ecological factors affecting growth on sites contaminated with heavy metals. In R.H. Hutnick and G. David (eds.). Ecology and Reclamation of Devastated Lands. Gordon and Breach, N.Y. 1973, pp 149-172.
38. Baxter, J.C., D.E. Johnson and E.W. Kienholz. Uptake of trace metals and persistent organics into bovine tissues from sewage treatment sludge - Denver Project. In G. Bitton, B.L. Damro , G.T. Edds, and J.M. Davidson (eds.) Sludge - Health Risks of Land Application. Ann Arbor Sci. 1980, pp. 285-311.
39. Edds, G.T., O. Osuna, and C.F. Simpson. Health effects of sewage sludge for plant protection or direct feeding to cattle, swine, poultry or animal tissue to mice. In G. Bitton, B.L. Damron, G.T. Edds and J.M. Davidson (eds.) Sludge - Health Risks of Land Application. Ann Arbor Sci. 1980, pp. 311-328.
40. Ahurrah, E.C. and R.T. Hartman. Survival and growth of red pine on coal mine spoil and undevastated soil in western Pennsylvania. In R.J. Hutnik and G. Davis (eds.). Ecology and Reclamation of Devastated Land. Gordon and Breach, N. Y. 1973, pp. 429-443.
41. Davis, G. Comparison of fall and spring plantings on strip mine spoils in the bituminous region of Pennsylvania. In R.J. Hutnik and G. Davis (eds.). Ecology and Reclamation of Devastated Land. Gordon and Breach, N.Y. 1973, pp. 525-538.
42. Plass, W.F. Genetic variability in survival and growth of Virginia pine planted on acid surface mine spoil. In R. J. Hutnik and G. David (eds.). Ecology and Reclamation of Devastated Land. Gordon and Breach, N.Y. 1973, pp. 443-508.
43. Geyer, W.A. Tree species performance on Kansas coal mine spoils. In R.J. Hutnik and G. Davis (eds.). Ecology and Reclamation of Devastated Land, Gordon and Breach, N.Y. 1973, pp. 81-90.
44. Davidson, W.H. Performance of Ponderosa pine on bituminous mine spoils in Pennsylvania. USDA Forest Service Research Paper. NE-358. 1977, 6 pp.
45. Brenner, F.J. Evaluation of abandoned strip mines as fish and wildlife habitats. Trans. N.E. Wildlife Conf. 1973, 30: 205-229.
46.                     , R.H. Crowley, M.J. Musaus and J.H. Goth III. Evaluation and recommendations of strip-mine reclamation

- procedures for maximum sediment-erosion control and wild-life potential. 3rd Symp. Surface Mine Reclamation. 1975, II: 3-23.
47. Vogel, W.G. A guide for revegetating coal mine soils in the eastern United States. U.S. Forest Service. General Technical Report. NE-66. 1981, 190 pp.
  48. Ruffner, S.D. and J.G. Hall. Crown vetch in West Virginia. West Virginia Agr. Exp. Bull. 1963, p 487.
  49. Brenner, F.J. and C. Goughler. Evaluation of surface mine seedlings to encourage natural selection. Restoration and Management Notes. 1983, 1:31-32.
  50. Jones, J.N., Jr., W.H. Armiger, and G.C. Hungate. Seed ledge improve stabilization of outer slopes on mine spoil. Unpub. Report, Agricultural Research Service.
  51. Brenner, F.J. 1978. Food and cover evaluation of strip mine plants as related to wildlife management. In D.E. Samuel, J.R. Stauffer, C.H. Hocutt and W.F. Mason (eds.). Proc. Surface Mining and Fish/Wildlife Needs in the Eastern United States. FWS/OBS. 1978, 78/81, 388 pp.
  52. Brenner, F.J. and J. Kelly. Characteristics of avian communities on surface mine lands in Pennsylvania. Environmental Management. 1981, 5: 441-449.
  53. \_\_\_\_\_, R.B. Kelly and J. Kelly. Mammalian community characteristics on surface mine lands in Pennsylvania. Environmental Management. 1982, 6: 241-249.
  54. DeCapita, M.R. and T.A. Bookhout. Small mammal populations, vegetational cover and hunting use of an Ohio strip mine area. Ohio J. Sci. 1975, 75: 305-313.
  55. Brenner, F.J. Aquatic and terrestrial habitats in Pennsylvania. In H.H. Genoways and F.J. Brenner (eds.). Species Of Special Concern in Pennsylvania. Special Pub. 10, Carnegie Museum of Natural History, Pittsburgh. In press.
  56. Botkin, D.R. and R.S. Miller. Complex exosystems: models and predictions. Amer. Scientist. 1974, 62: 448-451.
  57. \_\_\_\_\_, J. Janak, and J.R. Wallis. Rationale, limitations, and assumptions of a northeastern forest stimulator. IBM J. of Research and Development. 1972, 16:101-116.
  58. Davidson, W.H. Timber volumes of old Pennsylvania surface mine reclamation plantations. U.S. Forest Service Note 303. 1981, 5 pp.
  59. Brenner, F.J. and N.L. Simon. Direct seeding of mast producing trees on surface mines in Pennsylvania. Restoration and Management Notes. In press.
  60. Plass, W.T. Factors affecting the establishment of direct-

seeded pine on surface-mine spoils. USDA Forest Service Research Paper NE-290. 1974, 5 pp.

61. Brenner, F.J. and S. Michalski III. Evaluation of surface coal mines as ruffed grouse habitat. In preparation.
62. Kimmel, R.O. and D.E. Samuel. Ruffed grouse use of a twenty-year old surface mine. In D.E. Samuel, J.R. Stauffer, C.H. Hocutt and W.F. Mason, Jr. (eds.). Proc. Symposium on Surface Mining and Fish/Wildlife Needs in the eastern United States. FWS/OBS. 1978, pp. 345-351.
63. Brenner, F.J., M.J. Musaus and W. Granger. Selectivity of browse species of white-tailed deer on strip-mine lands in Mercer County, Pennsylvania. Proc. PA. Acad. Sci. 1977, 51: 105-108.
64. \_\_\_\_\_ and J.J. Mondok. Waterfowl nesting rafts designed for fluctuating water levels. J. Wildl. Manage. 1978, 43: 978-982.
65. Sandusky, J.E. The potential for management of waterfowl nesting habitats on reclaimed mined lands. In D.E. Samuel, J.R. Stauffer, C.H. Hocutt and W.F. Mason (eds.). Proc. Surface Mining Fish/Wildlife Needs in the Eastern United States. FWS/OBS 78/81. 1978, 388 pp.
66. Rosso, W.A. Reclaim your lands with lakes. Coal Age Magazine. Aug. 1980, pp. 76-77.