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Early Successional Plant Communities on an Abandoned Strip Mine in Butler County, Kentucky

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EARLY SUCCESSIONAL PLANT COMMUNITIES ON AN ABANDONED STRIP MINE IN BUTLER COUNTY, KENTUCKY

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Master of Science

by

Ralph G. Reiss

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EARLY SUCCESSIONAL PLANT COMMUNITIES ON AN ABANDONED STRIP MINE IN BUTLER COUNTY, KENTUCKY

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Dedicated to Lisa, for her patience, encouragement and love.

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Ralph G. Reiss August, 1986 77 Pages

Directed by: J. E. Winstead, K. A. Nicely and G. E. Dillard

Department of Biology Western Kentucky University

Plant growth and development during the growing season of 1985 were examined on a strip mine located in Butler County, Kentucky, abandoned in 1963. Analysis included field plot measures of the frequency, density, and percent cover of the established plant species and determination of biomass accumulation during the 1985 year. Experimental subplots were established in both field and laboratory settings and the growth of the herbaceous colonizers compared under natural and programmed growth chamber conditions. Microclimatic measures of temperature and solar insolation were conducted in the field along with soil texture and pH measures. Results indicate that in the early successional communities sampled in Butler County, *Pinus virginiana* Mill., *Elaeagnus angustifolia* L. and *Nyssa sylvatica* Marsh. are the most important tree species. Important forbs include *Lechea tenuifolia* Michx., *Bidens polylepis* Blake, *Lespedeza striata* (Thunb.) H. & A. and *Polygonum pensylvanicum* L. *Danthonia* sp. and *Festuca* sp. are the two most important grasses. Biomass production during the first quarter of the growing season accounted for approximately two-thirds of the annual biomass accumulation.

The data indicate that biomass production may be limited more by the harsh climatic conditions than by the sterile edaphic conditions present on the abandoned strip mine.

INTRODUCTION

According to the most recently published statistics, there are approximately 421,121 acres of "disturbed" land in the State of Kentucky. Of these, only 154,500 acres have been reclaimed or naturally revegetated (United States Environmental Protection Agency, 1984). Disturbed land, especially "orphaned" spoil from unreclaimed strip mine activities, presents serious environmental and economic problems. Some of the environmentally related problems are a loss of wildlife habitat, erosion, acid mine-drainage, siltation of streams and rivers and the destruction of natural watersheds. Abandoned strip mine spoil takes valuable land out of agricultural production, including both farm and forest production. Water resources have been greatly reduced in some parts of the State as a direct result of acid mine-drainage and siltation. The aesthetic value of the land in many parts of eastern and western Kentucky has been reduced, and this must certainly have an economic impact on tourism in those areas.

Orphaned strip mine spoils provide unique habitats for the study of successional processes by plant species endemic to coal-mined areas. Spoil habitats encompass a mosaic of conditions centered on a harshness of microclimatic and edaphic properties. Basic research aimed at understanding the processes which control initial colonization and further successional development of native and naturalized plants on spoil material will increase the effectiveness of land reclamation efforts. There are many special problems, both biotic and abiotic in nature, associated with the revegetation and successional development of strip mined lands. An overview of some of the most common problems follows.

ABIOTIC FACTORS INFLUENCING THE VEGETATION OF MINE SPOILS

Extremely high spoil surface temperatures during the summer months along with daily temperature fluctuations have been reported by several investigators. Graham (1947) attributed the zonation of vegetation on spoil banks in southeastern Ohio to spoil temperature. He noted that seedlings could not become established on slopes that faced the southwest because spoil temperatures were too high. Bramble and Ashley (1955) also mentioned that two year old, planted, red pine seedlings were affected by direct heat injury on spoils in central Pennsylvania. They reported spoil surface temperatures as high as 54.4 C during the month of August on leveled, dark-colored, carbonaceous spoil material. It is possible that some spoil surfaces can reach even higher temperatures. Slope angle and aspect, spoil composition, cloud cover, latitude and time of year all play a role in determining the daily insolation and temperature maxima of a particular spoil bank. Deely and Borden (1973) also concluded that heat injury to seedlings on spoil material is an important factor controlling the revegetation of strip mines.

Besides heat injury to seedlings, Bell and Ungar (1981) showed that high temperatures are the most probable cause of death of germinating seeds on bare spoil. They performed seed bank experiments which showed that both open and vegetated sites contained viable seeds. Seeds germinated in spoil material taken from both sites when placed under controlled, greenhouse conditions. Seeds either failed to germinate or failed to grow after germination under the field conditions existing in the open sites.

Another edaphic factor related to elevated spoil temperature is spoil moisture content, especially moisture in the upper 15 to 20 centimeters of spoil. Elevated temperatures cause increases in evaporation and a rapid drying of the spoil material. Strip mine spoil can develop a shale layer on its surface which contains a low proportion of fine soil particles (less than 2 mm in diameter), and this decreases the water-holding capacity of the spoil (Bramble and Ashley, 1955). Croxton (1928) also found that spoils with the highest proportions of shale were the least permeable to water. Excessive water losses due to runoff can drastically change the microclimate of a disturbed site in comparison to the surrounding undisturbed land. The net effect on the disturbed site is equivalent to a significant reduction in annual precipitation. Besides altering the microclimatic conditions of the site, runoff causes extensive damage due to erosion and the subsequent siltation of streams and rivers.

Wind exposure on open spoil is another factor which greatly affects revegetational processes. Increased wind exposure causes increases in evapotranspiration which can cause drought conditions in the summer. Wind-blown spoil particles can cause "sand-blasting" of the vegetation, and wind-stirring can cause ring-barking at ground level (Goodman et al., 1973).

Slumping of spoil banks can work against the establishment of vegetation on a disturbed site (Winstead, 1962). If the surface material is loose and steeply sloped, as is often the case, frost and water action can cause downslope movement of the spoil, and plant establishment becomes exceedingly difficult.

Spoil material is often highly acidic (Croxton, 1928; Bramble and Ashley, 1955; Barnhisel and Massey, 1969; Bell and Ungar, 1981). Hydrogen ion concentrations in the spoil are often at toxic levels for most plant species indigenous to our region, and only a few acid-tolerant species can become established under the highly acidic conditions (Limstrom, 1964). Associated with high acidity are high salt content and low nutrient availability (Berg and Vogel, 1973; Bradshaw and Chadwick, 1980; Goodman et al., 1973). Salts of heavy metals such as Fe, Mn, Cu, Ni, Mg and Al have increased solubility in acidic soils and can cause metal toxicity to plants growing in acid spoil. Plant nutrients such as Ca, K, P and N become less available to plants as pH decreases (Barbour et al., 1980). Therefore, many acid spoils have deficiencies in essential plant nutrients as well as excesses in metallic ions.

Microtopography may also play a major role in determining the distribution and abundance of plant species on strip mine spoils. Microtopography influences the vegetational patterns of sites undergoing both primary and secondary succession. Harper et al. (1965) studied the effect of microtopography on the germination of seeds of different species with varying seed sizes. Their experiments demonstrated the importance of physical heterogeneity at the soil surface. Small differences in surface topography provide a range of microhabitats both suitable and unsuitable for the germination of seeds of different species. Favorable sites probably provide suitable moisture and temperature conditions for germination.

Jenny (1941) proposed an equation for soil formation as a function of the following variables: 1) climate, 2) organisms, 3) topography, 4) parent material and 5) time. Kruckeberg (1969) modified Jenny's soil-forming equation and made soil microtopography a function of the five previously stated variables. From this premise he made inferences relating microtopography to plant competition, succession and distribution. Kruckeberg postulated that differences in microrelief would have three basic effects on a plant community: 1) Different species will respond uniquely to different configurations of soil microsites, and thereby create local differences in species distribution; 2) Microsite variations decrease the pressure of interspecific interference, if the species have distinct safe site preferences; 3) Changes in microsite through time from bare mineral soil through various successional stages will result in the selection for different species at each stage of the seral sequence.

Work by Sterling et al. (1984) seems to verify the postulations of Kruckeberg, at least in the earlier stages of succession. Sterling et al. found that microtopography, created by furrows in previously ploughed land, was a key factor responsible for vegetation structure in the early stages of secondary succession on sloping Mediterranean grassland. As succession proceeded, differences in microtopography decreased, and fine-grained vegetational patterns faded. At the same time, geomorphological gradients resulting from the sloping of the land increased in importance and became the dominant factor determining the appearance of coarse-grained vegetational patterns.

Riley (1979) conducted experiments on mine spoils in Ohio to see if microtopography had an effect on precipitation retention and salt leaching. Data were collected from four one-acre plots over periods ranging between 3 and 19 years. Each plot was situated on a slope of 12% or less, and each received a different treatment. Plots were either furrow graded, with furrows three feet deep and four feet apart; rough graded, with a pit and mound topography resulting in 6-12 inches of relief; ripped, with furrows two feet deep and three feet apart; or smooth graded, to serve as a control. Differences also existed in the spoil composition and species planted at each site, which makes the results of this study difficult to interpret. In spite of this flaw, one difference observed among the plots is noteworthy. The furrowed and rough graded plots were successfully revegetated within 14-19 years after treatment initiation, while the smooth graded plot had only 35% plant cover after 14 years. Riley found no definitive trends with respect to microrelief and its effect on the leaching of certain specific ions, but it undoubtedly affects spoil moisture by reducing runoff. Given enough time, furrows and depressions might serve as traps for detritus, since they are somewhat protected from the wind. This would increase the water holding capacity of the spoil and might even reduce the salt content near the surface. Berg and Vogel (1973) found that mulching with wood chips significantly reduced the levels of soluble salts in the upper 45 cm of spoil in just one year.

Further study is needed to understand the role of microtopography in the establishment of pioneer spoil communities and in the implementation of effective land restoration.

BIOTIC FACTORS INFLUENCING THE VEGETATION OF MINE SPOILS

Both the success of plant establishment and the subsequent successional development of the vegetation are heavily influenced by a number of biotic variables. A knowledge of microbial ecology, including bacterial and fungal decomposition, nutrient cycling, nitrogen fixation by bacteria and blue-green algae, iron and sulfur oxidation by chemoautotrophic bacteria and mycorrhizal associations among plants and fungi, is fundamental to an understanding of reclamation problems. The life histories and adaptive strategies of the plant community members, the populational ecology of each species, plant competition and vegetational zonation along environmental gradients all play a role in the development of new vegetation.

Soil microbes are a vital component of any ecosystem because of their key roles in energy flow and nutrient cycling. Detrital food chains are the major pathway of energy flow in terrestrial ecosystems (Smith, 1980). In grassland ecosystems where there is an absence of grazing by domesticated animals, as much as three-fourths of the energy stored in plant biomass may be returned to the soil (Hyder, 1969).

Decomposition occurs in three stages (Brinson, 1977). The first stage involves the formation of particulate detritus. Soil macrofauna, birds, small mammals and the action of wind and rain fragment the detritus, which makes it more readily available to microbial decomposers. The second stage of decomposition is called nutrient immobilization. Soil microbes utilize the easily digested components of the detritus which becomes unavailable for further cycling until the microbes die or succumb to predation. Humus is formed from the remaining plant compounds which are not so easily degraded by most soil microbes. Humus formation causes further nutrient immobilization due to its relatively high resistance to further decay and because of its capacity to form chelates with mineral ions from the soil parent material. The third stage of decomposition is called mineralization. Mineralization occurs when the humus is finally oxidized to carbon dioxide and water, and the mineral ions are made available for plant uptake. In ecosystems where the vegetation undergoes seasonal periods of dormancy, decomposition provides a means of retaining mineral nutrients until needed the following growing season.

Land disturbances, such as strip-mining activities, disrupt the natural cycle of decomposition, immobilization and mineralization. Mine spoil is initially devoid of vegetation, with little or no humus content, and has a sparse population of microbial decomposers. Any nutrients in the spoil that could support plant growth are mostly lost by leaching. Since spoil material is extremely infertile, especially in regard to nitrogen and phosphorous, plants adapted to grow under these conditions must either have the means to fix nitrogen or have low nitrogen requirements.

Durall et al. (1985) have demonstrated that timothy

(*Phleum pratense* L.) decomposition on spoil material in Alberta, Canada, is retarded because of spoil infertility and a sparse decomposer microflora. Much of the nutrient supply is lost to leaching, while more and more becomes locked up in slowly decaying timothy detritus.

Rice (1964) found that pioneer species on old fields in Oklahoma tend to have low nitrogen requirements, and many produce chemical compounds that inhibit the growth of nitrogen-fixing and nitrifying bacteria. By inhibiting these bacteria, pioneer species can outcompete climax plant species that require higher levels of soil nitrogen and thereby inhibit their eventual replacement in the plant community. Two of the most allelopathic grasses studied by Rice are members of the genera *Aristida* and *Andropogon*. Members of both genera can be found growing on abandoned mine spoil in western Kentucky. The relationship between microbial decomposers and plant species used in the reclamation of mine spoils is not well understood. Durall et al. (1985) have provided some new insights into this relationship. The rates of timothy litter decomposition on three sites differing in the length of time since reclamation were quantified. The elapsed time intervals since reclamation at the three sites were one, three and seven years respectively. Experiments revealed a trend of decreasing decomposition rates of timothy litter with increasing intervals of time since reclamation at the sites. Total plant biomass decreased as the time interval since reclamation increased, while timothy biomass comprised larger fractions of the total plant biomass with increases in time. It is known that timothy has low nutrient requirements and is tolerant of low soil fertility (Smoliak et al., 1981; as cited by Durall et al., 1985). These findings indicate a basic relationship between microbial decomposers and plant community structure. Rates of decomposition and nutrient cycling, and, ultimately, rates of plant succession, are dependent upon the plant community structure in association with its microbial decomposers.

Besides the important role that microbes play in the decomposition of organic matter, autotrophic bacteria can exert a profound influence on mine spoil plant communities in other ways. Chemoautotrophic bacteria like _Thiobacillus thiooxidans_ and _T_. _ferrooxidans_, can use reduced forms of sulfur and iron as an energy source in ways analogous to the utilization of light energy by photosynthetic plants. Pyrite and shale are often found in contact with coal seams or sandwiched between two coal seams (Dugan, 1975). During mining operations, the pyrite and shale are separated from the coal and left behind as part of the spoil material. The exposed pyrite is then chemically and biologically oxidized in a series of reactions which ultimately yield sulfuric acid, ferric hydroxide and ferric hydroxy sulfate. These compounds all have deleterious effects on both aquatic and terrestrial organisms when in high concentrations. The effects of acid mine-drainage can be seen on and around abandoned spoils throughout the eastern United States.

Singer and Stumm (1970) studied the role of Thiobacillus ferrooxidans metabolism in the oxidation of pyrite and concluded that the reaction is catalyzed by the bacterium with increases in the rate of oxidation up to one million times the chemical rate. They postulated that some pyrite is dissociated or oxidized initially by chemical means. Ferrous iron is then used by T. ferrooxidans as an energy source with the resultant production of ferric iron. Ferric iron reacts with pyrite and water to form sulfate and more ferrous iron which can be used again by T. ferrooxidans as an electron source. The rate limiting step is catalyzed by the acidophilic bacterium, and the optimal pH of the reaction is between 2.5 and 3.5.

Dugan (1975) has observed that microbes are involved in acid mine-drainage in at least four ways: 1) Acidophilic Thiobacillus bacteria increase the production of acid by their metabolic activity; 2) Sulfuric acid inhibits the survival and growth of organisms normally present in non-acidic receiving streams; 3) The growth of acid tolerant microbes can aid in the recovery of acid contaminated streams if the source of contamination is eliminated; 4) Some bacteria can reduce sulfate back to sulfide which can then be precipitated as iron sulfide.

Dugan and Lundgren (1964) have studied the inhibitory effects of some compounds on the iron oxidation of Thiobacillus ferrooxidans in laboratory cell suspensions. It was discovered that the anionic surfactants, alkylbenzene sulfonate and sodium lauryl sulfate, were active inhibitors of _T_. _ferrooxidans_. Several low molecular weight organic acids also were found to inhibit the iron oxidation of _T_. _ferrooxidans_. Interestingly enough, all of the acids synthesized in the Kreb's cycle are inhibitory to the bacterium. The use of these inhibitors in the control of acid mine-drainage is not likely to be practical, but the importance of this knowledge lies in a better understanding of the microbial ecology of acid mine spoil.

Nitrogen fixation by microbes is also important to the revegetation of strip mine spoils, because the spoil material usually cannot provide enough nitrogen to meet the requirements of most plants (Barnhisel and Massey, 1969). Biological nitrogen fixation is accomplished by bacteria which live in a symbiotic association with the roots of plants, by free-living aerobic bacteria and by blue-green algae (Smith, 1980).

Probably the most important nitrogen fixing symbiosis known occurs between members of the legume plant family and the bacterial genus _Rhizobium_. Inoculated legumes such as black locust (_Robinia_ _pseudoacacia_ L.) are frequently planted on newly reclaimed mine spoils. Legumes naturally invade mine spoils and other sites that are low in nitrogen fertility. Some non-leguminous plants can also establish a symbiotic relationship with nitrogen fixing bacteria. Among such plants are _Alnus_, _Ceanothus_ and _Elaeagnus_ (Smith, 1980).

Little appears to be known about the fixation of nitrogen by free-living bacteria and blue-green algae in strip-mine spoil. If these microbes are capable of growth under the adverse conditions present in mine spoil, they may be one of the primary sources of nitrogen on unreclaimed sites. Spoil amendments which enhance the growth of blue-green algae and nitrogen fixing bacteria could improve land restoration techniques.

Studies of the symbiotic associations between plant roots and fungi, known as mycorrhizae, also show much potential for improvements in applied reclamation technology. Under natural soil conditions, mycorrhizal associations are extremely common, and non-mycorrhizal plants are the exception, not the rule (Marx, 1975). There are three basic types of mycorrhizal association. They are the ectomycorrhizae, the endomycorrhizae and the ectendomycorrhizae.

The initiation of ectomycorrhizal infection begins when plant feeder-root exudates stimulate fungal spores or hyphae in the rhizosphere to form a mantle around the root. After mantle formation, the hyphae penetrate the root cortex and form an intercellular network called the Hartig net. Basidiomycetes are the most common ectomycorrhizal symbiont of forest trees. In order to complete their life cycles, most ectomycorrhizal fungi require certain essential carbohydrates, amino acids and vitamins from their tree hosts (Marx, 1975). Millions of spores are disseminated by wind and water from the fruiting bodies of these fungi. Some ectomycorrhizal fungi are fairly host specific; others have a broad host range.

Many important forest tree species form endomycorrhizal associations, and some trees can form both ectomycorrhizal and endomycorrhizal associations. Endomycorrhizal fungi are the symbionts of most economically important agronomic and forage crops (Marx, 1975), as well as many grasses and herbs found growing on spoil material (Daft et al., 1974). Endomycorrhizal fungi do not develop the dense mantle or Hartig net found in ectomycorrhizae, nor do they produce large, above-ground fruiting bodies for the dissemination of spores. The hyphae of endomycorrhizal fungi actually penetrate into the cortical cells of the root, and many species develop specialized structures called arbuscules which function in absorption and nutrient exchange. These species also form vesicles within the cortical cells and are often referred to as vesicular-arbuscular mycorrhizae. Endomycorrhizal fungi most often produce large, conspicuous, thick-walled spores in the rhizosphere, on root surfaces and sometimes in feeder-root tissues. Others form large sporocarps on the roots. Dissemination occurs by direct root contact, moving water and insect and mammal vectors (Marx, 1975; Ponder, 1980). In the absence of a host, spores can survive for many years in the soil. Most of the endomycorrhizal fungi studied so far have a broad host range.

Little is known about the ectendomycorrhizal fungi. They have the morphological features of both ectomycorrhizal and endomycorrhizal fungi. Ectendomycorrhizal fungi are generally found on tree species that are normally ectomycorrhizal. It is not known if they play a significant role in the nutrition and growth of their hosts.

Schramm (1966) studied plant colonization on anthracite wastes in Pennsylvania and concluded that early ectomycorrhizal development was essential for seedling establishment of Betula lenta L., B. populifolia Marsh., Pinus rigida Mill., P. virginiana Mill., Populus tremuloides Michx., Quercus rubra L. and Q. velutina Lam. All of the initial spoil colonizers were either nitrogen fixing symbionts or ectomycorrhizal symbionts.

Schramm also concluded that Pisolithus tinctorius ectomycorrhizae were associated with the most vigorously growing seedlings. Marx and Bryan (1971) discovered that P. tinctorius could form ectomycorrhizae on Pinus taeda L. at soil temperatures as high as 40 C, which may explain why P. tinctorius is often the first and most beneficial mycorrhizae associated with mine spoil colonizers. Many investigators have attributed extremely high spoil temperatures during the summer months to poor seedling establishment (Bell and Ungar, 1981; Bramble and Ashley, 1955; Deely and Borden, 1973; Graham, 1947; Schramm, 1966). Marx (1975) surveyed mine wastes throughout the eastern United States and found that Pisolithus ectomycorrhizae were the predominant, and sometimes the only, mycorrhizal fungus on the roots of *Pinus virginiana*, *P. taeda*, *P. resinosa* Ait. and several species of *Betula* in Indiana, Pennsylvania, Ohio, Virginia, West Virginia, Kentucky, Tennessee and Alabama.

Only a few reports have documented the presence of endomycorrhizae on early plant colonizers of strip-mine spoil. Daft et al. (1974) found abundant endomycorrhizae on the roots of grasses and other herbaceous plants growing on mine spoils in Pennsylvania and Scotland. Spores of *Gigaspora gigantea* (*Endogone gigantea*) were collected and identified from the Pennsylvania site. Later tests showed that these spores could infect and stimulate the growth of corn planted in mine spoil. It was concluded that endomycorrhizae could be essential for the survival and growth of herbaceous plants on coal wastes.

Marx (1975) makes reference to the observations of several of his associates on the incidence of endomycorrhizal symbiosis in mine spoils. They found endomycorrhizal associations in a number of wild and cultivated grasses growing on both artificially and naturally revegetated coal spoils in Kentucky and Virginia. Further research could reveal species of endomycorrhizal fungi which are as important to the establishment of grasses on disturbed land as some ectomycorrhizal fungi are to the establishment of trees.

Along with an understanding of the microbial ecology of strip mined land, it is obvious that knowledge of the plant ecology of abandoned spoils is fundamental to any land restoration efforts. In the past, one of the primary goals of reclamation research has been to identify the plant species most highly adapted to strip mine conditions. Work by many ecologists has shown that as a result of natural selection, genetic, physiological and morphological differences occur within a species, and not just among species. Different races, or ecotypes, within a species have different adaptive characteristics, and this factor must be considered if effective land restoration is expected to result.

Hurt and Winstead (1980) demonstrated that one ecotype of the grass *Andropogon virginicus* L. is best adapted to some early successional mine spoil habitats; another ecotype of this grass is best adapted to early successional old field habitats. A slower growth rate and later flowering time was observed in the mine spoil population, and it was proposed that these characteristics are adaptations to a harsher, less fertile habitat. Chapman and Jones (1975) also reported ecotypic differentiation in *A. virginicus*. They found two ecotypes; one from old fields, and another from granite outcrops.

Gibson and Risser (1982) conducted experiments with *Andropogon virginicus* populations growing in northeastern Oklahoma. The results of their experiments indicate that an old field population was genetically distinct from other populations tested, but there was no difference between populations growing in metal contaminated and non-contaminated soils. This is probably the only work which suggests that inherent tolerance to metalliferous soils occurs in a plant species. Many investigations have shown that both metal tolerant and intolerant races of plants exist in a number of species, and they support the hypothesis that species growing on metalliferous soils evolved tolerant populations (Antonovics, 1971; Bradshaw, 1952; Gadjil, 1969; Gregory and Bradshaw, 1965; Jowett, 1958; and Wilkins, 1957).

Knowledge of the environmental parameters most limiting to plant growth, as well as the ecotypes best adapted to those parameters, are essential prerequisites for successful land restoration. On the other hand, species which are inherently tolerant to a wide range of environmental parameters must also be identified with certainty, because these species will have the widest application for use in land reclamation.

Plant establishment on a disturbed site is only the first phase of land restoration. Unless plant communities similar to the ones present before the disturbance can eventually return to the site, the land has not been restored to its original potential. But even if strip mine spoil can eventually support pre-mining communities, this does not mean that the land has been completely restored. The impact on faunal communities, aquatic communities, local hydrology and water quality must all be assessed before an accurate measure of the effectiveness of the reclamation effort can be made.

If methods can be devised to measure the rates and stages of successional development for mine spoil plant communities, this information could be useful in assessing the rate and degree of restoration expected for a site under a specified set of environmental parameters and reclamation treatments. Long-term studies of community structure and productivity on permanent plots should yield valuable information for evaluating successional development.

Bell and Ungar (1981) studied plant establishment on mine spoil in southeastern Ohio. They concluded that high spoil temperatures along with low spoil moisture inhibits the germination and establishment of plants on spoil material while low pH, high aluminum concentration and low nutrient levels do not affect mature individuals. The conclusion by Bell and Ungar that edaphic properties of the spoil have no effects on mature plants is based on the results of transplant experiments involving two grass species.

Since there has been very little work done on the productivity and structure of mine spoil plant communities, particularly in Kentucky, one of the objectives of this study is to provide some of the baseline data that will be needed for comparisons with future studies. Measurements of the net productivity and species composition of several mine spoil plant communities were obtained along with some of the environmental parameters which are most limiting to plant growth. Whenever possible, an attempt has been made to correlate differences in community structure and productivity with differences in the limiting environmental parameters.

METHODS

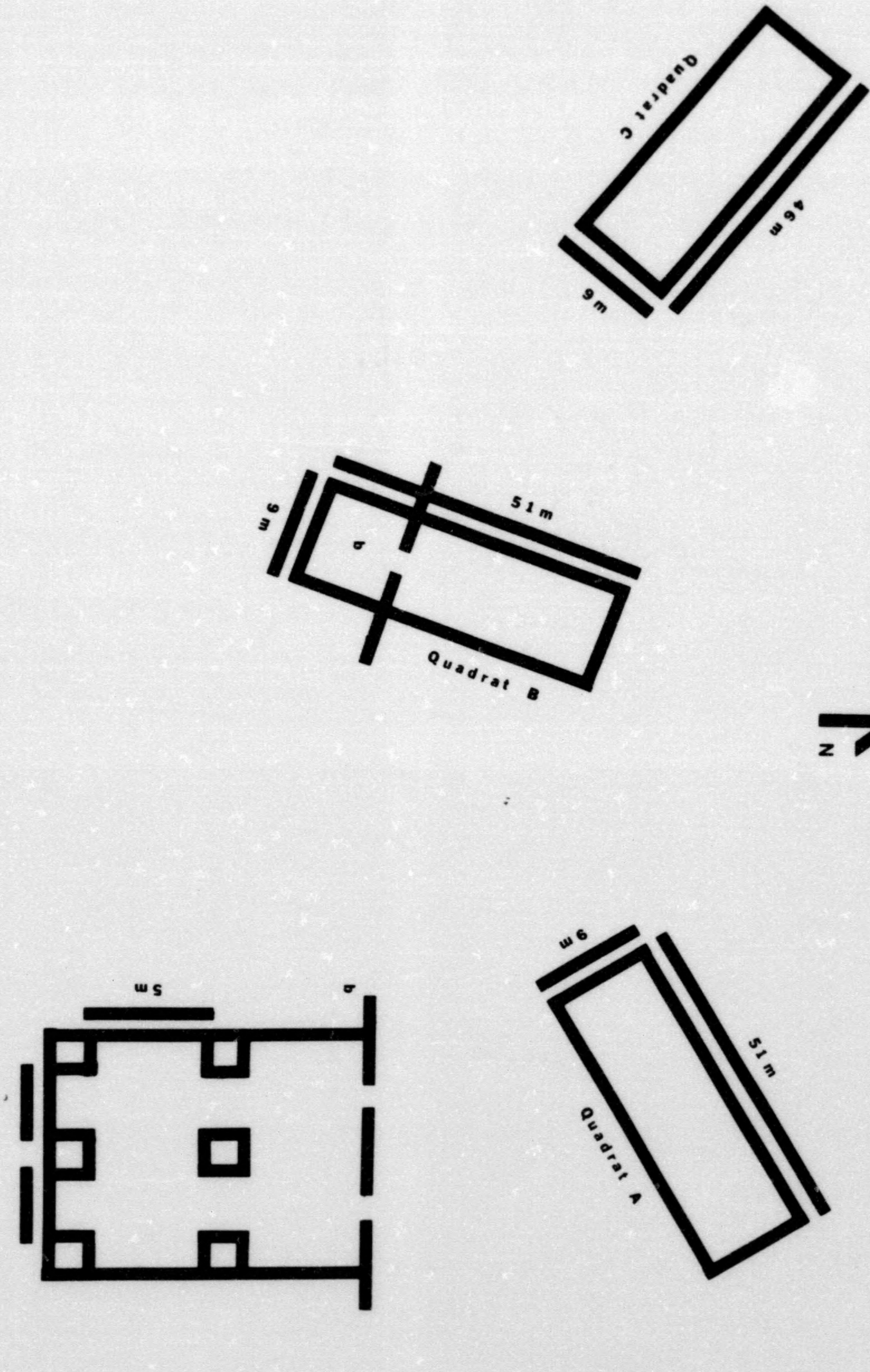
The study area is located approximately 5.5 kilometers southwest of Morgantown, Butler County, Kentucky, at a latitude of 37 degrees, 12 minutes N and a longitude of 86 degrees, 44 minutes W. With help from the Division of Abandoned Lands of the Kentucky Natural Resources Cabinet, a site that had not been actively mined for the last 23 years and with no record of reclamation efforts was located.

During mining operation, bituminous coal was taken from the Mining City coal bed in the Caseyville and Tradewater Formations of the Lower and Middle Pennsylvanian Series. The abandoned site forms a bench cut into the hillside, and it follows the contours of the Mining City coal bed. Overburden consisting of soil, sandstone, siltstone and fragments of coal and shale make up the spoil material. The spoil was leveled before abandonment of the mine, and it forms a strip along the contours of the hillside. The flat strip of overburden has an average width of approximately 60 meters and a thickness ranging from one meter on the upslope side near the coal seam to about 10 meters in thickness on the outer edge of the strip. Steeply sloped rock and overburden lie above and below the flats, and erosion is severe and extensive.

The closest weather station is located about 35 kilometers to the west of the study site in Greenville, Kentucky, at a latitude of 37 degrees, 12 minutes N and a longitude of 87 degrees, 12 minutes W. Weather data from the Greenville Weather Station were obtained for the years 1951 through 1978. During this time, mean annual precipitation was 120.18 cm with an average growing season of 185 days. Precipitation is generally well distributed throughout the year with about half the mean annual precipitation occuring during the growing season. Mean monthly temperatures during the growing season range from 15.0 C in April to a high of 25.0 C in July and then back down to 15.0 C in October.

In order to sample early successional plant communities, three quadrats were established in the study area on the leveled strip of spoil. Quadrat A, as depicted in Figure 1, was located near the eastern edge of the study site with the long axis of the quadrat on a line with a compass bearing of 60 degrees E of N. Quadrat A was a rectangular plot with dimensions of 9 m by 51 m and contained 33 one square meter subplots distributed systematically throughout the quadrat. Quadrat B was located approximately 180 meters to the west of Quadrat A, and it also had dimensions of 9 m by 51 m with 33 one square meter subplots. The long axis of quadrat B was on a line with a compass bearing of 20 degrees E of N. Quadrat C was located 60 meters west of quadrat B and had dimensions of 9 m by 46 m. Quadrat C was located with the long axis along a line with a compass bearing of 50 degrees W of N, and contained 30 one square meter subplots distributed

Figure 1. A diagram of the quadrat layout at the study site. The dimensions of the quadrats are drawn to scale, but the distances between the quadrats are not. A sectional enlargement of quadrat B is located in the lower, right corner of Figure 1, and is marked b. In enlargement b, the systematic placement of subplots is depicted and is representative of all three quadrats.



Quadrat C
46m
9m
Quadrat B
51m
9m
b
N
Quadrat A
51m
9m
5m
b

systematically throughout the quadrat.

Quadrat C was slightly smaller than the other two quadrats because vegetation was not distributed evenly throughout this quadrat, and it was determined that increasing the area of the quadrat would not increase the accuracy of the sample. The subplots within each quadrat were used to sample the frequency, density and percent cover of all woody plants and forbs encountered. The density of grasses and lichens was not determined due to the extreme difficulty in making accurate counts of these plants, but frequency and percent cover data were collected for grasses and lichens. Subplots were distributed systematically throughout the quadrats, rather than randomly, because vegetation within the quadrats was not evenly distributed, and systematic sampling will generally be more accurate than random sampling in this situation.

Within each quadrat, three rows of the one square meter subplots were established for vegetation sampling of the communities and for sampling biomass production. The rows were spaced three meters apart with five meter spaces between the subplots in each row.

Species frequency, density and percent cover were determined for each subplot and from these data a relative frequency, relative density, relative dominance and importance value was calculated for each species according to the methods described by Smith (1980).

The coefficient of community index was also calculated according to methods from Smith (1980). The coefficient of community index is based on frequency data only, and values were calculated for each of the three different possible pairings of quadrats.

Community biomass production was estimated by the harvest method. Four subplots each from quadrats A and B and two subplots from quadrat C were selected for the measurement of biomass production. The subplots designated for measurement of biomass production were divided into 16 subdivisions, each subdivision being 25 cm by 25 cm, or 625 square centimeters. Three 625 square centimeter samples from each of the 10 designated subplots were used to estimate net community biomass production. One sample from each subplot was harvested on 28 May to determine spring biomass production. A second set of samples was carefully dug up, with the plants remaining rooted and intact in the spoil material, and then immediately transferred to the lab where the samples were placed in Environator growth chambers. Growth chambers were programmed to a 16-8 hour day-night cycle with a 12-12 hour temperature cycle of 32-16 C. Plants were watered as necessary and harvested on 4 October. The third set of samples was marked in the field on 28 May and was harvested on 3 October to estimate annual net community biomass production and for a comparison with the yields of growth chamber grown vegetation.

Harvests consisted of above ground biomass only, and no standing, dead, plant material from previous years was collected. Plants were oven-dried before weighing.

Measurements of daily fluctuations in ambient air temperature and relative humidity were made with a Taylor Instrument Company recording thermograph and a Weathermeasure Corporation model H311 hygrothermograph. Minimum and maximum air temperatures at ground level were measured over one to two week periods, on average, with the use of Taylor Instrument Company min-max thermometers. Solar insolation was measured with a GM Manufacturing and Instrument Corporation light meter.

Spoil pH was determined with use of a Sargent-Welch model IP S-30010-50 pH meter. A 1:1 mixture of spoil and deionized water was used for pH measurements. Spoil temperatures were measured with Weksler soil thermometers. Percentages of sand, silt and clay were determined by the Bouyoucos Hydrometer Method (Bouyoucos, 1936).

RESULTS

MICROCLIMATE

Measurements of ambient air temperatures, minimum and maximum air temperatures at ground level, spoil temperatures near the surface, ambient relative humidity and solar insolation at the spoil surface were made in order to describe some of the most important features of microclimate at the study site. Microclimate varies between locations within the study site and between on-site and off-site locations. Monthly comparisons of ambient air temperatures from the study area with ambient air temperatures from the nearest weather station in Greenville, Kentucky, are presented in Table 1. Values listed for the study area are for 1985 and are based on a limited number of days. June values are based on 15 days of measurement, July values on 23 days, August values on 19 days and September values on 14 days. Values listed for the Greenville Weather Station are averaged over a 27 year period from 1951 to 1978. During all four months, the mean ambient air temperature on the spoil was higher than at the weather station. Differences ranged from 1.0 C in August to 1.7 C in September. Minimum ambient air temperatures on the spoil exceeded those from the weather station in all cases, and differences ranged from 5.0 C in June to 10.6 C in September. On the spoil, maximum ambient

Table 1. Comparison of minimum, maximum, and mean ambient air temperatures at the Butler County study site (BC) and the Greenville Weather Station (GWS) during June, July, August, and September. Values listed for the Greenville Weather Station are averages for the years 1951-1978.

Month	Mean Temperature (C)		Minimum Temperature (C)		Maximum Temperature (C)	
	BC	GWS	BC	GWS	BC	GWS
June	24.8	23.2	14.4	9.4	36.1	34.4
July	26.1	25.0	17.8	11.7	36.1	35.6
August	25.4	24.4	18.9	10.6	34.4	35.0
September	22.6	20.9	15.6	5.0	31.1	33.9

Table 2. Minimum and maximum air temperatures at ground level for randomly selected subplots.

Date	Quadrat A			Quadrat B			Quadrat C		
1985	Cover*	Temperature (C) Min	Max	Cover*	Temperature (C) Min	Max	Cover*	Temperature (C) Min	Max
6/14-6/21	N	10.0	32.2	N	11.7	35.6	N	10.6	34.4
	N	8.3	35.6	H	9.4	37.8	H	7.8	37.2
6/21-6/28	N	14.4	36.7	N	18.3	40.0	N	17.2	39.4
	N	14.4	38.9	H	16.1	44.4	H	14.4	43.3
6/28-7/5	N	13.3	34.4	N	16.1	34.4	N	13.9	33.9
	N	13.3	31.7	H	14.4	41.1	H	13.9	42.2
7/19-7/26	N	16.7	38.9	N	20.0	41.1	N	17.8	40.0
	H	16.7	40.0	H	19.4	40.6	H	18.3	45.6
7/26-8/7	N	----	----	N	15.6	38.9	N	12.2	36.7
	H	12.2	37.8	H	14.4	40.0	H	15.0	40.0
8/7-8/18	N	15.0	38.3	N	18.9	40.6	N	16.7	40.0
	H	15.6	40.0	H	17.8	39.4	H	16.7	41.7
8/18-8/25	N	12.2	34.4	N	15.6	36.7	N	13.9	34.4
	H	13.3	35.6	H	14.4	40.0	H	13.3	38.3

Table 2 (continued)

Date	Quadrat A			Quadrat B			Quadrat C		
1985	Cover*	Temperature (C) Min	Max	Cover*	Temperature (C) Min	Max	Cover*	Temperature (C) Min	Max
8/25-9/9	N	10.6	37.8	N	13.3	40.0	N	11.1	38.9
	H	11.7	38.9	H	15.0	43.3	H	15.6	40.0
9/9-9/16	-	----	----	-	----	----	N	2.8	39.4
	-	----	----	-	----	----	H	3.3	38.9
9/16-10/5	-	----	----	-	----	----	N	0.0	27.8
	-	----	----	-	----	----	H	-5.6	34.4

*N = no cover; H = herbaceous cover

Table 3. Mean differences between minimum and maximum air temperatures in degrees Centigrade for both unvegetated and vegetated microsites in each of the three quadrats. The mean ($\bar{x}$) and standard deviation (SD) for the unvegetated sites are based on a total sample of n = 26. The $\bar{x}$ and SD for the vegetated sites are based on a total sample of n = 21.

Site	Quadrat A	Quadrat B	Quadrat C	$\bar{x}$	SD
Unvegetated	23.1	22.2	23.0	22.8	2.49
Vegetated	28.2	25.7	26.7	25.8	2.41

air temperature was 1.7 C higher in June, and 2.8 C lower in September, than at the weather station. Differences for July and August were less than 0.7 C.

Minimum and maximum air temperatures at ground level are listed for various locations within each quadrat in Table 2. During each time interval, microsites on quadrat A almost always had the lowest minimum and maximum air temperatures at ground level, while microsites on quadrat B nearly always had the highest minimum and maximum air temperatures at ground level.

Table 3 lists for each quadrat the mean difference between minimum and maximum air temperatures on both vegetated and unvegetated sites during the period from 14 June to 9 September, 1985. The mean difference for unvegetated sites was 22.8 C with a standard deviation of 2.49 C. A mean difference of 25.8 C for the vegetated sites was 3.0 C greater than for the unvegetated sites, and the standard deviation was 2.41 C. Among the three quadrats, the mean difference in temperature extremes at unvegetated sites varied less than 1.0 C, while the mean difference in temperature extremes at vegetated sites varied as much as 2.5 C.

Spoil temperatures to a depth of 4.5 cm were recorded during the afternoons of 5 June and 9 September, 1985. Table 4 presents a comparison of spoil temperatures on a clear June day for three different microsite conditions. C-104 was devoid of vegetation and contained dark colored spoil

Table 4. Spoil temperatures to a depth of 4.5 cm on a clear day, 5 June 1985

Time of Day	C-104* Temperature (C)	C-107** Temperature (C)	C-207*** Temperature (C)
1:00 PM	31.7	31.1	24.4
2:00 PM	32.2	32.2	25.0
3:00 PM	32.2	32.8	25.6
4:00 PM	32.2	33.3	25.6
5:00 PM	31.1	31.7	25.6
6:00 PM	30.0	30.6	25.6

*C-104 was devoid of vegetation; spoil material was mostly clay, and covered with black shale and coal fragments.

**C-107 was devoid of vegetation; spoil material was composed of red clay and sandstone gravel.

***C-207 had a fescue cover which was approximately 75 cm in height on 5 June 1985.

Table 5. Spoil temperatures to a depth of 4.5 cm on a partly cloudy day, 9 September 1985

Time of Day	C-108* Temperature (C)	C-208** Temperature (C)	C-302*** Temperature (C)
12:00 PM	36.1	30.6	37.8
12:30 PM	36.7	30.6	38.9
1:00 PM	36.7	30.0	38.9
1:30 PM	37.8	31.1	40.0
2:00 PM	38.3	31.7	41.1
2:30 PM	38.9	31.7	42.2
3:00 PM	38.9	31.1	42.2
3:30 PM	38.3	31.1	41.7
4:00 PM	37.8	30.6	41.7
4:30 PM	37.8	30.6	41.7
5:00 PM	36.7	30.0	41.1

*C-108 had less than 5% vegetative cover; spoil was composed of clay and sandstone gravel.

**C-208 was coverd with lespedeza and fescue.

***C-302 was devoid of vegetation; spoil was composed of sand and clay with black shale and coal fragments covering the surface.

Table 6. Irradiance (foot-candles) at ground level for a vegetated and an unvegetated microsite on a partly cloudy day, 9 September 1985.

Time of Day	Vegetated Irradiance (ft-c)	Unvegetated Irradiance (ft-c)
12:00 PM	2500	5200
12:30 PM	2300	5100
1:00 PM	2400	5000
1:30 PM	2400	5000
2:00 PM	1600	4000
2:30 PM	1600	3800
3:00 PM	1800	3600
3:30 PM	1600	3200
4:00 PM	1800	3300
4:30 PM	1500	2600
5:00 PM	1200	2000

material. C-107 was also devoid of vegetation, but contained lighter colored spoil material. C-207 had a 75 cm tall fescue cover. Temperature differences between the two barren microsites were less than 1.0 C throughout the afternoon, and both had temperatures 5.5 to 7.0 C higher than the fescue covered microsite. Table 5 compares spoil temperatures on a cloudy, September day under microsite conditions similar to those in Table 4. The temperature differences among the microsites of Table 5 are also similar to those in Table 4 with the unvegetated sites having substantially higher spoil temperatures than the vegetated site.

Daily patterns of changing ambient relative humidity remained fairly constant throughout the summer months. Generally, the ambient relative humidity reached a maximum of about 90% sometime near midnight, and remained at this level until about 8:00 AM, when it dropped abruptly to a low of 50 to 60 percent. Around 4:00 PM the ambient relative humidity would start to rise again until it reached its maximum at about midnight.

Solar insolation was measured on a partly cloudy day, 9 September, 1985. Measurements for one vegetated and one unvegetated microsite were made at half-hour intervals between 12:00 PM and 5:00 PM. Irradiance at the unvegetated site nearly doubled the irradiance at the vegetated site throughout the course of the afternoon, as shown in Table 6.

EDAPHIC PROPERTIES

Although there are many soil properties which affect the growth and development of plants, two of the properties of strip mine spoil most detrimental to plant growth are a low pH and a disproportionate particle size distribution. Low pH can cause toxicity and nutrient deficiencies in plants, and soil texture influences the infiltration, percolation, water storage, aeration, erosiveness and fertility potential of the soil.

Table 7 gives the pH of randomly selected samples taken from the upper 6 cm of spoil material. Four subplots were selected from each quadrat, and the vegetation growing in each subplot is given along with the pH of the spoil. The pH of all twelve samples ranged within the same order of magnitude, the lowest being 2.5 and the highest 3.4. The pH of all twelve samples was acidic enough to be toxic to most plant life. There appears to be no clear correlation between pH and vegetative cover, but the two unvegetated subplots that were sampled had the lowest pH spoil.

Along with pH measurement, analysis of particle size distribution was conducted on the twelve samples. All twelve samples were classified texturally as clay, and the percent total clay of the samples ranged from 40.9 to 70.7 percent. Of the percent total clay in each sample, at least 84.5% of it was fine clay with a particle diameter of .002 mm or less. The samples were highly variable in regard to percent sand, and ranged from 0.3 to 44.0 percent.

VEGETATIONAL ANALYSIS

Vegetational analysis consisted of measurements of two

Table 7. pH of spoil samples taken to a depth of 6 cm from randomly selected subplots.

Subplot	Vegetation*	pH
A-100	*Danthonia* sp. Unidentified Compositae *Pinus virginiana*	3.1
A-201	*Danthonia* sp. *Cladonia cristatella* Unidentified Compositae *Pinus virginiana*	3.1
A-204	*Danthonia* sp. *Cladonia cristatella* *Andropogon virginicus*	3.1
A-310	*Cladonia cristatella* *Danthonia* sp. *Panicum* sp. *Pinus virginiana*	3.2
B-105	*Polygonum pensylvanicum* *Lechea tenuifolia* *Danthonia* sp. *Pinus virginiana*	2.6
B-109	*Bidens polylepis* *Andropogon virginicus*	2.6
B-302	*Danthonia* sp. Unidentified Compositae *Festuca* sp. *Pinus virginiana*	3.4
B-304	*Danthonia* sp. *Lechea tenuifolia* *Andropogon virginicus* *Festuca* sp. *Cladonia cristatella*	2.9
C-100	None	2.6
C-205	*Festuca* sp. *Rosa* sp. *Bidens polylepis* *Solidago* sp.	3.0
C-302	None	2.5
C-303	*Bidens polylepis* *Danthonia* sp.	3.0

*Vegetation for each subplot is listed in the order of greatest to least abundance.

Table 8. Particle size distribution of spoil samples taken to a depth of 6 cm from randomly selected subplots

Sample Number	Percent Total Sand	Percent Total Clay	Percent Fine Clay*	Percent Total Silt	Textural Class
A-100	23.4	45.7	41.0	30.9	Clay
A-201	26.3	40.9	36.8	32.8	Clay
A-204	25.9	47.0	43.0	27.1	Clay
A-310	36.6	44.8	40.8	18.6	Clay
B-105	2.1	65.6	55.4	32.3	Clay
B-109	5.6	59.6	53.5	34.8	Clay
B-302	0.3	61.4	53.2	38.3	Clay
B-304	4.9	67.8	57.6	28.3	Clay
C-100	8.6	66.0	57.8	25.4	Clay
C-205	44.0	45.1	39.0	10.9	Clay
C-302	5.3	70.7	64.1	24.0	Clay
C-303	23.4	47.6	41.1	29.0	Clay

*Particle diameter of .002 mm or less.

components basic to community structure, net biomass production and species composition. Field plot samples were harvested to estimate annual net community biomass production, and field plot measures of species frequency, density (excluding grasses and lichens) and percent cover were made in order to estimate the importance of each community member.

Measurements of biomass production during the 1985 growing season were made in the field, once in the spring and once in the fall. This was done because other studies have shown that the phenology and magnitude of community production can reflect the degree of the community's successional development (Odum, 1960), as well as the adaptive strategies of community members (Hurt and Winstead, 1980). The measurement of biomass production was also made on field plot samples that were grown for 130 days in the laboratory under a moderate temperature and moisture regimen. This was done to test the hypothesis that field conditions of extreme heat and drought are most limiting to the growth and development of established spoil vegetation.

Table 9 lists the weights of the harvested samples used in the estimation of community production and in the controlled microclimate experiment. Mean biomass production during the spring was estimated at 130.6 grams dry weight/square meter. Quadrat A yielded 11% more biomass than quadrat B, but both quadrat A and B yielded over twice the biomass of quadrat C. From the fall harvest, mean annual net

Table 9. Biomass production during 1985 (grams dry weight/meter^2)

Quadrat and Sample No.	Harvest Spring	Growth Chamber	Fall
A-100	47.8	70.4	93.7
A-201	254.2	258.7	205.8
A-204	356.9	286.4	306.0
A-310	14.8	54.4	62.7
$\bar{x}$	168.4	167.5	167.1
B-105	255.5	319.1	575.7
B-109	39.3	112.8	363.8
B-302	250.4	260.0	264.5
B-304	52.2	60.7	56.7
$\bar{x}$	149.3	188.1	315.2
C-205	101.9	230.2	80.6
C-303	46.2	53.8	177.9
$\bar{x}$	74.1	142.0	129.2
Mean Production	130.6	165.9	203.8

production was estimated at 203.8 grams dry weight/square meter. On average, spring biomass production accounted for 64% of the net biomass production for 1985. Net biomass production was negligible on quadrat A after the spring harvest while quadrats B and C showed continued growth of vegetation throughout the summer. Vegetation in quadrat B attained 53% of its annual production during the summer and fall; 43% of the annual production in quadrat C occurred during this time.

Quadrat A samples that were grown under controlled conditions in the laboratory showed no increases in biomass production over the spring and fall harvested field samples of that plot. In quadrat B, laboratory samples produced 40% less biomass than fall harvested field samples. Flowering and senescence of Polygonum pensylvanicum, a major constituent of quadrat B production, occurred in the laboratory samples almost three weeks before it occurred in the field plot samples. In quadrat C, an 11% increase in biomass production occurred in the laboratory samples, as compared to the fall harvested field samples.

Importance values were calculated for each species observed during the study. Plants were divided into four groups: woody plants, forbs, grasses and cryptogams. Table 10 gives the relative values for the frequency, density and dominance of each woody species, along with the importance value. Calculations are based on the combined data of all three quadrats, and importance values are on a scale of 0 to

Table 10. A species list of all woody plants sampled with each respective relative frequency (RF), relative density (RDen), relative dominance (RDom) and importance value (IV)

Species	RF	RDen	RDom	IV
Pinus virginiana	59.9	46.7	35.5	47.4
Elaeagnus angustifolia	10.3	6.5	29.8	15.5
Nyssa sylvatica	1.3	3.8	17.2	7.4
Acer rubrum	10.3	7.5	3.6	7.1
Rosa sp.	2.6	12.1	2.1	5.6
Rubus sp.	6.5	9.3	0.4	5.4
Oxydendrum arboreum	1.3	3.8	6.9	4.0
Ulmus alata	1.3	3.8	3.5	2.9
Quercus sp.	2.6	2.8	0.5	2.0
Liriodendron tulipifera	1.3	1.9	0.2	1.1
Betula sp.	1.3	0.9	0.1	0.8
Rhus copallina	1.3	0.9	0.2	0.8

Table 11. A species list of all forbs sampled with each respective relative frequency (RF), relative density (RDen), relative dominance (RDom) and importance value (IV)

Species	RF	RDen	RDom	IV
Lechea tenuifolia	10.5	53.5	10.9	24.9
Bidens polylepis	21.1	15.5	37.5	24.7
Lespedeza striata	7.3	15.2	10.5	11.0
Polygonum pensylvanicum	4.9	6.4	14.2	8.5
Solidago sp.	14.7	2.8	7.7	8.4
Desmodium sp.	5.7	1.5	7.2	4.8
Eupatorium hyssopifolium	7.3	1.1	3.9	4.1
Unidentified Compositae	10.5	0.3	1.1	4.0
Lespedeza hirta	6.5	1.5	3.8	3.9
Diodia teres	3.3	1.7	1.4	2.1
Aster sp.	4.1	0.4	1.3	2.0
Cassia nictitans	4.1	0.3	0.5	1.6

Table 12. A species list of all grasses sampled with each respective relative frequency (RF), relative dominance (RDom) and importance value (IV)

Species	RF	RDom	IV
Danthonia sp.	35.6	47.6	41.6
Festuca sp.	26.7	51.0	38.9
Andropogon virginicus	15.9	0.6	8.2
Panicum sp.	15.9	0.6	8.2
Aristida sp.	4.9	0.2	2.6
Echinochloa crusgalli	1.0	0.0	0.5

Table 13. A species list of the lichens and bryophytes sampled with each respective relative frequency (RF), relative dominance (RDom) and importance value (IV)

Species	RF	RDom	IV
Cladonia cristatella	55.3	64.7	60.0
Cladonia subtenuis	39.4	34.1	36.8
Unidentified bryophyte	5.3	1.2	3.2

100. Pinus virginiana was by far the most important woody plant found on the site with an importance value of 47.4. Elaeagnus angustifolia was second in importance with a value of 15.5. All other woody species were of relatively minor importance.

Of all the forbs surveyed, Lechea tenuifolia and Bidens polylepis were the most significant species, as shown in Table 11. Lespedeza striata, Polygonum pensylvanicum and Solidago sp. also ranked high in this component of the vegetation.

The grass component of the vegetation was dominated by Danthonia sp. and Festuca sp. Andropogon virginicus and Panicum sp. were also important grasses. The importance values for the grasses are listed in Table 12.

Only three cryptogamic species were observed growing on the study site. The lichen, Cladonia cristatella, was the most prevalent cryptogam, although it was restricted to quadrats A and B. Cladonia subtenuis was next in importance and was restricted almost exclusively to quadrat C. One unidentified moss was also observed growing on the study site. This bryophyte was the least important cryptogam and was restricted primarily to quadrat B. Table 13 lists the importance values for these species.

Importance values were calculated for each of the four plant groups based on their relative frequency and relative dominance (percent cover) within the three quadrats (Table 14). Grasses were highest in importance, followed by forbs,

Table 14. Importance values for each of the four plant groups in the study based on their relative frequency and relative dominance

Plant Group	Importance Value
Woody plants	20.2
Forbs	22.9
Grasses	40.1
Cryptogams	16.8

woody plants and cryptogams.

Table 15 is a compilation of data pertaining to the general vegetational structure within each of the three quadrats of the study. The frequency, density, percent cover and number of species of the four major plant groups are tabulated for each quadrat. From the table it can be seen that woody plants have the greatest frequency, density, percent cover and number of species within quadrat A. In quadrat C, forbs and grasses have the greatest frequency and percent cover. The number of forb species was also highest in quadrat C. The number of grass species in quadrat C was only one less than in quadrat A, due to the presence of *Echinochloa crusgalli* in quadrat A. *Echinochloa crusgalli* was the least important grass species in the study, being present in only one sample. Quadrat B had the least density, percent cover and number of woody plant species. Quadrat B also had the least number and percent cover of grass species. The highest number of cryptogamic species was in quadrat B, but their frequency and percent cover were lowest in this quadrat.

A complete list of all species observed in the three quadrats is given in Table 16. Along with each species, three importance values are listed. Each importance value indicates the importance of that species within a particular quadrat in relation to other members of the same plant group in that quadrat. *Pinus virginiana* was the most important woody plant in both quadrats A and B but was completely

Table 15. Frequency (% of samples containing each plant group), density (#/m^2), percent cover (%/m^2) and number of species in each quadrat

	Frequency		
	Quadrat A	Quadrat B	Quadrat C
Woody plants	60.6	36.4	30.0
Forbs	21.2	60.6	73.3
Grasses	63.6	63.6	70.0
Cryptogams	39.4	30.3	43.3

	Density		
	Quadrat A	Quadrat B	Quadrat C
Woody plants	1.45	0.88	0.95
Forbs	2.09	111.36	69.60

	Percent Cover		
	Quadrat A	Quadrat B	Quadrat C
Woody plants	7.7	3.7	6.9
Forbs	0.2	5.4	13.3
Grasses	16.3	6.5	22.6
Cryptogams	8.1	0.7	5.0
Total cover	32.3	16.3	47.8

	Number of Species		
	Quadrat A	Quadrat B	Quadrat C
Woody plants	8	3	7
Forbs	5	7	11
Grasses	5	3	4
Cryptogams	1	3	2
Total*	19	16	24

*Total number of different species found in all three quadrats was 33.

absent in quadrat C. Of the three most important woody species in quadrat C, two were completely absent from quadrats A and B. The third, *Rubus* sp., was absent from quadrat B and the least important woody species of quadrat A. *Lechea tenuifolia* was the most important forb of quadrats A and B: it was absent from quadrat C. Of the grasses, *Danthonia* sp. was the most important in quadrat A but the least important one in quadrat C. The reverse is true of *Festuca* sp. It was the most important grass of quadrat C but was absent from quadrat A. The two lichens in this study show a pattern similar to that of the previously mentioned grasses. *Cladonia cristatella* was the only lichen present in quadrat A, but it was absent in quadrat C. *Cladonia subtenuis* was the only lichen in quadrat C, but it was absent from quadrat A.

Since it is obvious that there are distinct differences in the species composition of the three quadrats, a coefficient of community index (CCI) was calculated for each of the three possible pairwise comparisons of quadrats. The CCI calculations are based on species frequency data, and the CCI values are on a relative scale of 1 to 100. The higher the CCI value, the greater the similarity between the two communities. Table 17 lists the comparisons and their respective CCI values. Quadrats A and B were the most similar with a CCI of 57.0. The similarities were much lower in the comparisons of quadrats A versus C and B versus C with values of 21.2 and 30.3, respectively.

Table 16. A list of all species observed during the study. The numbers represent the importance values of each species at each quadrat. The species are divided into four groups and listed as follows: woody plants, forbs, grasses and cryptogams. Each importance value is relative to both the quadrat and the plant group to which the species belongs.

		Quadrat		
Family	Species	A	B	C
Pinaceae	*Pinus virginiana*	52.5	72.1	0.0
Elaeagnaceae	*Elaeagnus angustifolia*	13.7	20.5	19.3
Nyssaceae	*Nyssa sylvatica*	0.0	0.0	23.8
Aceraceae	*Acer rubrum*	8.7	7.4	6.5
Rosaceae	*Rosa* sp.	0.0	0.0	23.1
Rosaceae	*Rubus* sp.	2.0	0.0	23.0
Ericaceae	*Oxydendrum arboreum*	9.2	0.0	0.0
Ulmaceae	*Ulmus alata*	6.5	0.0	0.0
Fagaceae	*Quercus* sp.	4.8	0.0	0.0
Magnoliaceae	*Liriodendron tulipifera*	2.6	0.0	0.0
Betulaceae	*Betula* sp.	0.0	0.0	0.1
Anacardiaceae	*Rhus copallina*	0.0	0.0	4.3
Cistaceae	*Lechea tenuifolia*	30.6	52.1	0.0
Compositae	*Bidens polylepis*	17.0	16.2	34.9
Compositae	*Solidago* sp.	6.8	2.1	12.0
Compositae	*Eupatorium hyssopifolium*	0.0	0.0	6.7
Compositae	Unidentified Compositae	26.9	5.0	0.5
Compositae	*Aster* sp.	18.7	1.2	1.6
Leguminosae	*Lespedeza striata*	0.0	0.0	21.9
Leguminosae	*Desmodium* sp.	0.0	0.0	7.9
Leguminosae	*Lespedeza hirta*	0.0	1.2	6.2
Leguminosae	*Cassia nictitans*	0.0	0.0	2.7
Polygonaceae	*Polygonum pensylvanicum*	0.0	22.2	1.3
Rubiaceae	*Diodia teres*	0.0	0.0	4.3
Gramineae	*Danthonia* sp.	76.7	47.8	4.9
Gramineae	*Festuca* sp.	0.0	37.0	76.9
Gramineae	*Andropogon virginicus*	4.6	15.2	6.6
Gramineae	*Panicum* sp.	12.5	0.0	11.6
Gramineae	*Aristida* sp.	4.7	0.0	0.0
Gramineae	*Echinochloa crusgalli*	1.5	0.0	0.0
Cladoniaceae	*Cladonia cristatella*	100.0	78.7	0.0
Cladoniaceae	*Cladonia subtenuis*	0.0	6.0	96.3
	Unidentified bryophyte	0.0	15.3	3.7

Table 17. Vegetational comparisons among the three quadrats using a coefficient of community index (CCI) based on species frequency data. CCI = 100 indicates identical communities; CCI = 0 indicates no common species.

Comparison	CCI
A vs. B	57.0
A vs. C	21.2
B vs. C	30.3

DISCUSSION AND CONCLUSIONS

Alteration of the environmental parameters of the study site, as a result of previous strip mining activities imposes restrictions on vegetational establishment and successional development into a more stable ecosystem. Recovery is slow because only a small fraction of the total area of disturbed land offers favorable sites for the growth and reproduction of any plant species, and because the species adapted to even the most favorable sites are few in number.

Although the temperature data for the study site are incomplete and include only one growing season, they do suggest the possibility of real differences in ambient air temperatures between disturbed and undisturbed areas. Throughout the summer, mean ambient air temperatures on the abandoned strip mine were 1.0 to 1.7 C higher than the 27 year averages recorded at the Greenville Weather Station. Maximum ambient air temperatures on the mine spoil were slightly higher than at the Greenville Weather Station during the first half of the study, but during the second half of the study there was a reversal in this trend. Minimum ambient air temperatures were between 5.0 and 10.6 C higher on the mine spoil during the entire study. If these temperature differences are real, and not just the result of stochastic events in the temperature patterns of one growing season, then vegetational development could be altered by this new temperature regime. An increase in the ambient air temperature will result in a decrease in the relative humidity and an increase in the rate of evapotranspiration on the disturbed site, and these effects will also have a negative influence on vegetational development.

Besides the climatic differences between disturbed and undisturbed lands, many of which have not been addressed in this study, there are important differences in the edaphic properties as well. Spoil material is a heterogeneous mixture of overburden and soil, rather than a highly structured and well defined system comprising distinct horizons of organic and mineral material. Mature soils often require many thousands of years to develop, and they are the product of many chemical and physical processes in dynamic equilibrium. Vegetational development is highly dependent on this equilibrium which is generally lacking in spoil material.

Soil pH is an edaphic property crucial to most vegetational development, because it affects the concentration of both available plant nutrients and toxic metals in the soil solution. Typical soils have a pH in the range of 4.0 to 8.0 (Barbour et al., 1980). A soil pH below the range of 3.5 to 4.0 is classified as toxic to most plant species (Croxton, 1928; Limstrom, 1964). The pH of the twelve samples taken during the study ranged from 2.5 to 3.4 which is well below the typical pH range of soils of the western Kentucky coalfields, and is toxic to most of the plants that would normally colonize the abandoned spoil.

Textural analysis of the field samples revealed the presence of a large proportion of clay in the spoil material. Clay soils are commonly found in this region of Kentucky, so clay texture is not a unique property of the spoil material. However, the fact that the spoil is high in clay content, along with its inherently low pH, may intensify the problem of vegetational establishment for several reasons. Clay is not very permeable to water, and without a vegetative cover, clay spoil loses a large fraction of the available precipitation to runoff. This feature, compounded by a higher ambient air temperature, makes the study site more prone to drought conditions than would normally be expected. Secondly, the extensive erosion that takes place as a result of runoff washes away plant seeds and propagules, and undermines the existing vegetation. Thirdly, leaching of the spoil may be important in purging the system of toxic substances, such as acids and salts. The leaching effects of precipitation are diminished on highly impermeable spoil, because runoff is increased (Croxton, 1928).

Discussion so far has focused on a comparison of the environmental differences that exist between two types of ecosystems. The differences between the two systems are many. One system is fragmented, the result of disruptive activities by man. The other system is unified, the result, for the most part, of the processes of natural selection and evolution.

This idea of a fragmented versus a unified ecosystem brings up another contrasting point in the comparison. One ecosystem is relatively stable and homogeneous in nature, and drastic fluctuations in its environment are not usually evident. The other ecosystem is generally unstable and susceptible to erratic fluctuations in some of its environmental parameters. Results from this study have documented some of the spatial and temporal variations in the environment of an abandoned strip mine. These results can be used to explain, to some degree, the distribution of the vegetation found there.

The results of this study generally agree with the findings of Croxton (1928) in the correlation between the pH and the water permeability of acidic spoil. From Tables 7 and 8 it can be seen that the spoil samples with the lowest pH also had the highest percentage of total clay, but there is one anomaly in the data. Sample B-302, which had the highest pH recorded, also had one of the highest percentages of total clay. Slight differences in the microtopography or chemical composition of subplot B-302 could account for this deviation in the pattern. On the other hand, these data could indicate the absence of any pattern at all. This important question cannot be answered at the present time but merits further investigation because of its importance to land reclamation.

Croxton also concluded that, generally speaking, spoil pH has the greatest impact on the distribution of strip mine vegetation, but that spoil moisture content, which is also related to the permeability of the material, can sometimes override the effects of pH. The results of the present investigation cannot confirm this conclusion. The data in Table 7 indicate that there were no large fluctuations in spoil pH at the Butler County site, so it is impossible to tell if there was any vegetational zonation based on hydrogen ion concentration.

While the spoil material of the Butler County study area has not provided favorable conditions for the growth of most plant species, its texture and pH near the surface have proven to be fairly uniform. The soil component of the substrate is primarily clay, and its pH, though highly acidic, is relatively constant throughout. Superficially, the substrate of this abandoned strip mine appears to be a homogeneous mixture of materials, yet the vegetation that it supports is patchy and sparse. The occurrence of "islands" of vegetation, separated by large expanses of barren spoil, is the most conspicuous feature of this abandoned strip mine. A high degree of variability in the temperature and light intensity of the various microsites within the study area was observed which suggests that microclimate plays an important role in determining the distribution of strip mine vegetation.

Measurements of the minimum and maximum air temperatures at ground level revealed some interesting facts about the various microsites on the abandoned strip mine. Differences were observed in the air temperature extremes of vegetated and unvegetated microsites (Table 3). Vegetated microsites showed larger temperature fluctuations at ground level than unvegetated microsites and almost always attained higher maximum air temperatures than unvegetated microsites.

Tremendous heat loads are placed upon the strip mine ecosystem during the summer months because of the high solar irradiance and sparse vegetation. Even on a cloudy day in September, solar irradiance was as high as 5,200 ft-c in the open areas (Table 6). This is over one-half the average value measured in full sunlight at sea level (Barbour et al., 1980). Because the strip mine vegetation is sparse, and grows low to the ground, irradiance at ground level in the vegetated microsites is still very high. Solar insolation in the vegetated microsites is roughly 50% of the values recorded for unvegetated microsites. The sparse strip mine vegetation does not provide much shading of the ground, but it probably does interrupt laminar air flow over the ground, and this will impede heat exchange by convection. Temperature oscillations are damped both day and night by heavy, continuous plant cover, but the situation may be reversed if the plants are widely dispersed (Barbour et al., 1980).

Table 2 lists the minimum and maximum air temperatures recorded at ground level throughout the summer. Maximum air temperatures in the vegetated microsites were in the range of

34.5-45.5 C. If most of the plant species inhabiting the study site have a C3 photosynthetic pathway, then the optimal temperature range for photosynthesis is 20-30 C (Barbour et al., 1980). Of the grass species inhabiting the abandoned strip mine, only *Echinochloa crusgalli* is known positively to be a C4 plant (Krenzer et al., 1975). The abundance of *E. crusgalli* was extremely low, and the fact that it has a C4 photosynthetic pathway does not appear to be an adaptive advantage at the Butler County study site. Although this is not confirmed, *Andropogon virginicus* and *Panicum* sp. are also likely candidates for a C4 photosynthetic pathway. Teeri and Stowe (1976) suggested that high minimum temperatures during the growing season have the strongest correlation with the relative abundance of C4 grass species in a given floral region, and minimum temperatures at the study site were considerably higher than at the Greenville Weather Station. C4 grasses may be well adapted for growth on some abandoned waste lands, and their relative abundance in those habitats should be measured. *Elaeagnus angustifolia* and *Polygonum pensylvanicum*, both important species in this study, are known to be C3 plants (Krenzer et al., 1975), and it is probable that most of the other forb and tree species are also C3 plants. High air temperatures would reduce photosynthesis and biomass production in the C3 plants. This might explain why the vegetative islands are so slow to expand and grow into a contiguous plant cover.

Another spatial difference in the minimum and maximum air temperatures at ground level was observed during this study. Microsites in quadrat A almost always had the lowest minimum and maximum air temperatures for any given time interval while microsites in quadrat B were just the opposite. Quadrat A was protected on its north and east flanks by a high, steep hill. Along the south flank of quadrat A grew a thick stand of Virginia pines with a height of approximately 6-7 m. The protection from sun and wind that quadrat A received can account for its lower minimum and maximum air temperatures and may contribute to the vegetational differences that were observed there. Quadrat B, on the other hand, was the most exposed quadrat of the three. It received no protection from the sun and wind on its south side and only minor protection on its other three sides. This increased exposure appears to have left its mark on the plant community in quadrat B, as later discussion will reveal.

Spatial variation in the temperature of the upper 4.5 cm of spoil was observed during both a clear day in late spring and a cloudy day in late summer. Tables 4 and 5 list the afternoon temperature changes that occurred in three of the most common types of microsites observed on the abandoned strip mine. Basically, the microsite conditions were as follows: barren spoil covered with a layer of black coal fragments; barren spoil with a surface of red clay and sandstone pebbles; and vegetative islands composed of grasses and a few forbs. Spoil temperature was radically reduced by the presence of a plant cover. Spoil temperatures were as much as 7.5 and 11.0 C lower in the vegetative islands than in the black colored substrates during the spring and summer, respectively. The temperature of the red colored substrate was up to 2 C lower than the temperature of the black colored substrate, but both microsites presented inhospitable conditions for seed germination and seedling development throughout most of the growing season. Temperatures in excess of 42 C were recorded in the black colored spoil during a cloudy day in late summer, so it is reasonable to assume that temperatures can reach even higher values on clear days in midsummer. Bramble and Ashley (1955) recorded spoil temperatures of almost 55 C on the south facing slopes of spoil banks in Pennsylvania. With spoil temperatures this high, it is no wonder that plant colonization is so slow on abandoned strip mines.

Plant colonization of the abandoned strip mine has occurred in small patches. These patches undoubtedly delimit the locations of microsites that were initially the most conducive to plant growth, whereas barren spoil marks the locations of unfavorable microsites. It is a fairly simple task to document environmental differences between vegetated and unvegetated microsites. Conversely, it is a formidable undertaking to recognize the subtle differences that allow plant establishment at one location while preventing it at another location only a few meters away. There is a general lack of knowledge concerning the effects of microsite variation on strip mine revegetation. Analyses of the climatic and edaphic components of microsite variation on disturbed land should provide the information necessary to make land reclamation much more effective.

Biomass production was measured twice at the Butler County study site (Table 9). Mean biomass production during the early spring (approximately the first 42 days of the growing season) was determined to be 130.6 grams dry weight (gdw)/square meter. This was 64% of the estimated mean biomass production for the entire 1985 growing season. In other words, during the first quarter of the growing season nearly two-thirds of the annual biomass accumulation had occurred. After approximately 171 days of growth, mean biomass production at the study site was estimated at 203.8 gdw/square meter which is comparable to the annual production of a semidesert scrub ecosystem (Whittaker, 1975).

Odum (1960) observed changes in the phenology of community production during the early secondary succession of vegetation on old fields in South Carolina. During the first year after abandonment, community production was five times greater in the fall than it was in the spring. In subsequent years there was a gradual shift in biomass production rates from the fall to the spring, resulting in a more even distribution of production throughout the growing season. This pattern of a relatively constant and uniform production rate for the entire growing season was evident within three to five years after field abandonment, and it suggests that the existent environmental conditions in the old fields were fairly stable. The productivity data from this study suggest that even after a period of abandonment of 22 years, the environmental conditions of the strip mine in Butler County are still quite unstable. Temperature and moisture conditions at the strip mine are most favorable during the spring, and many of the plant species found growing there have adaptations which allow them to maximize this brief period of favorable environmental conditions. Bell and Ungar (1981) concluded that in southeastern Ohio, the climatic conditions of the mine spoil during the growing season were more limiting to plant establishment and growth than the edaphic properties of the spoil material. The productivity data from this study generally support that conclusion, with some possible exceptions.

Table 9 lists the estimated production of the vegetation from each quadrat. The figures indicate that annual biomass production at quadrat A was virtually complete within the first quarter of the 1985 growing season. <u>Danthonia</u> sp., which was the most important grass species in the study (Table 12) and the most abundant plant in quadrat A (Tables 15 and 16), matured and set seed during the spring. Since minimum and maximum air temperatures were the lowest at quadrat A, selection of plant species which are best adapted to moderate temperature and moisture conditions may be occurring there.

Annual biomass accumulation was greatest in quadrat B with over half of it produced during the last three-quarters of the growing season. *Pinus virginiana*, *Elaeagnus angustifolia*, *Lechea tenuifolia*, *Polygonum pensylvanicum*, and *Andropogon virginicus* all had their highest importance values at quadrat B, which contained the fewest number of plant species of the three quadrats (Tables 15 and 16). Exposure to the sun and wind was greatest at quadrat B as were the minimum and maximum air temperatures. Since climatic conditions were the most severe at quadrat B, the fewest number of plant species were capable of surviving there. The plants that did grow in quadrat B were adapted to the most marginal climatic conditions and were capable of sustained growth during the hot, dry summer months. The data suggest that the distribution and abundance of plants in quadrat B was no coincidence but was the result of selective pressures imposed upon the plant community by specific environmental parameters.

A greater number of plant species and a consistently smaller biomass accumulation was found in quadrat C than in the other two quadrats. This is somewhat puzzling since quadrat C appeared to be very similar to quadrat B with respect to climatic and edaphic conditions, and yet the vegetation in these two quadrats was markedly different. One possible explanation for this difference is that some plant cover has existed at quadrat C for a longer period of time than it has at the other two quadrats. The vegetation at quadrat C was dominated by grasses and forbs with Festuca sp., Bidens polylepis, Lespedeza striata and Solidago sp. all having their greatest importance values in this quadrat. There are indications which suggest that some attempt was made to revegetate at least parts of the strip mine on areas outside the specific plots in this study. There are some sizable stands of Pinus virginiana and P. taeda growing on the mine spoil, as well as some areas with extensive cover from Elaeagnus angustifolia and Festuca sp. All of these species are commonly used to revegetate strip mine spoil, and their presence on the Butler County study site is surely no accident. If a fescue cover were established in or near quadrat C immediately after cessation of mining operations, then some plant cover has been in existence there for a longer period of time than at the other two quadrats. If this is true, then there has been a longer period of time in quadrat C for the establishment of intermediate successional species which do not normally appear in the community until after the invasion of the first colonizers. The lower biomass production observed at quadrat C may be due to the predominance of Festuca sp. in the plant community there. Festuca sp. may be the dominant community member at quadrat C simply because it was planted there and not because it has the best adaptations for growth at that microsite. Natural selection has probably played a bigger role in determining the community structure in quadrat B than it has in quadrat C. Therefore, it would be reasonable to expect a higher biomass production from quadrat B than from quadrat C, because the plant community at quadrat B is better adapted to its environmental situation.

Because of poor design, an experiment to show the effects of climate on the biomass production of strip mine vegetation provided inconclusive results. The experiment was not begun until 28 May, 1985. By this time in the growing season, the vegetation in the study area had already attained over one-half of its annual biomass production. Some vegetation, especially at quadrat A, had already attained full biomass production for the year before initiation of the experiment. That is why the estimate of biomass accumulation is the same for all three harvests at quadrat A. In quadrat B, the growth chamber samples actually showed a substantial reduction in biomass production when compared with the fall samples that were collected at the same time in the field. The samples from quadrat B contained an abundance of *Polygonum pensylvanicum*, and it was noted during the experiment that plants grown in the environmental chambers completed their life cycles almost three weeks before the field grown plants. *P. pensylvanicum* is probably a long day plant. The 16 hr/day photoperiod of the environmental chambers probably induced the *P. pensylvanicum* plants to flower prematurely, and this may have caused the reduction in biomass accumulation that was observed in the samples from quadrat B. Quadrat C contained the only vegetation that showed a positive response, though only a slight one, to the milder climatic conditions in the growth chambers. Since the majority of the vegetation at quadrat C may have been established artificially, the increased biomass of the samples grown in the environmental chambers may be attributed to the adaptations of some of the community members to milder climatic conditions.

To obtain meaningful results from this kind of experiment, the following steps should be taken: 1) Experimentation should begin no later than mid April; 2) The experimental units should be comprised of individual species, as well as groups of species representing whole communities; and 3) Care should be taken that the climatic conditions in the environmental chambers do not drastically change the life cycles of the species being investigated. The greenhouse is probably a better place to conduct these experiments because it offers the advantages of increased space availability to accommodate a larger number of experimental units. Additionally, it offers a more natural climate, though less rigidly controlled, than do the environmental chambers. Finally, the experiment should include more than one treatment and for each treatment there should be an appropriate control group.

After approximately 22 years of abandonment, a large portion of the Butler County strip mine is only sparsely inhabited by vegetation. Plant succession has proceeded at an extremely slow pace here compared to the expected rate of secondary succession for other ecosystems of similar age.

The plant communities consist primarily of grasses and forbs but tree seedlings and saplings are a major constituent of some of the communities. Important ground cover is provided by lichens in the most sparsely vegetated sites. On a former strip mine in Laurel County, Kentucky, a Virginia pine-mixed hardwoods community was the predominant vegetation type in unplanted areas (Thompson, 1984). This type of community had developed in the 18 years since abandonment of the mine, and it represents a successional sere which has advanced well beyond that of any of the plant communities observed growing in the plots of the Butler County study site.

Of all the woody plant species found growing at the Butler County site, Pinus virginiana had the highest importance value at 47.4, three times greater than the importance value of Elaeagnus angustifolia, the second most important woody species growing there (Table 10). Thompson et al. (1984) also observed that P. virginiana was approximately three times more important than the next leading tree species at the Laurel County site. Nyssa sylvatica and Acer rubrum were two other trees with high ranking importance values at both the Butler County and Laurel County sites.

Overall, the five most important forbs growing on the Butler County strip mine were Lechea tenuifolia, Bidens polylepis, Lespedeza striata, Polygonum pensylvanicum and Solidago sp., respectively (Table 11). Lechea tenuifolia, which forms a mat of only 5-10 cm in height, was the most important forb at both quadrats A and B but was absent from quadrat C (table 16). Quadrat B was the most highly exposed quadrat and had the lowest total ground cover at 16.3% (Table 15). Lechea tenuifolia had its highest importance value at quadrat B, presumably because of a lack of competition for light, and because its low profile is advantageous at highly exposed sites. At quadrat A, total ground cover was still quite low at 32.3%, and L. tenuifolia was the dominant forb there also. In quadrat C, where the total ground cover was nearly 50%, L. tenuifolia probably could not effectively compete for light and was therefore absent from that site. Polygonum pensylvanicum may also be a superior competitor at highly exposed sites due to its low, shrubby, sprawling habit of growth. Polygonum pensylvanicum was restricted almost exclusively to quadrat B. Both Bidens polylepis and Solidago sp. were fairly common in all three quadrats, but both species had their lowest importance values at quadrat B where exposure to the wind was greatest. Lespedeza striata was restricted to the most heavily vegetated sites in quadrat C, possibly because it is adapted to the more moderate spoil temperature and moisture conditions that exist there.

Grasses were the most predominant type of vegetation on the abandoned strip mine in Butler County (Table 14). Andropogon virginicus was the most evenly distributed grass at the study site and was common in all three quadrats. Danthonia sp. and Festuca sp. were almost equally ranked as the two most important grasses, but their distribution was negatively correlated (Table 16). The importance value for Danthonia sp. was highest at quadrat A, and it declined steadily in a westward direction to a low at quadrat C. Almost the exact opposite was observed for Festuca sp. Its importance values went from highest to lowest in an eastward direction, from quadrat C to quadrat A.

The cryptogams showed an interesting pattern of zonation which is evident from the data in Table 16. Cladonia cristatella was the only lichen found in quadrat A; Cladonia subtenuis was the only lichen found in quadrat C. Only at quadrat B were all three cryptogams found growing together. Lichens have been used for many years as ecological indicators, and at least one study has shown a strong correlation between lichen zonation and soil pH (Alvin, 1960). A cline of some type, while not evident from the results of this study, may be responsible for the observed pattern of distribution of grasses and lichens at the abandoned strip mine in Butler County. Further research should be aimed at answering this question, because a better understanding of the factors responsible for vegetational zonation on abandoned strip mines could provide valuable, new insights for future land reclamation strategy.

The results of this study indicate the existence of measurable differences in the microclimates of three sites all located within the proximity of about one hectare of strip mined land. Along with the climatic differences between the sites, differences in the vegetation at each site are also evident. Differences among the three sites in community structure and composition are compared in Tables 15 and 16. As a final measure of the relative difference in the plant communities at each quadrat, a coefficient of community index (CCI) based on species frequency data was calculated for each pairwise comparison of the three communities. Table 17 lists the CCI values for each comparison and is further evidence of the vegetational differences in the three microsites that were studied. The communities in quadrats A and B were the most similar, while both showed much less similarity to the community of quadrat C. These comparisons suggest, once again, that the communities in quadrats A and B might have been naturally established, whereas the community in quadrat C might have been artificially established.

In conclusion, there are indications that the islands of vegetation growing on an abandoned strip mine in Butler County, Kentucky, are actually distinct plant communities, each subject to the influence of a discrete set of environmental parameters. Microclimate plays an important role in defining the distribution, composition and productivity of the plant communities. There is a great need for further research in the area of microsite variability on strip mines, especially climatic variability. Further work is needed to determine how microclimatic variables can be quantified more accurately. The factors that cause microclimatic variability need investigation, along with an identification of the more important ones. How different native species of plants respond to microsite variability should be a priority of future work. Without more complete answers to these questions, a continual deterioration of our land will go unchecked, and we will suffer the loss of some of our most valuable natural resources.

LITERATURE CITED

Alvin, K. L. 1960. Observations on the lichen ecology of South Haven Peninsula, Studland Heath, Dorset. J. Ecol. 48:331-339.

Antonovics, J. 1971. The effects of a heterogeneous environment on the genetics of natural populations. Am. Sci. 59:593-599.

Antonovics, J., A. D. Bradshaw and R. G. Turner. 1971. Heavy metal tolerance in plants, p. 1-85. J. B. Cragg (Ed.), Advances in Ecological Research, Vol. 7. Academic Press, London.

Barbour, M. G., J. H. Burk and W. D. Pitts. 1980. Terrestrial Plant Ecology. Benjamin/Cummings, Menlo Park.

Barnhisel, R. I. and H. F. Massey. 1969. Chemical, mineralogical and physical properties of eastern Kentucky acid-forming coal spoil materials. Soil Sci. 108:367-372.

Bell, T. J. and I. A. Ungar. 1981. Factors affecting the establishment of natural vegetation on a coal strip mine spoil bank in southeastern Ohio. Am. Midl. Nat. 105: 19-31.

Berg, W. A. and W. G. Vogel. 1973. Toxicity of acid coal-mine spoils to plants, p. 57-68. R. J. Hutnik and G. Davis (Eds.), Ecology and Reclamation of Devastated Land, Vol. 1. Gordon and Breach, New York.

Bouyoucos, G. J. 1936. Directions for making mechanical analyses of soils by the hydrometer method. Soil Sci. 42:225-229.

Bradshaw, A. D. 1952. Populations of _Agrostis tenuis_ resistant to lead and zinc poisoning. Nature (Lond.), 169: 1098.

Bradshaw, A. D. and M. J. Chadwick. 1980. The Restoration of Land. Blackwell, Oxford.

Bramble, W. C. and R. H. Ashley. 1955. Natural revegetation of spoil banks in central Pennsylvania. Ecology, 36: 417-423.

Brinson, M. B. 1977. Decomposition and nutrient exchange of litter in an alluvial swamp forest. Ecology, 58: 601-609.

Chapman, R. H. and S. B. Jones Jr. 1975. Ecotypic differentiation in Andropogon virginicus (Gramineae). Bull. Torrey Bot. Club, 102:166-171.

Croxton, W. C. 1928. Revegetation of Illinois coal stripped lands. Ecology, 9:155-175.

Daft, M. J., E. Hacskaylo and T. H. Nicholson. 1975. Arbuscular mycorrhizas in plants colonizing spoils in Scotland and Pennsylvania. Symposium on Endotrophic Mycorrhizas, University of Leeds, (July, 1974). Academic Press, New York.

Deely, D. J. and F. Y. Borden. 1973. High surface temperatures on strip-mine spoils, p. 69-79. R. J. Hutnik and G. Davis (Eds.), Ecology and Reclamation of Devastated Lands, Vol. 1. Gordon and Breach, New York.

Dugan, P. R. and D. G. Lundgren. 1964. Acid production by Ferrobacillus ferrooxidans and its relation to water pollution. Dev. Ind. Microbiol. 5:250-257.

Fernald, M. L. 1950. Gray's Manual of Botany, 8th ed. American Book Co., New York.

Gadgil, R. L. 1969. Tolerance of heavy metals and the reclamation of industrial waste. J. Appl. Ecol. 6:247-259.

Gibson, D. J. and P. G. Risser. 1982. Evidence for the absence of ecotypic development in Andropogon virginicus (L.) on metalliferous mine wastes. New Phytol. 92: 589-599.

Goodman, G. T., C. E. R. Pitcairn and R. P. Gemmell. 1973. Ecological factors affecting growth on sites contaminated with heavy metals, p. 143-173. R. J. Hutnik and G. Davis (Eds.), Ecology and Reclamation of Devastated Land, Vol. 1. Gordon and Breach, New York.

Graham, E. H. 1947. The Land and Wildlife. Oxford University Press, New York.

Gregory, R. P. G. and A. D. Bradshaw. 1965. Heavy metal tolerance in populations of Agrostis tenuis Sibth. and other grasses. New Phytol. 64:131-143.

Harper, J. L., J. T. Williams and G. R. Sagar. 1965. The behaviour of seeds in soil. I. The heterogeneity of soil surfaces and its role in determining the establishment of plants from seed. J. Ecol. 53:273-286.

Hurt, V. K. and J. E. Winstead. 1980. Ecotypic differentiation of broom sedge in relation to strip mine spoil banks. Trans. Ky. Acad. Sci. 41:132-137.

Hyder, D. N. 1969. The impact of domestic animals on the structure and function of grassland ecosystems, p. 243-260. R. L. Dix and R. G. Beidleman (Eds.), The Grassland Ecosystem: A Preliminary Synthesis. Range Science Dept., Science Serial No. 2, Colorado State University, Fort Collins.

Jenny, H. 1941. Factors of Soil Formation. McGraw-Hill, New York.

Jowett, D. 1958. Populations of Agrostis spp. tolerant to heavy metals. Nature (Lond.) 182:816-817.

Krenzer, E. G. Jr., D. N. Moss and R. K. Crookston. 1975. Carbon dioxide compensation points of flowering plants. Plant Physiol. 56:194-206.

Kruckeberg, A. R. 1969. Soil diversity and the distribution of plants, with examples from western North America. Madrono, 20:129-154.

Limstrom, G. A. 1964. Revegetation of Ohio's strip-mined land. Ohio J. Sci. 64:112-119.

Marx, D. H. and W. C. Bryan. 1971. Influence of ectomycorrhizae on survival and growth of aseptic seedlings of loblolly pine at high temperatures. For. Sci. 17:37-41.

Marx, D. H. 1975. Mycorrhizae and establishment of trees on strip-mined land. Ohio J. Sci. 75:288-297.

Odum, E. P. 1960. Organic production and turnover in old field succession. Ecology, 41:34-49.

Ponder, F. 1980. Rabbits and grasshoppers: vectors of endomycorrhizal fungi on new coal mine spoil. Research note NC-250. North Central Forest Experiment Station, St. Paul.

Rice, E. L. 1964. Inhibition of nitrogen-fixing and nitrifying bacteria by seed plants, part I. Ecology, 45: 824-837.

Riley, C. V. 1979. Spoil chemistry as modified by surface topography and precipitation, p. 820-829. M. K. Wali (Ed.), Ecology and Coal Resource Development, Vol. 2. Pergamon Press, New York.

Schramm, J. R. 1966. Plant Colonization Studies on Black

Wastes from Anthracite Mining in Pennsylvania. American Philosophical Society, Philadelphia.

Singer, P. C. and W. Stumm. 1970. Acid mine drainage: The rate limiting step. Science, 167:1121-1124.

Smith, R. L. 1980. Ecology and Field Biology, 3rd. ed. Harper & Row, New York.

Smoliak, K. S., M. Bjorge, D. Penny, A. M. Harper and J. S. Horricks. 1981. Alberta forage manual. Alberta Agriculture, Agdex 120/20-4.

Sterling, A., B. Peco, M. A. Casado, E. F. Galiano and F. D. Pineda. 1984. Influence of microtopography on floristic variation in the ecological succession of grassland. Oikos, 42:334-342.

Teeri, J. A. and L. G. Stowe. 1976. Climatic patterns and the distribution of C4 grasses in North America. Oecologia, 23:1-12.

Thompson, R. L., W. G. Vogel and D. D. Taylor. 1984. Vegetation and flora of a coal surface-mined area in Laurel County, Kentucky. Castanea, 49:111-126.

United States Environmental Protection Agency. 1984. Report to Congress: nonpoint source pollution in the United States, 139 p. Prepared by the United States E. P. A., Office of Water Program Operations, Water Planning Division, Washington, D. C.

Whittaker, R. H. 1975. Communities and Ecosystems, 2nd. ed. Macmillan Publishing Co., New York.

Wilkins, D. A. 1957. A technique for the measurement of lead tolerance in plants. Nature (Lond.) 180:37-38.

Winstead, J. E. 1962. The revegetation of strip-mined spoil banks near McArthur, Ohio. M. S. Thesis, Ohio University, Athens.

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