To the Graduate Council:

I am submitting herewith a thesis written by Anne Smith Stocum entitled "Natural Vegetation and Its Relationship to the Environment of Selected Abandoned Coal Surface Mines in the Cumberland Mountains of Tennessee." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Ecology.

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Edward E. C. Clebsch, Major Professor

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NATURAL VEGETATION AND ITS RELATIONSHIP TO THE ENVIRONMENT OF SELECTED ABANDONED COAL SURFACE MINES IN THE CUMBERLAND MOUNTAINS OF TENNESSEE

A Thesis

Presented for the

Master of Science

Degree

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ABSTRACT

The vegetation of eight abandoned coal surface mines (12-23 yrs. old) and the surrounding undisturbed vegetation of selected mines were studied. The mines were restricted to elevations approximating 610 m and south to west slope aspects. Fifty-five plots (110-350 m^2) were distributed in a stratified random manner on the mines and stem counts in 2.5 cm size classes by species within these plots were used to estimate the basal area and density of the canopy trees (> 2.5 cm DBH) and the density of the understory (shrubs and trees < 2.5 cm DBH and > 1 m tall). The percent cover of the ground cover species (< 1 m tall) was estimated in 1 m^2 plots distributed within the larger plot. Environmental variables such as slope aspect and angle, spoil pH, texture, color and particle size distribution, plot distance from the highwall and relief position were recorded for each plot.

Cluster analysis of species' importance values (IV) based on the sum of relative density and relative basal area revealed the presence of five types in the canopy: Tulip Poplar, Black Locust, Red Maple, Pine-Red Maple-Black Locust and Shortleaf Pine. Discriminant analysis of species' IVs confirmed the integrity of these types. Reciprocal averaging of species' IVs and discriminant analysis of the environmental variables in each type suggested correlation of the canopy vegetation with spoil pH, relief position (bench, crest of spoil bank or outslope) and slope angle measured perpendicular to the contour. Spoil pH is an indicator of nutrient availability and relief and slope angle were assumed to be primarily indicators of spoil moisture availability.

A similar analysis of the understory revealed six types: Blackberry, Catbrier, Red Maple, Red Maple-Blackberry, Red Maple-Liana and Tulip Poplar. Discriminant analysis of environmental variables and reciprocal averaging of species relative densities suggested correlation of the understory to percent canopy closure, spoil pH and available spoil moisture.

Common ground cover species were _Acer rubrum_, _Andropogon virginicus_, _Aster spp._, _Eupatorium purpureum_, _E. rugosum_, _Helianthus microcephalus_, _Lonicera japonica_, _Microstegium vimineum_, _Panicum spp._, _Parthenocissus quinquefolia_, _Rhus radicans_, _Solidago caesia_ and _S. flaccidifolia_. Reciprocal averaging of the ground cover species was hampered by a quadratic relationship between the first and second axis. The resulting arch was removed with detrended correspondence analysis. The sample first axis correlated with spoil pH and the species ordination suggested a response to spoil moisture availability. The second axis remained largely uninterpretable.

Comparison of mine vegetation with the surrounding undisturbed forest was performed by sampling the undisturbed vegetation of six mines (27 400 m^2 plots). Generally these stands were dominated by _Quercus prinus_ with _Q. rubra_, _Liriodendron tulipifera_ and _Acer rubrum_ also important. Species reciprocal averaging of the combined mine and undisturbed samples (in presence/absence mode) separated the species which are more shade tolerant and less adapted to long distance dispersal (characteristic of the undisturbed forests) from those which are less shade tolerant and adapted to long distance dispersal (characteristic of the mine vegetation). Generally, the mine vegetation was reflective of the surrounding seed sources available in the undisturbed forest. The effect of local seed sources on the distribution of the species may be important.

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CHAPTER I

INTRODUCTION

Coal mining in Tennessee has been practiced since early in the nineteenth century but significant production was not achieved until the middle of that century. From that time until the 1940's, mining was performed almost exclusively underground. With the advance in design of earthmoving equipment, surface mining became feasible and since then has contributed a large portion of the total output of Tennessee coal (Luther 1959) and has dramatically changed the character of the landscape in the Cumberland Mountains. Reclamation of surface mines has been required by law since 1967 but prior to that time the areas were left to revegetate naturally.

Little has been published concerning natural revegetation of surface mines in the Cumberland Mountains of Tennessee. The objectives of this study were to describe the vegetation of abandoned or "orphan" surface mines of a restricted type and location and to relate the pattern of the vegetation as much as possible to the environmental pattern of the mine. Additionally, it was hoped that the study would reveal some interesting perspectives on patterns and rates of succession on these ecologically unique areas. These objectives were met through a stratified random sampling of the vegetation and the environment of selected orphan mines and their surrounding vegetation. Multivariate numerical techniques were used to reveal the pattern in the vegetative and environmental data sets and conclusions were based primarily on those results.

CHAPTER II

REVIEW OF SELECTED LITERATURE

Mining Methods

Overlying the relatively thin layered Pennsylvanian aged coal beds of the Cumberland Mountains are sedimentary rocks (shales, siltstones and sandstones) of continental origin (Englund 1968). The coal beds and their associated strata occur in generally horizontal, parallel beds, with coal seams separated by as little as 7 m (Luther 1959). In areas of high relief such as the Cumberland Mountains, contour surface mining is practiced. The mining operation removes the coal in a strip which follows the contour of the mountain. To remove the coal, large amounts of the overlying material, the overburden, must be removed. Until recently, the overburden was pushed over the side of the mountain forming long, steep and sometimes unstable slopes, termed outslopes. As the coal is removed, a flat area, the bench, is formed and the last cut into the mountain leaves a vertical wall, the highwall [in steep areas, there is usually only one cut made (Englund 1968)]. In the Cumberlands, these operations are generally performed with bulldozers and power shovels. Additionally, the coal seams may be augered, a process which involves drilling laterally into the coal seam to reach coal which is located beneath overburden too thick to remove economically.

Physical and Chemical Properties of Spoil

The following descriptions of the physical and chemical properties of spoil banks are derived from studies of eastern surface mines and with few exceptions these studies were conducted on bituminous coal mines.

The spoil bank consists of a heterogeneous mixture of easily weatherable shales, weather-resistant sandstone fragments, coal and soil. This mixture of variable material causes chemical conditions which change very rapidly over the surface of the spoil bank (Kohnke 1950, Miles et al. 1969). The strata associated with the major coal seam or with a rider seam are usually dark shales which contain variable amounts of acid producing pyrite (FeS_2) (Limstrom 1960, Berg and May 1969, Cornwell 1971). In the above described method of mining, these potentially toxic shales would often be the last material dumped onto the newly created spoil bank, forming a chemically toxic surface layer upon which plant colonization must occur. In addition, high surface temperatures associated with the dark gray to black shales present the possibility of heat injury to seedlings, as described by Schramm (1966) and Thompson and Hutnik (1972) on anthracite coal breaker refuse and by Deely and Borden (1969) on central Pennsylvanian surface mines. Toxicity may be associated with other strata, such as sandstones, which cannot be identified by color and which may be found 3-7 m above the commercial coal seams (Berg and May 1969).

The spoil material weathers rapidly. The fraction of spoil material which consists of soil size particles is most often 35% to 70% by weight (Cummins et al. 1965, Olok 1967, Beyer and Hutnik 1969, Byrnes and Miller 1969, Sobek 1972, Plass and Vogel 1973), and is well above the 20% lower limit cited by Bramble (1952) for successful establishment of vegetation. The texture of the soil fraction is usually loamy but ranges from sand to clay (Cummins et al. 1965, Olok 1967, Barnhisel and Massey 1969, Beyer and Hutnik 1969, Byrnes and Miller 1969, Sobek 1972).

The moisture relationships of the spoil banks are complex and not much quantitative data are available. Schramm (1966) felt that moisture was adequate for plant growth on coal breaker refuse based on a series of experiments with seedlings and observations of mature trees. Stiver (1949) concluded that spoil banks are well supplied with soil moisture because of large pores in the bank which break capillarity and allow local accumulations of nearly tension-free water. Tryon and Markus (1953) and Smith et al. (1971) who worked on iron ore spoil banks also indicated that spoil moisture is adequate in spite of the coarse texture of material and may be greater than undisturbed soil in dry years. Thompson and Hutnik (1972) found constant adequate moisture levels on refuse banks below a shallow dry layer. Limstrom (1952) gathered quantitative data on moisture conditions of spoil banks by measurement of electrical resistance through plaster of Paris blocks imbedded in spoil banks at 6 and 12 inch depths. In the experimental areas in Ohio, which were not subject to any periods of extended wet or dry weather, the ungraded spoil banks had conditions too wet or too dry less than 10% of the time, with the 12 inch depths generally wetter than 6 inch depths. Sobek (1972) found in laboratory tests that available water (volume at the one-third bar tension) of the spoil fraction < 6.35 mm in diameter compares well with a gravelly soil but was much less than a stonefree natural surface soil.

Many investigators have found that spoil reaction is associated with poor growth of plants in the field (Croxton 1928, Kohnke 1950, Finn 1958, Brown and Tyron 1960, Limstrom 1960, Miles et al. 1969, Smith et al. 1971). This is not usually because of the direct effect of H ion concentration on plants which has been shown by Arnon and Johnson (1942) to only occur at extremely low pH values (< 4.0) but because of the indirect effect of H ions on the solubility of essential nutrients and toxic ions (Truog 1946). Even on so-called toxic spoil banks (pH < 4.0) (Cummins et al. 1965, Olok 1967, Beyer and Hutnik 1969, Sobek 1972), the direct effect of H ion concentration cannot be separated from the indirect effect on solubility of ions (Wilde 1954). However, Beyer and Hutnik (1969), in nutrient solution experiments with _Betula pendula_, _B. lenta_, _Pinus sylvestris_, and _P. resinosa_ found that a decrease in growth due to H ion concentration occurred at pH 3.0-3.5 in _Betula spp_. and 2.5-3.0 in _Pinus spp_.

The source of extreme acidity in surface mine spoil is the oxidation of FeS_2 to H_2SO_4 through a series of complex reactions (Belly and Brock 1974). The chemical oxidation of FeS_2 is aided by _Thiobacilli_ bacteria which may accelerate acidification by a factor of 10^6 (Singer and Stumm 1970). In the absence of FeS_2 containing rocks (e.g. pyrites), pH values commonly exceed 5.0.

Extreme acidity may develop rapidly on fresh spoil if pyritic material is present (Massey and Barnhisel 1972). Because of the intense weathering associated with extreme acidity, leaching of large amounts of soluble salts (75,600 lbs/4 acre-ft.) may occur (Struthers 1964). The pH of the spoil banks may then increase with time as the products of sulfide oxidation are neutralized. Geyer and

Rogers (1972) found that the mean pH of a single spoil bank increased from 5.6 to 6.1 over a period of 20 years while Limstrom (1960) reported an increase in pH in a single spoil bank that raised the classification of the bank from toxic (< 75% of the area with pH > 4.0) to acid (> 50% of the area with pH 4.0-6.9) after eight years.

Most information on the nutrient status of spoils is from spoil banks which are considered to be barren or toxic and so can only be applied to the more general range of orphan mines with caution. In addition, variations in analytic procedure and assignment of toxic levels make comparisons between studies difficult. Further, most investigators have found element concentrations of spoil banks to be highly variable.

Generally, samples with low pH values are most likely to contain toxic levels of Al (Lowry 1961, Struthers 1964, Berg 1965, Cummins et al. 1965, Olok 1967, Cornwell and Stone 1968, Beyer and Hutnik 1969) and Fe (Lowry 1961, Cummins et al. 1965, Olok 1967, Barnhisel and Massey 1969). In a species by species comparison, Lawrey (1977a) found generally higher levels of Fe, Al and Zn in plant tissues of an acid strip mine area than an adjacent unstripped area and Lawrey (1977b) reported higher levels of Fe and Zn in the strip mine spoil than the soil.

Manganese has been implicated as a potentially toxic element on some surface mines but its relationship to pH is less clear (Lowry 1961, Berg 1965, Cummins et al. 1965, Barnhisel and Massey 1969, Thompson and Hutnik 1972, Lawrey 1977c) although Berg and Vogel (1968) found pH to be a good predictor of Mn toxicity in legumes, including *Robinia pseudo-acacia*.

Suspected toxic levels of Zn, Cu and Ni have been found in East Kentucky spoil banks by Massey and Barnhisel (1972) at low pH values (< 3.0) not commonly encountered on surface mines.

A low Ca to Mg ratio in spoil banks has been noted frequently in the literature (Struthers 1964, Cummins et al. 1965, Olok 1967, Barnhisel and Massey 1969, Sobek 1972) and has been associated with low pH values (< 4.0) in several instances (Struthers 1964, Olok 1967, Barnhisel and Massey 1969).

Phosphorus is commonly cited as a limiting element on spoil banks (Cummins et al. 1965, Berg and May 1969, Beyer and Hutnik 1969, Sobek 1972, Sturm 1973, Plass and Vogel 1973, Ott 1978), but it has also been found in higher concentrations on stripped areas than surrounding undisturbed soils (Geyer and Rogers 1972, Lawrey 1977c). Interestingly, Cornwell and Stone (1969) found that foliar P concentrations of gray birch (<u>Betula populifolia</u>) were highest on the most acid spoil of their study area, apparently due to intense acid weathering of the freshly exposed spoil material. On the other hand, Cummins et al. (1965) and Beyer and Hutnik (1969) found that spoil bank P concentrations were lower on toxic (i.e., more acid) banks than the nontoxic banks.

Potassium levels in spoil banks are reported in levels considered low (Cummins et al. 1965, Sobek 1972, Ott 1978) to adequate (Cummins et al. 1965, Plass and Vogel 1973).

Nitrogen levels are low on surface mines and may limit the growth of some species (Cummins et al. 1965, Berg 1969, Schramm 1966, Olok 1967, Beyer and Hutnik 1969, Plass and Vogel 1973). The source of N in spoil banks may be explained by traces of organic matter from the surface soil which is mixed into the freshly crushed rocks of the spoil bank during mining, by external abiotic and biotic inputs (Schramm 1966) and under intense acid weathering conditions, by release of fixed ammonium through destruction of silicate lattices in shales (Stevenson 1959, Cornwell and Stone 1968).

Obviously, the response of a plant growing on a surface mine is much more complex than single element analyses will ever adequately explain. Interactions between some elements are relatively well researched in terms of plant uptake (e.g., Al and P) but many other relationships most likely exist which have not been adequately investigated (Cummins et al. 1965, Cornwell and Stone 1968). In addition, differential species or even species variety response to nutrient levels confound the issue (Ligon and Pierre 1932, Vose and Randall 1962, Foy et al. 1965, Beyer and Hutnik 1969, Berg and Vogel 1968, Cornwell and Stone 1969, Sturm 1973).

Natural Revegetation

Most published studies of natural succession on surface mines have been conducted on area surface mines, a type of mining not possible in landscapes of great relief. This method of mining results in a series of parallel ridges and valleys, possibly consisting of hundreds of acres (Riley 1975). Both area mining and contour mining result in masses of unconsolidated material, containing very little soil and therefore virtually no viable buried seed. Only at the edge of the disturbance, where undisturbed vegetation is in contact with spoil or where native soil is exposed in the spoil bank, is vegetative reproduction possible or buried seed a potential for colonization.

The main difference between area surface mines and contour surface mines is their aerial extent and thus their proximity to seed sources. The periphery of the area mines is more apt to receive larger numbers and kinds of seeds than the central areas, resulting in a relatively richer flora on the edges of the mine (Deitschman and Lane 1952, Cornwell 1971).

Because of this lack of buried seed or vegetative propagules, it is not surprising that the most commonly occurring species on surface mines are those whose seeds are wind or bird disseminated. For example, in Pennsylvania, the most common woody plants on surface mines are *Betula* spp., *Populus* spp., *Acer rubrum*, *Prunus pensylvanica*, *Rubus* spp., and *Rhus* spp. The most common herbs are *Aster* spp., *Solidago* spp., *Erechtites hieracifolia*, *Lysimachia quadrifolia*, *Hieracium* spp., *Potentilla canadensis*, and *Viola* spp. along with *Carex* spp., and grasses such as *Agrostis* spp., *Danthonia spicata*, *Panicum* spp. and *Poa compressa* (Bramble and Ashley 1955, Cornwell 1971).

In most areas studied (Ohio, Pennsylvania and Indiana), woody species invade the surface mines along with herbs and grasses within the first 1-3 years after mining, the young community becoming dominated by tree species (Merz and Plass 1952, Bramble and Ashley 1955, Byrnes and Miller 1969, Cornwell 1971). Croxton (1928), however, studied spoil banks in Illinois and described succession which proceeded from a smartweed stage (dominated by *Polygonum pensylvanicum*) to a sweet clover (*Melilotus alba*) stage within 5 years on areas with neutral or slightly alkaline pH. Trees and shrubs invaded with the herbaceous vegetation but tended not to dominate the vegetation, instead they grew in open stands. On acid areas, no distinct herbaceous stages were described, the smartweed stage persisting while being invaded by acid tolerant cottonwood (*Populus deltoides*) and sycamore (*Platanus occidentalis*). The underlying reason for the differences in early succession between Croxton's study and others may be due to chemical characteristics of the spoil in the Illinois study area which promoted the rapid development of dense herbaceous vegetation or to differences in seed source availability.

Controlling successful germination and establishment of the seed which reaches the surface mine are factors such as surface temperature and surface spoil moisture (Bramble and Ashley 1955, Brewer and Triner 1956, Schramm 1966), as well as slope instability and soil reaction (Croxton 1928, Bramble and Ashley 1955, Brewer and Triner 1956, Brown and Tryon 1960). The spoil material is very heterogeneous. Within a few decimeters, surface chemical, temperature and moisture conditions may change significantly. On a larger scale, the general relief patterns of the mines make seedling establishment more likely in some areas than others. As a result of this heterogeneity, a common pattern of distribution on surface mines is one of isolated stands of vegetation separated by bare areas or vegetation of a much younger successional age (Deitschman and Lane 1952, Brown and Tryon 1960, Limstrom 1960, Byrnes and Miller 1969). Once the most favorable areas for seedling establishment are colonized, the earliest colonizers may act as nurse plants, relieving some of the surface adversity and allowing continued colonization (Deitschman and Lane 1952, Schramm 1966). Brierley (1956) noted the importance of stabilization of heaps by individual plants which then provided suitable microhabitats for germination of other species and Schramm (1966) demonstrated the importance of shading and litter accumulation in the germination of *Betula* seedlings on coal waste heaps affected by high surface temperatures.

Cornwell (1971) found single aged stands of *Betula populifolia* on acidic shale spoil banks in eastern Pennsylvania, indicating that most colonization took place over a narrow time interval. Cornwell offers two possible explanations: the pattern may be the result of acidification of spoil materials and consequent intense weathering and leaching which produced adverse physical and chemical conditions a short time after mining; alternatively, good seed years or favorable moisture conditions over a short span of years may have fostered the colonization over a narrow time interval.

In a study of natural revegetation of spoil banks in central Pennsylvania, Ashley (1950) found a similar situation. Aspen (*Populus spp.*) reached peak colonization 2-3 years after mining on a variety of spoil banks of varying ages. Following this period, a greatly decreased colonization rate occurred even though surface cover was low, less than 40% on the 10 year old mine. In addition, in spoil banks ranging in age from 2-29 years in age, percent stocking (percent milacre plots containing any vegetation) did not increase with age. Ashley speculated that the decrease in colonization rate was due to development of surface adversity as a result of the longer period of intense weathering.

Mycorrhizae may also be important in establishment of vegetation on mine spoils. On coal mine spoils in eastern states, Marx (1975) found that several pine and birch species, including *Pinus virginiana* were infected with Pisolithus and P. tinctorius has been identified on surface mines in Tennessee (Hile and Hennen 1969). Schramm (1966) demonstrated that plants infected with ectomycorrhizae exhibited better growth characteristics than individuals not ectomycorrhizal on anthracite spoil wastes and speculated that this may be due to increased ability of mycorrhizal plants to absorb N.

Endomycorrhizally infected individuals of such species as Apocynum cannabinum, Festuca arundinacea, Hieracium spp., Panicum clandestinum, Potentilla erecta, Robinia pseudo-acacia and Rubus spp. were found on anthracite spoil in Pennsylvania (Daft and Hacskaylo 1976). Endomycorrhizae have been shown to enhance red maple seedling growth on anthracite spoil, possibly due to the endomycorrhizal seedlings' increased ability to absorb P (Daft and Hacskaylo 1977).

Descriptions of natural revegetation of surface mines in the Cumberland Mountains of Tennessee are very limited. In a study closest in kind to the present one, Evans (1975) investigated a naturally revegetated 18 year old mine in the Cumberland Mountains of Morgan County, Tennessee, at approximately 550 m in elevation. Evans found differences in stand composition due to aspect and relief position on the mine: bench (sample including portions of the spoil bank and colluvial material of the highwall), top of spoil bank and mid-outslope. Liriodendron tulipifera was abundant on all relief positions on the north aspects, Acer rubrum was important on the bench of the south aspects and Pinus echinata was abundant on top of the spoil bank and outslope on south aspects. Other species noted were Robinia pseudo-acacia, Rhus spp., Prunus serotina, Nyssa sylvatica, Fraxinus, Sassafras albidum, Oxydendrum arboreum and Salix spp.

Also in the Cumberland Mountains of Tennessee, but on a toxic, low elevation surface mine Ott (1978) noted the following naturally invading species: on drier sites--*Pinus virginiana*, *Phytolacca americana*, *Smilax bona-nox*, *Aster pilosus*, *Daucus carota*; on hydric sites surrounding water impoundments--*Typha latifolia*, *Carex spp*., *Cyperus spp*. and *Polygonum pensylvanicum*.

CHAPTER III

STUDY AREA

The study sites are in the section of the Cumberland Mountains to the southwest of the Jacksboro fault and northwest and west of Pine Mountain, designated as the Wartburg Basin by Wilson et al. (1956) (Figure 1). The area is characterized by a dendritic drainage system and deep V-shaped valleys which cut into the nearly horizontal beds of shale, siltstone and sandstone (Englund 1968). Climatic data recorded at three nearby weather stations and their locations are summarized in Appendix A (Table 16, Figure 33). The mean January temperature was 3.6°C, the mean July temperature was 24°C. Precipitation averaged 12.3 and 12.1 cm for January and July, respectively (U.S. Dept. Agric. Weather Bureau 1960, U.S. Dept. Commerce Weather Bureau 1961-1965, U.S. Dept. Commerce Environmental Sciences Administration 1966-1970, U.S. Dept. Commerce National Oceanic and Atmospheric Administration 1971-1978).

The vegetation of the study area is included in the Mixed Mesophytic Forest Region of Braun (1950). However, Braun considered the Wartburg Basin to be an outlier section which did not as often support the rich forests of the Mixed Mesophytic type and its mesic segregates, noting the greater preponderance of _Quercus prinus_ dominated forests in this region. Of course, Braun's descriptions refer to the original forests of the area which have been disturbed to varying degrees by chestnut blight, logging, fire and settlement; the present day forests will be described in more detail in a later section.

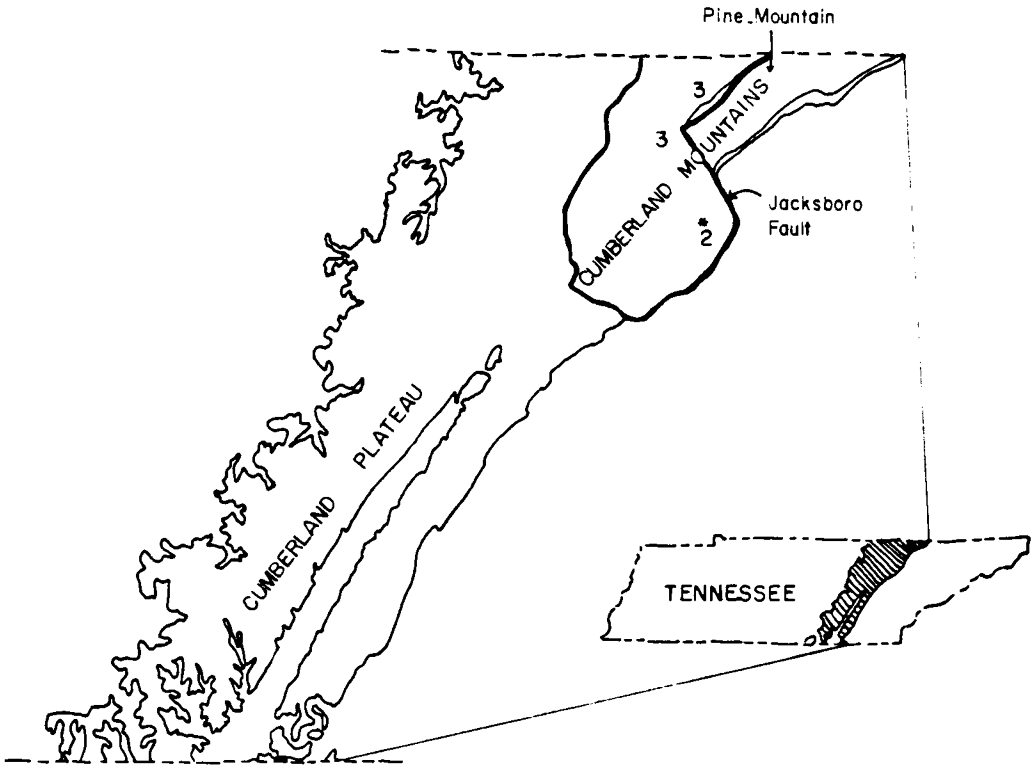

Figure 1. Map of the Study Area. The Wartburg Basin is outlined in heavy line. The numbers refer to the number of sites in a local area. The star indicates the location of Cross Mountain.

The Pennsylvanian aged rocks of the Cumberland Mountains are members of the upper shaley sequence of the Pottsville series as defined by Wilson et al. (1956). This upper shaley sequence was further divided into six groups. Of interest to this study are the uppermost portion of the Graves Gap Group and the Redoak Mountain Group (Figure 2). This delineation includes the three coal seams encountered in this study: Windrock, Big Mary and Red Ash. Other coal seams encountered in this sequence rarely are of commercial importance. The upper portions of this sequence are often near the tops of the mountains which, in this area, only occasionally exceed 800 m in elevation except in the vicinity of Cross Mountain. Thus, of the eight mines studied, six were within approximately 120 m of the original tops of their mountains. The other two (mines 5 and 6), located on Redoak Mountain in the vicinity of Cross Mountain, were approximately 300 m from the top of the mountain. This difference has a profound effect on the nature of the surrounding vegetation, a factor which will be discussed in a later section. See Appendix B (Figures 34-36) for the location of the eight study sites.

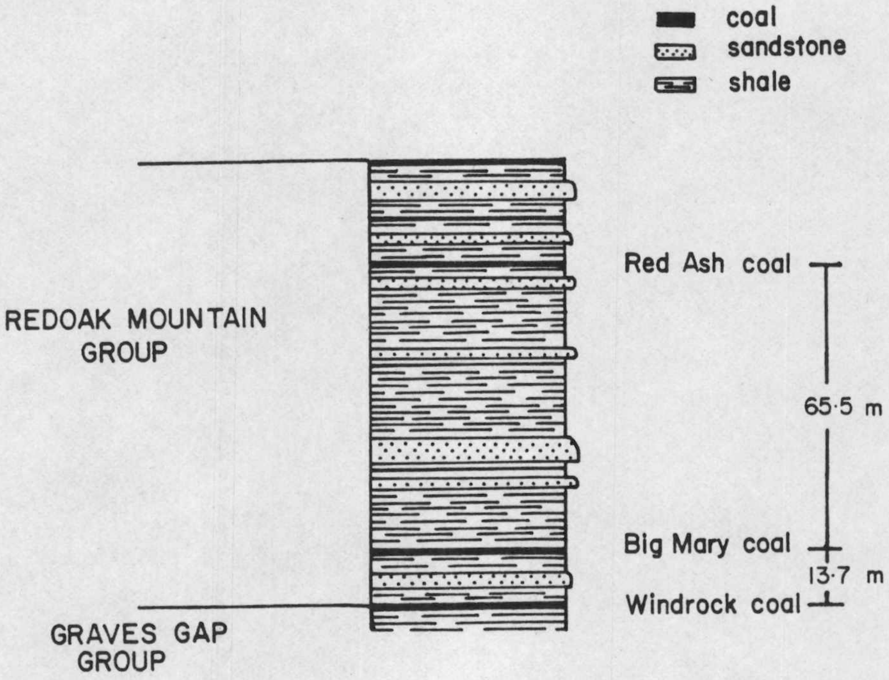

Figure 2. Generalized Geologic Sequence in Study Area. Windrock coal seam is located at approximately 600 m elevation. Adapted from Wilson et al. (1956).

CHAPTER IV

METHODS

Site Selection

Sites selected were restricted to mines meeting the following criteria: no evidence of reclamation, approximately 610 m elevation and a south to west aspect (180°-270°). The site selection was aided by 7.5 minute topographic quadrangle maps provided by the Tennessee Valley Authority Orphan Mine Reclamation Project upon which all orphan (abandoned), reclaimed and active mines in the Tennessee Cumberland Mountains were mapped. Field data were obtained in the summers of 1978 and 1979.

Because of the great rate of remining of orphan mines, the number of sites meeting the above criteria was limited and consequently most areas located and determined to be accessible were sampled. Because of the reclamation laws passed in 1967, mines were restricted in age to those at least 11 years old. However, several very recent wildcat (illegal) mines were located during the study period which provided information on very early periods of colonization. The ages of the eight sites selected for study, at the time of sampling were 12, 15, 15, 18-19, 21, 21, 22 and 22 years.

Sampling Design

On each site selected three transects were established perpendicular to the highwall. The location of each transect was established in the following manner: after finding an accessible point to the mine, the mine was walked until reaching an aspect of south to west in an area which did not have water impounded next to the highwall and which showed little disturbance since mining. The rationale for these last criteria was to avoid confusing temporal heterogeneity within a mine with spatial heterogeneity. Thus, an area next to the highwall which had experienced a massive landslide or other disturbance was avoided because of the impossibility of dating the disturbance. Once the first transect was established, subsequent transects were established in the adjacent area which met the above criteria. Each transect was located (with one exception) at least 60 m from the preceding transect. An ideal transect would have three plots placed along it, one immediately at the highwall (bench plot), one on top of the spoil bank (crest plot) and one on the middle of the outslope (outslope plot) (Figure 3). The bench plot included, primarily, the vegetation growing in the colluvial material forming at the base of the highwall as the result of its weathering. However, a portion of the pit area, defined as the area between the spoil bank and the colluvium from the highwall, usually was also included in the bench sample. The end of the outslope was defined by the usually obvious break between the young trees of the mine and the mature forest. However, an occasional large tree would survive the mining intact or would root sprout in the outslope area and would subsequently be included in this sample.

The ideal transect was not always completed because of a variety of disturbances which may have occurred since mining. For example, a road located along the top of the spoil bank would preclude sampling this area while small scale deep mining might preclude

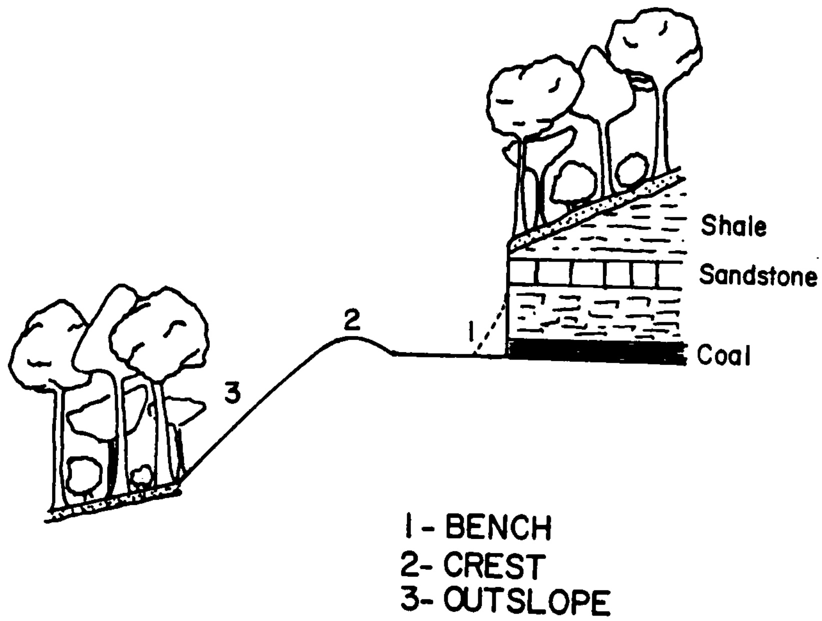

Figure 3. Schematic Profile of Orphan Surface Mine Showing Plot Positions within Transects.

sampling the bench. See Appendix B (Table 17) for the distribution of sampling on each mine.

The plots consisted normally of five circular contiguous subplots, each approximately 50 m^2 in size. The size of the subplots in bench plots was sometimes decreased to 28 m^2 and the number of subplots increased to seven to accommodate a narrow bench. The plots on mine 3 were increased to include seven 50 m^2 subplots because of the very low density of stems on this mine. Because of the severe restrictions imposed by the sampling design, it was not always possible to find an area, particularly on the bench, large enough to accommodate a plot of 250 m^2 in size; therefore, in a few cases the plot size was decreased (by decreasing the subplot number). However, only plots greater than 110 m^2 were used in the analysis.

Within each plot, all trees and shrubs greater than 1 m tall were tallied by species in 2.5 cm size classes. Percent cover of individuals less than 1 m tall (ground cover) was sampled in 1 m^2 plots distributed evenly throughout the plot. At the outset of sampling, 2 m^2 plots/subplot were sampled. The sampling intensity was increased to 3 m^2 approximately one quarter of the way through the sampling period to accommodate the heterogeneity of the ground cover. Percent cover by species was estimated using the Braun-Blanquet cover-abundance scale (Mueller-Dombois and Ellenberg 1974). For analysis, the midpoints of the cover classes were used and the covers in the m^2 plots were averaged for each 250 m^2 plot.

The density and basal area of each species were relativized by sample totals in each plot to relative density (RD) and relative basal area (RBA), respectively. The addition of RD and RBA yielded an importance value (IV) for each species. Species constancy was calculated as percent occurrence in all stands sampled. The term frequency refers to the percent occurrence of a species in a given vegetation type.

Nomenclature follows that of Radford et al. (1968) unless otherwise indicated.

Aspect, slope angle perpendicular to the contour of the highwall, slope angle parallel to the highwall, slope shape (convex or concave), estimated percent canopy closure, estimated percent cover, estimated canopy height and litter depth were recorded in each subplot and means of these values for each plot were used in the analysis. Aspect was measured with a Silva Forester compass, slope angle with a Keuffel and Esser Abney level. Highwall height, distance from highwall, coal seam and age were recorded for each plot. Spoil was sampled in two locations in a randomly chosen subplot, one near the border of the plot nearest the highwall, one near the border of the plot distal to the highwall. Samples were taken at 15 and 30 cm depths and were air dried and stored for later laboratory analysis.

Eight mines were used in the study and 55 plots were established in 23 transects on the mine sites. In an effort to characterize the forests surrounding the mines, in the summer of 1979 the transects were continued above and below the mine into the undisturbed forest where 400 m^2 plots were placed (with few exceptions) at least 20 m from the edge of disturbance. The plots consisted of two 200 m^2 circular contiguous subplots and all trees and shrubs greater than 1 m tall were tallied. This procedure was possible for only 16 transects, due to disturbance surrounding the mines.

The age of each mine was established in six of eight cases by talking to the mine operator. However, since in most cases the operator was relying on memory, the age cannot be fixed beyond $\pm$ 1-2 years with certainty. In the remaining two cases (mines 2 and 8), both of which happened to be mined by the same operator at approximately the same time, the age was established by talking to several residents of the nearby town who all agreed on the same year of mining.

Laboratory Analysis

Spoil analysis followed outlines provided by Sobek et al. (1978). Spoil samples were gently crushed with a rolling pin and percent particle size distribution by weight was determined by sifting the spoil into particles > 19 mm, 6.35-19 mm and < 6.35 mm in size. The fraction < 6.35 mm in diameter was divided into two approximately equal fractions. One fraction was ground to pass a 0.25 mm sieve (60 mesh) for pH analysis. The other portion was used to obtain the percent spoil (by weight) < 2 mm in diameter. This < 2 mm fraction was used for textural analysis. Spoil pH was determined in a 1:1 spoil:water mixture using an Orion Research Digital Ionalyzer (Model 701A) pH meter. The four spoil pH values per plot were converted to H ion concentration, averaged and converted again to pH for the numerical analysis since averaging of pH values tends to underestimate H ion concentration.

Twenty samples of spoil < 2 mm in size were randomly chosen for textural analysis using a modified Buoyoucous hydrometer method (Foth et al. 1976). Although the method was checked against samples of known particle size distribution donated by The University of Tennessee Plant and Soil Sciences Department and found to be satisfactory for the purposes of this study, it became evident later that the technique may have underestimated percent silt by a few percent. The remaining approximately 200 samples were tested for texture using the field or "feel" method according to guidelines established by the Soil Survey Staff (1975). In the numerical analysis, the midpoint of the clay and the sand within each class was used.

Color of the ground fraction was established using Munsell Standard Color Chips with natural midday light.

Numerical Analysis

Multivariate numerical techniques used in this study were cluster analysis, reciprocal averaging ordination and multiple discriminant analysis. What follows is a brief review of these techniques and a discussion of their specific applicability to this study.

The purpose of all multivariate analysis techniques as applied to vegetation research is the revelation of pattern in the data (Orloci 1975). Noy-Meir and Whittaker (1978) point out two major kinds of patterns which have been of interest to ecologists: 1) sequences or directions of community compositional variation which directly relates to gradients of environmental factors and 2) groupings of related samples and species. Ordination (Whittaker 1978) has been used to study the first kind of pattern while classification has been among the techniques used to study the second type.

Ordination and classification have been viewed as mutually exclusive approaches by some authors (see review by McIntosh 1967). This attitude arose, of course, from the controversy between the

Classification and Individualist or Continuum schools of thought (McIntosh 1967). However, objective methods of classification are often undertaken with purely utilitarian objectives (Orloci 1975) and not as a means of testing a hypothesis. In fact, the mere choice of a technique does not answer the fundamental question of vegetation distribution: does the vegetation exist as distinct natural groups of stands or does the vegetation exist as a continuum (Pielou 1977)? The success of either approach may rely as much on the preconceived notions and sampling designs of the investigator as on the actual distribution of the vegetation (McIntosh 1967).

Others have viewed classification and ordination as complementary techniques, each revealing different information about the data (Goodall 1963, Orloci 1967, Grigal and Goldstein 1971, Whittaker and Gauch 1978, Robertson 1978, Whittaker 1978). In this study, such a combined ordination-classification approach was taken. Classification was used to facilitate the description of the vegetation and to provide groups from which tests of the vegetation to environment could be made (via multiple discriminate analysis). Indirect ordination was used to further examine the relationships of stands and species to one another and to the environmental gradients along which they presumably vary (Beals 1973, Whittaker and Gauch 1978).

Ordination. Reciprocal averaging is an ordination technique related to weighted averages (Whittaker 1967) and to the eigenvector technique, principle components analysis (Gauch et al. 1977). The technique was brought to the attention of ecologists by Hill (1973, 1974). One algorithm of reciprocal averaging begins with assignment of arbitrary scores to species, from which sample scores are calculated by averaging the species scores within a sample. From these sample scores, new species scores are derived by averaging the scores of the samples in which that species occurs; from the new species scores, the sample scores are recalculated. This process continues back and forth until arrival at a stable solution. Thus, final scores (positions on the first ordination axis) exist for both samples and species, scores which are derived simultaneously (Hill 1973). Species and sample scores are derived for second and higher axes in an identical manner, except that at the end of each iteration a regression on the next lower axis is taken out, so that new scores are uncorrelated with the next lower order axis scores (Hill 1979). If solved as an eigenvector problem the same result is obtained (Hill 1973).

Use of simulated data sets based on Gaussian distributions of species (Gauch and Whittaker 1972, 1976) reveal that reciprocal averaging is less subject to distortion and displacement than principle components analysis when faced with data sets of high beta diversity, noise and sample clusters (Gauch et al. 1977). Reciprocal averaging is sensitive to sample outliers and to disjunction within the data set. Gauch et al. (1977) recommend removal of outliers and division of data sets which are disjunct before running the final ordinations. Reciprocal averaging also has a tendency, because of its scaling properties, to contract the ends of the axes so that samples occupying the same distance from one another will appear closer together at the ends of the axis and farther apart in the middle (Hill 1979).

Simulated data sets based on models other than Gaussian species distributions indicate that reciprocal averaging may be subject to involution under certain conditions (Austin 1976). Tests with field data favor reciprocal averaging over principle components analysis but indicate that the second axis of reciprocal averaging may not offer useful information and should be interpreted cautiously (Gauch et al. 1977, Robertson 1978). This is the result of the well-known arch effect common to polar ordination and all eigenvector techniques (Whittaker and Gauch 1978). Detrended correspondence analysis is a modified version of reciprocal averaging which circumvents this by a more stringent requirement of "no systematic relation of any kind between the higher axes and the first" (Hill 1979). The detrending occurs at the end of each reciprocal averaging sample iteration. The sample first axis is divided into segments, within which the sample scores of the second axis are readjusted to a mean of zero. This detrending is performed three times, with segment positions varying each time. Final sample scores are the averages of the three detrendings.

Recent applications of reciprocal averaging include analysis of vegetation of the lower Alabama Piedmont (Golden 1979), Enchantment Lakes Basin (del Moral 1979), central Washington Cascades (del Moral and Watson 1978), southern Illinois floodplain (Robertson 1978) and Cumberland Plateau of Tennessee (Hinkle 1978).

Reciprocal averaging and detrended correspondence analysis were performed with programs written by Gauch (1977) and Hill (1979), respectively.

Classification. Orloci's (1967) sums of squares method of classification (cluster) was used to classify the plots. This is a hierarchical polythetic agglomerative technique which utilizes the increase in within-group sums of squares based on a distance function (Euclidean distance, in this case) in uniting cases and groups. At each step in the procedure, each group or case is united with every other group or case and the within-group sums of squares is calculated. The combination which yields the least increase in the within-group sums of squares of the newly formed groups is retained and the analysis continues iteratively until one large group containing all cases is formed (Orloci 1967). Thus, at every stage the variance within groups is minimized while the variance between groups is maximized (Goodall 1973). The values assigned to the various levels of the dendrogram resulting from the analysis refer to within group mean squares expressed as percentage of the sample mean square, referred to here as percent dispersion (Orloci 1967). The methodology involved in choosing the level of the dendrogram at which to identify groups will be discussed below.

Orloci's method has been tested by a number of authors and has been found to be satisfactory in its ability to recognize groups which correspond to groups derived from other classifications and from ordinations (Grigal and Goldstein 1971, Goldstein and Grigal 1972, Robertson 1978).

Cluster analyses were performed with a program written by Post and Shepherd (1974) (CLUSTR) whose algorithms correspond to Wishart (1969, from Post and Shepherd 1974) and Orloci (1967).

Multiple discriminant analysis. Multiple discriminant analysis (hereinafter, discriminant analysis) has as its objective derivation of linear combinations of weighted variables (discriminators) which "force" predetermined groups to be as statistically distinct as possible. The linear combinations of variables are called discriminant functions and are of the form:

$$D_i = d_{i1}Z_1 + d_{i2}Z_2 + \ldots d_{ip}Z_p$$

where D_i is the score on discriminant function i, the d's are weighting coefficients and the Z's are the standardized scores of the p variables used in the analysis (Klecka 1975). Necessary inputs to discriminant analysis are independently determined groups of cases (plots, in this case) and their associated variables (species or environmental variables).

The derived discriminant functions maximize the ratio of the between-group sums of squares to the within-group sums of squares (Tatsuoka 1971). The first discriminant function accounts for the maximum amount of variation possible, while subsequent orthogonal axes account for the remainder (Cooley and Lohnes 1971). The relative percentage of the eigenvalue associated with each function (based on the sum of the eigenvalues of all functions) is a measure of the total variance explained by the function (Klecka 1975). The group centroids (means) may be plotted on the discriminant functions (or axes) in order to demonstrate the degree of spatial separation between groups.

Once discriminant functions have been derived, they may be used for two main purposes: classification and analysis. Analytical applications include an overall significance test of the discrimination between groups and significance testing of each discriminant function as it is derived (assuming multivariate normality). Important to this study is the relative value of the standardized weighting coefficient of each variable in the discriminant functions. Ignoring the sign of the coefficient, its magnitude indicates the importance of that variable in the spatial separation between group means along each axis or function. The sign of the coefficient indicates the direction of the axis along which the variable will move the group means when plotted.

Discriminant analysis can be used to check on the success of the independent classification of groups. A separate linear combination of the discriminating variables is derived for each group from which a probability of each observation belonging in any group is calculated. Each observation is reassigned to the group to which it has the highest probability of belonging. An empirical measure of success of discrimination between groups is the percent correct classification for each group. In addition, an F-matrix can be constructed upon which significant differences between groups can be tested (Klecka 1975).

Discriminant analysis has been used by ecologists in a variety of ways including species niche definition (Dueser and Shugart 1978, Mann 1977), comparison of classification techniques (Grigal and Goldstein 1971, Goldstein and Grigal 1972, Crow and Grigal 1979) and, as an indirect gradient analysis technique (Norris and Barkham 1970, Matthews 1979). In addition, Kercher and Goldstein (1977) and Schmalzer et al. (1978) have used discriminant analysis to confirm that groups of plots derived from cluster analysis based on species variables can be discriminated using environmental variables. The environmental variables important in discriminating between groups can be identified when the standardized weighting coefficients are examined (Schmalzer et al. 1978).

Kessel and Whittaker (1976) tested discriminant analysis as a simple ordination technique and found it to be generally inappropriate for this purpose but recommended further study of this technique in phytosociological data analysis.

In the present analysis, discriminant analysis was used for the following purposes:

1) As discussed above, the cluster analysis results in a dendrogram with increasing levels of dispersion (within-group mean squares) resulting in decreasing number of groups. The question of which level of dispersion to choose in determining the number of groups often requires a subjective or arbitrary decision on the part of the investigator (Goodall 1973, Mueller-Dombois and Ellenberg 1974, Pielou 1977). Discriminant analysis was used to help make this decision less subjective. By analyzing n group, n + 1 group, n + 2 group levels, the classification success at each level could be obtained and used to determine how well the species variables were discriminating between groups at each level. The assignment of membership probabilities assumes multivariate normality, however. This condition may not be met by this data (Pielou 1977, Matthews 1979) but since only the relative value of classification success was used here, it was thought that use of these values was valid. Thus, the dispersion level with the highest classification success was used in the subsequent analyses.

2) Once the appropriate number of groups was determined, environmental variables were substituted for species variables and the discriminant analysis was performed again. Important information gained from this analysis was the relative magnitude of coefficients of discriminating variables and the spatial orientation of groups and group members.

The discriminant analysis program used in this analysis was BMDP7M (Dixon 1975). This is a stepwise discriminant analysis which has, as an option, the Jackknife classification procedure which was used in this study. This option lessens the bias inherent in the normal classification procedure. The bias arises from the fact that cases are used to derive discriminant functions from which group means are then calculated. These same cases are then compared to these group means in determining discriminant distance and membership probability. The Jackknife procedure reduces bias in the following manner. As each case is considered, group means are recalculated minus the case under consideration and discriminant distance is computed on the basis of the new groups (Dixon 1975). Thus, this is a more conservative test of classification success.

Descriptive statistics. All descriptive statistics, correlations and regressions were performed using programs supplied by Statistical Analysis Systems (SAS) (Barr et al. 1976, Helwig and Council 1979).

Diversity. Diversity indices were used to further describe the stand types encountered in this study. Three indices were calculated for each sample in the total woody data set (described below) and averaged for each canopy type and the undisturbed samples:

1) Species number or richness:

$$d = S/\text{Log } A$$

where S is the number of species in the sample and A is the area sampled;

2) Simpson's index, a measure of dominance concentration

$$C = \sum_{i=1}^{s} p_i^2$$

where p is RD;

3) Shannon-Wiener index, a measure of equitability

$$H' = -\sum_{i=1}^{s} p_i \text{Log } p_i$$

(Whittaker 1975). Dominance concentration and equitability are inversely correlated (Whittaker 1975, Pielou 1977). These indices were also calculated for the ground cover data set; in this case p is the relative percent cover of each species. The total woody data set was used for these indices because a comparison between mine and undisturbed samples was desired (only woody species were sampled in the undisturbed plots) and because nearly all the mine plots are dominated by woody species.

Data sets. The total data set was divided into four subsets. The first three subsets consisted of mine plots only, the last of mine and undisturbed plots.

I. Canopy - trees > 2.5 cm DBH; species with < 5% occurrence in the mine plots deleted.

II. Understory - trees < 2.5 cm DBH and > 1 m tall, and shrubs > 1 m tall; species with < 5% occurrence in the mine plots deleted.

III. Ground cover - trees, shrubs and herbs < 1 m tall; species with < 10% occurrence in the mine plots deleted.

IV. Total woody - all woody individuals > 1 m tall, in presence/absence mode; plots in transects where undisturbed sampling was not possible were excluded; species with < 5% occurrence in these plots deleted.

The arbitrary division of the data set into canopy and understory deserves comment. Although these young stands do not display the vertical stratification common to mature eastern deciduous forests, it was desirable to analyze in the canopy data set, individuals which had been subject to site selection over time. It was also desirable to analyze the shrub and woody vine species separately from the trees; this division effectively achieved this.

Common names of tree species will be used in the text of the remainder of this work; see Appendix C for corresponding scientific names.

CHAPTER V

CANOPY

Cluster Analysis

All clusters of this data set were performed using importance value (IV), based on the addition of relative density (RD) and relative basal area (RBA) as the species' value. The reciprocal averaging ordination, discussed below, revealed the presence of four outlier samples which seriously affected the ordination; these were removed in the final ordination. To make the ordination and cluster analyses compatible, the classification procedure was performed on the total canopy data set (Cluster I) and on the canopy data set minus the outliers (Cluster II). The outlier samples and one additional sample formed a distinct group in Cluster I, the Shortleaf Pine type (SLP). Otherwise the two clusters were identical in their group compositions. Since the SLP group was obviously distinct, Cluster II was used to define the remaining samples into groups (Figure 4).

The 40%, 45% and 50% levels of dispersion were tested using discriminant analysis. These levels resulted in 6 groups, 5 groups, and 4 groups, respectively. The overall classification success at the 50% level of dispersion gave the highest percent correct classification, 81.3, compared to 64.6 and 66.7 for the 45% and 40% levels, respectively. When the SLP type was added to the four groups obtained from the 50% level of dispersion, discriminant analysis revealed a percent correct classification of 84.9. The plot of group centroids

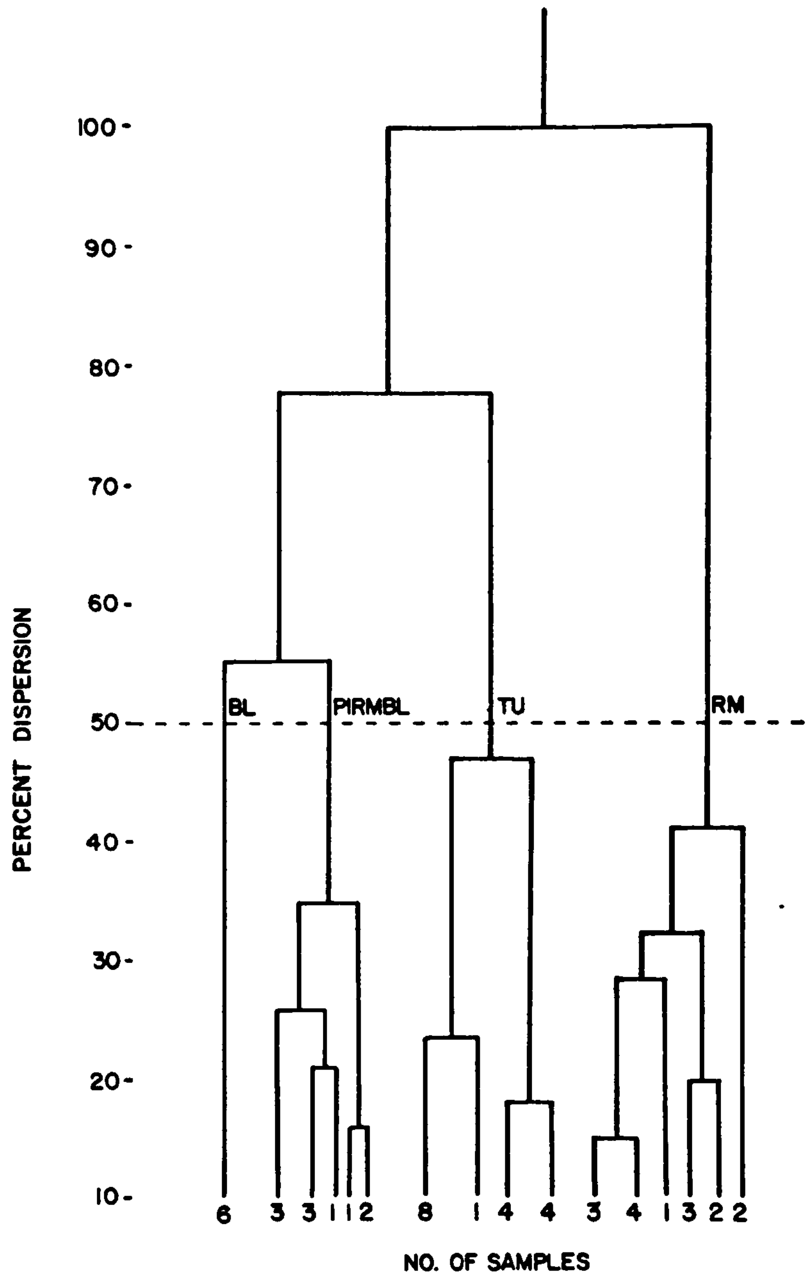

Figure 4. Dendrogram Resulting from Cluster Analysis of Canopy Data Set Excluding Outliers (Cluster II). BL = Black Locust, PIRMBL = Pine-Red Maple-Black Locust, TU = Tulip Poplar, RM = Red Maple.

and cases is shown in Figure 5 (See Appendix G, Tables 24 and 25, for classification and F-matrix tables). Note the isolation of the SLP type and the overlap between the Red Maple (RM) and Black Locust (BL) types. The first two axes explained 72.8% of the variance contained in the four significant axes.

A brief description of the five types follows. The mean IV's of the canopy species in the five types are listed in Table 1 and the RD's of the understory species in these types in Table 2. See Appendix D, Tables 19 and 20, for the mean basal area and density values of the canopy species in each type.

The Tulip Poplar type (TU) is dominated by tulip poplar (IV = 87.8), with black locust (IV = 35.9) and red maple (IV = 30.9) also important. A number of species, although with low IV, attain their greatest frequency and abundance in this type: hickory spp., flowering dogwood, white ash and white oak. The understory is dominated by red maple (RD = 33.8) with tulip poplar (RD = 16.9), Rubus spp. (RD = 9.1) and Smilax glauca (RD = 8.5) important contributors to total density.

Biomass and productivity were not measured in this study but parameters such as basal area, density and canopy height, when taken together, indicate at least the relative productivities of the canopy types. The TU type had the highest basal area (13.6 m^2/ha), density (2074 stems/ha) and estimated canopy height (7.8 m) indicating that it was the most productive type. Means and significance tests of these variables show that the TU type had a significantly higher basal area than the Red Maple, Pine-Red Maple-Black Locust and Shortleaf Pine types, significantly higher density than the Shortleaf Pine type and

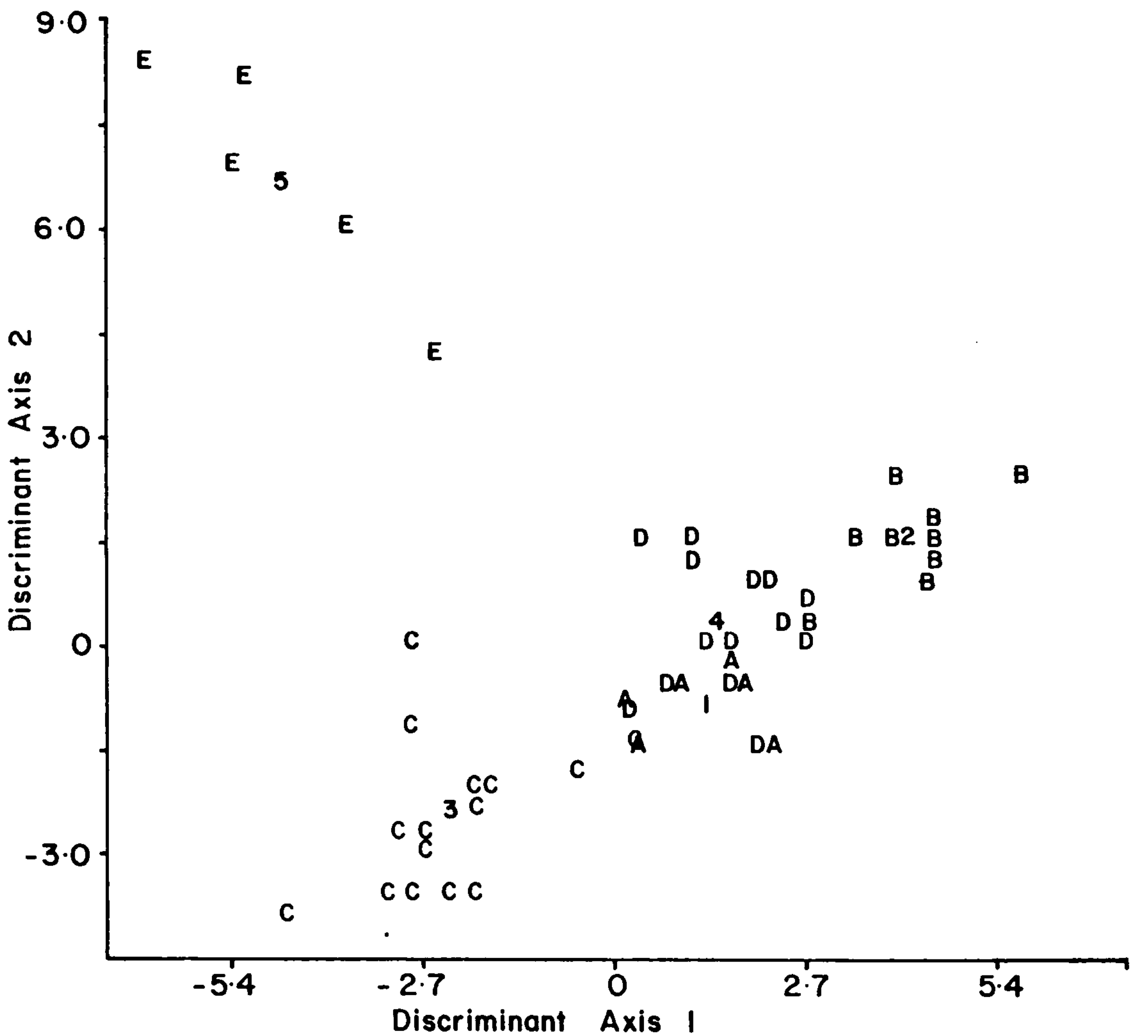

Figure 5. Canopy Species Discriminant Analysis. The 1 and A refer to the group centroid and cases for the Black Locust type, respectively; 2 and B, Pine-Red Maple-Black Locust; 3 and C, Tulip; 4 and D, Red Maple; 5 and E, Shortleaf Pine.

Table 1. Constancy and Importance Values of Canopy Species by Canopy Type.

Species	Constancy	Canopy Types / Importance Value				
		BL	TU	PIRMBL	RM	SLP
Acer rubrum	96.2	44.4	30.9	41.4	103.8	19.9
A. saccharum	9.4	1.2	1.3	1.1		
Betula lenta	1.9		0.3			
Carya spp.	9.4	1.0	3.9			
Celtis occidentalis	1.9	1.2				
Cercis canadensis	3.8		0.9			
Cornus florida	17.0	1.0	3.3		0.3	0.3
Diospyros virginiana	1.9		0.1			
Fraxinus americana	24.5	1.2	2.7	0.5	0.1	
Juglans nigra	1.9		0.2			
Liquidambar styraciflua	11.3	1.6	0.1	1.0	0.8	
Liriodendron tulipifera	81.1	18.7	87.8	20.9	25.6	0.8
Magnolia acuminata	1.9				0.1	
Malus pumila	1.9		0.3			
Nyssa sylvatica	43.4	3.0	2.9	1.8	5.2	4.1
Oxydendrum arboreum	34.0	1.0	1.3	2.6	7.8	0.3
Paulownia tomentosa	1.9	0.6				
Pinus echinata	49.1		8.9	16.4	7.4	160.6
P. virginiana	43.4		5.0	59.2	7.1	4.5
Populus grandidentata	1.9					1.3
Prunus serotina	11.3	1.0	0.2	5.1	0.6	
Quercus alba	13.2	0.6	3.5		0.6	
Q. coccinea	1.9				3.0	
Q. prinus	32.1	3.5	3.3	1.8	13.9	2.2
Q. rubra	24.5		3.1	1.5	1.9	
Q. velutina	7.5			1.9	1.5	
Rhus copallina	5.6			0.7	0.4	
R. glabra	13.2		1.6	2.6		0.3
Robinia pseudo-acacia	73.6	116.2	35.9	41.1	16.5	5.5
Sambucus canadensis	1.9			0.3		
Sassafras albidum	7.5		1.0		2.8	
Ulmus rubra	1.9				0.4	
Vitis spp.	9.4	3.5	1.4		0.1	

Table 2. Mean Relative Density (RD) of Understory Species by Canopy Type.[a]

Species	Types				
	BL	TU	PIRMBL	RM	SLP
Acer rubrum	20.9	33.8	25.5	34.0	12.5
A. saccharum	1.3	1.6	0.5		0.1
Cornus florida	1.0	4.2	0.3	0.7	0.3
Euonymus americanus		1.0			
Fraxinus americana	2.0	1.5	1.8	0.3	
Kalmia latifolia			0.1	1.1	0.8
Liriodendron tulipifera	4.1	16.9	3.2	8.3	0.8
Lonicera japonica	0.2	1.6	4.5	2.1	
Nyssa sylvatica	1.2	1.6	0.8	4.7	7.5
Oxydendrum arboreum		2.0	0.7	2.7	1.1
Parthenocissus quinquefolia	4.8	1.5	0.1		
Pinus echinata		0.1	2.7	2.5	15.2
P. virginiana		0.3	5.8	2.6	7.0
Quercus prinus	0.6	0.2	1.8	1.6	0.2
Q. rubra		1.8	1.2	0.7	0.2
Rhus copallina			1.2	1.1	
R. glabra	1.4	0.4	0.8	0.3	0.7
R. radicans	0.7	1.2	0.2		
Robinia pseudo-acacia	2.7		2.9	1.5	0.2
Rosa spp.	0.2	1.1			
Rubus spp.	40.2	9.1	25.2	21.9	20.1
Sambucus canadensis	8.8	0.4	0.2	1.7	
Sassafras albidum	0.3	0.3		1.4	
Smilax glauca	0.8	8.5	16.3	3.3	29.3
S. rotundifolia	2.1	2.9	1.0	3.3	1.1
Vaccinium spp.			0.1	0.6	2.2
Vitis spp.	4.1	2.7	1.3	0.8	0.6

[a]Species with RD < 1 in all types excluded. These are: *Aesculus octandra*, *Amelanchier spp.*, *Betula lenta*, *Carpinus caroliniana*, *Carya spp.*, *Celtis occidentalis*, *Cercis canadensis*, *Diospyros virginiana*, *Hydrangea arborescens*, *Juglans nigra*, *Juniperus virginiana*, *Liquidambar styraciflua*, *Magnolia acuminata*, *Malus pumila*, *Paulownia tomentosa*, *Populus grandidentata*, *Prunus serotina*, *Quercus alba*, *Q. coccinea*, *Q. velutina*, *Rhododendron spp.*, *Ulmus americana*, *U. rubra*, and *Viburnum acerifolium*.

significantly higher canopy height than the Black Locust, Pine-Red Maple-Black Locust and Shortleaf Pine types (Table 3).

The size class distribution of this type is of interest (Figure 6). Black locust contributes density in the largest size classes but its contribution at small size classes is much reduced compared to red maple and tulip poplar. Red maple, on the other hand, has the largest number of stems in the smallest size classes but rapidly loses importance above the 15 cm size class. This pattern is repeated by red maple in each type, indicating high mortality rates of young red maple saplings.

It is not clear whether the pattern exhibited by black locust in Figure 6 and its similar pattern in the other types in which it is important (BL, RM, Pine-Red Maple-Black Locust (PIRMBL)) is due solely to a basically different strategy in seedling reproduction from red maple or whether this pattern is also indicative of an impending decreased importance of black locust and increased importance of red maple in these stands.

Differences in growth rates and lack of age distribution data prevent tests of hypotheses relating to the order of arrival and establishment of species on the surface mine based on these size class distributions.

A final point concerning Figure 6 concerns the presence of a peak in the distribution of total stems at the largest size classes which is contributed to only partially by black locust. Contributing to this peak are isolated individuals which survived the mining procedure on the outslope of the mine. These individuals are significant in the red maple type also.

Table 3. Means of Selected Vegetation Variables of Canopy Types and Results of Analysis of Variance and Duncan's Multiple Range Test of Difference Between Means.

Variable	Canopy Type[a] BL	TU	PIRMBL	RM	SLP	P ≤	D.F.[b]	D.F.[c]
Total Cover (%)	85.6 (21.0) A B	91.4 (5.4) A	72.8 (21.4) B	65.7 (26.6) B	38.0 (34.0) C	.001	4,47	47
Canopy Closure (%)	39.4 (13.6) B C	68.1 (9.8) A	51.8 (20.4) B	46.1 (26.7) B	20.2 (23.2) C	.001	4,47	47
Canopy Height (m)	5.7 (3.4) B C	7.8 (0.54) A	6.2 (1.8) B C	6.5 (2.0) A B	4.2 (2.1) C	.01	4,44	44
Litter Depth (cm)	0.9 (0.9) B C	1.8 (1.1) A B	2.3 (1.6) A	1.0 (1.0) B C	0.4 (0.7) C	.01	4,48	48
Density (stems/ha)	1282 (433) A B	2074 (505) A	1466 (599) A B	1990 (1149) A B	1104 (1140) B	.05	4,48	48
Basal Area m^2/ha	13.6 (9.3) A B	16.3 (5.8) A	8.9 (4.6) B	9.3 (6.6) B	5.6 (6.7) B	.01	4,48	48

Table 3. (continued)

Variable	Canopy Type[a] BL	TU	PIRMBL	RM	SLP	P ≤	D.F.[b]	D.F.[c]
Total Woody Data Set: Richness (d)	4.81 (1.10)	5.72 (2.19)	4.91 (0.96)	5.09 (1.48)	3.62 (2.78)			
Dominance Concentration (C)	.2633 (.1080)	.2475 (.1192)	.2882 (.1052)	.2962 (.1252)	.3726 (.1728)			
Equitability (H')	.7583 (.1483)	.7850 (.1955)	.7312 (.1158)	.7234 (.1642)	.5790 (.2847)			
Ground cover Data Set Richness (d)	23.49 (8.82)	21.26 (7.15)	16.04 (6.22)	17.76 (5.68)	12.70 (13.96)			
Dominance Concentration (C)	.1997 (.0471)	.1662 (.0704)	.1592 (.0462)	.1874 (.1460)	.2628 (.1082)			
Equitability (H')	.9623 (.1120)	1.0333 (.1552)	.9882 (.0790)	.9973 (.2443)	.8122 (.3183)			

[a]Figures in parentheses are standard deviations; means with different letters are significantly different at α = .05.

[b]Analysis of variance.

[c]Duncan's multiple range test.

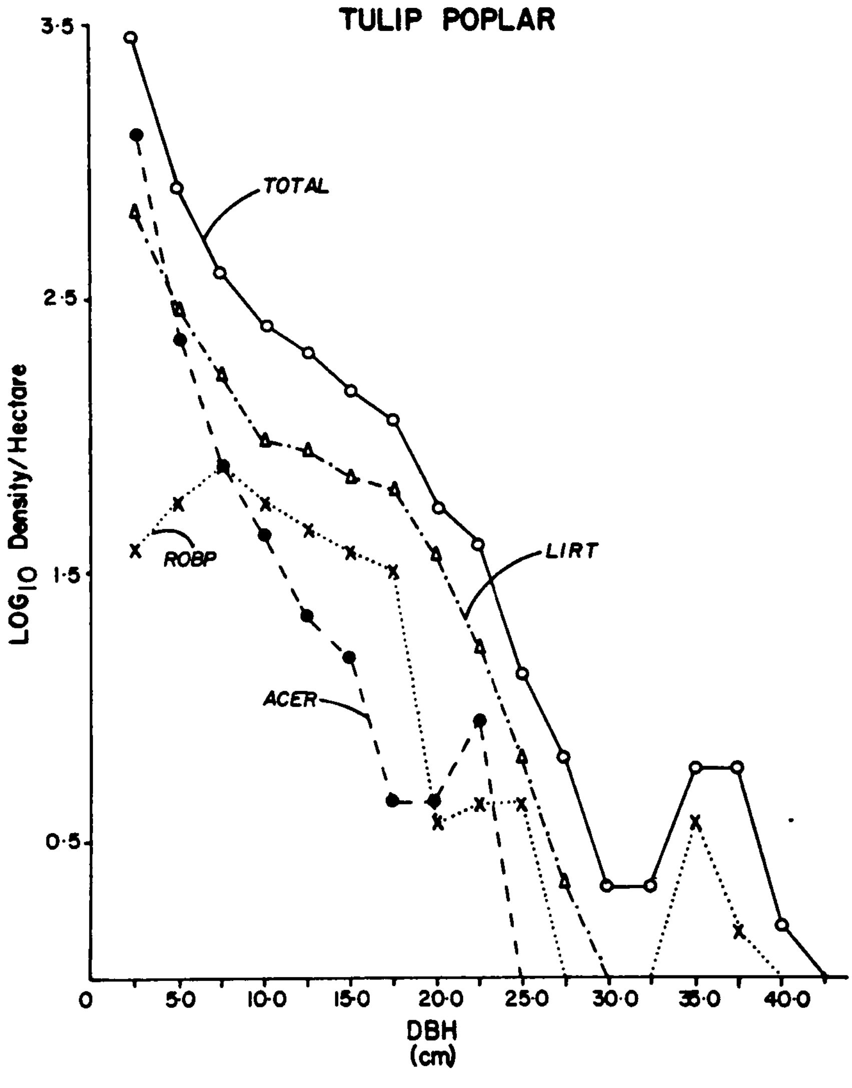

Figure 6. Size Class Distribution of Important Species in Tulip Poplar Canopy Type. ROBP = black locust, ACER = red maple, LIRT = tulip poplar.

The Black Locust type (BL) is dominated by black locust (IV = 116.2) with red maple (IV = 44.4) and, to a lesser degree, tulip poplar (IV = 18.7) important. The BL and TU types are similar. They share their three most important species, although in different proportions, and the species characteristic of the tulip type, such as the hickories, flowering dogwood, white ash and white oak also sometimes occur in the BL type. Tulip poplar, relative to its presence in other types, does not seem to be favored in BL stands, although black locust is favored in TU stands. *Vitis spp*. and sweetgum attain their highest importance and frequency in this type, while the two pine species found on the surface mines are totally absent. The understory of this type is dominated by *Rubus spp*. (RD = 40.2) with red maple (RD = 20.9) and *Sambucus canadensis* (RD = 8.8) also important.

The mean total density of this type was low relative to the other types but its average total basal area was quite high, indicating rapid growth of black locust and thinning (or exclusion) of other stems (Table 3). The size class distribution of this type illustrates this relationship between basal area and density (Figure 7).

The Red Maple type (RM) is clearly dominated by red maple (IV = 103.8) with tulip poplar (IV = 25.6), black locust (IV = 16.5) and chestnut oak (IV = 13.9) of some importance. The importance of chestnut oak in this type is partially the result of survival of individual trees and root sprouting of damaged trees on some outslope plots. Black gum and black oak reach their highest mean IV and frequency and sourwood its greatest mean IV in this type. The understory is dominated by red maple (RD = 34.0) and *Rubus spp*. (RD = 21.9) with tulip poplar (RD = 8.3) also important.

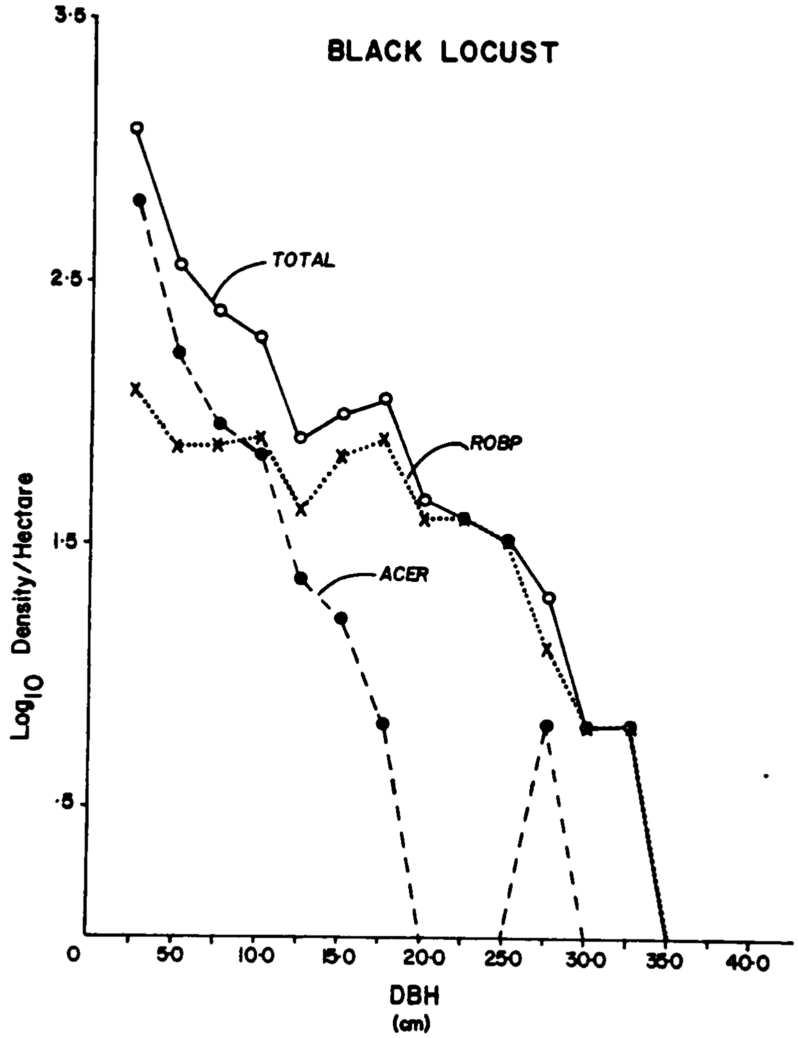

Figure 7. Size Class Distribution of Important Species in Black Locust Canopy Type. ACER = red maple, ROBP = black locust.

The Red Maple type has a relatively high density but moderate basal area when compared to the other types (Table 3, page 42). This relationship is evident in Figure 8, the size class distribution of selected species in this type.

The Pine-Red Maple-Black Locust type (PIRMBL) is co-dominated by Virginia pine (IV = 59.2), red maple (IV = 41.4) and black locust (IV = 41.1) with tulip poplar of notable importance. Shortleaf pine sometimes replaces Virginia pine as the co-dominate in this type. Wild black cherry and smooth sumac attain their greatest importance here. The understory is dominated by red maple (RD = 25.5), Rubus spp. (RD = 25.2) and Smilax glauca (RD = 16.3).

This type has a relatively moderate mean basal area and mean density (Table 3). The size class distribution is shown in Figure 9. The pine species presented high densities at small size classes as well as contributing to the larger size classes.

The Shortleaf Pine type (SLP) is overwhelmingly dominated by shortleaf pine (IV = 160.6); red maple (IV = 19.9) is the only other species of any great importance. Other species with IV > 1.0 were black locust, Virginia pine, black gum and chestnut oak. The understory is dominated by Smilax glauca (RD = 29.3), Rubus spp. (RD = 20.1), shortleaf pine (RD = 15.2) and red maple (RD = 12.5). This type has the lowest mean total density and the lowest mean total basal area as well as the lowest total percent cover (Table 3). Figure 10 illustrates the size class distribution of the important species in this type. Notice that the distribution is truncated along the diameter axis relative to the previous types (i.e., the trees are

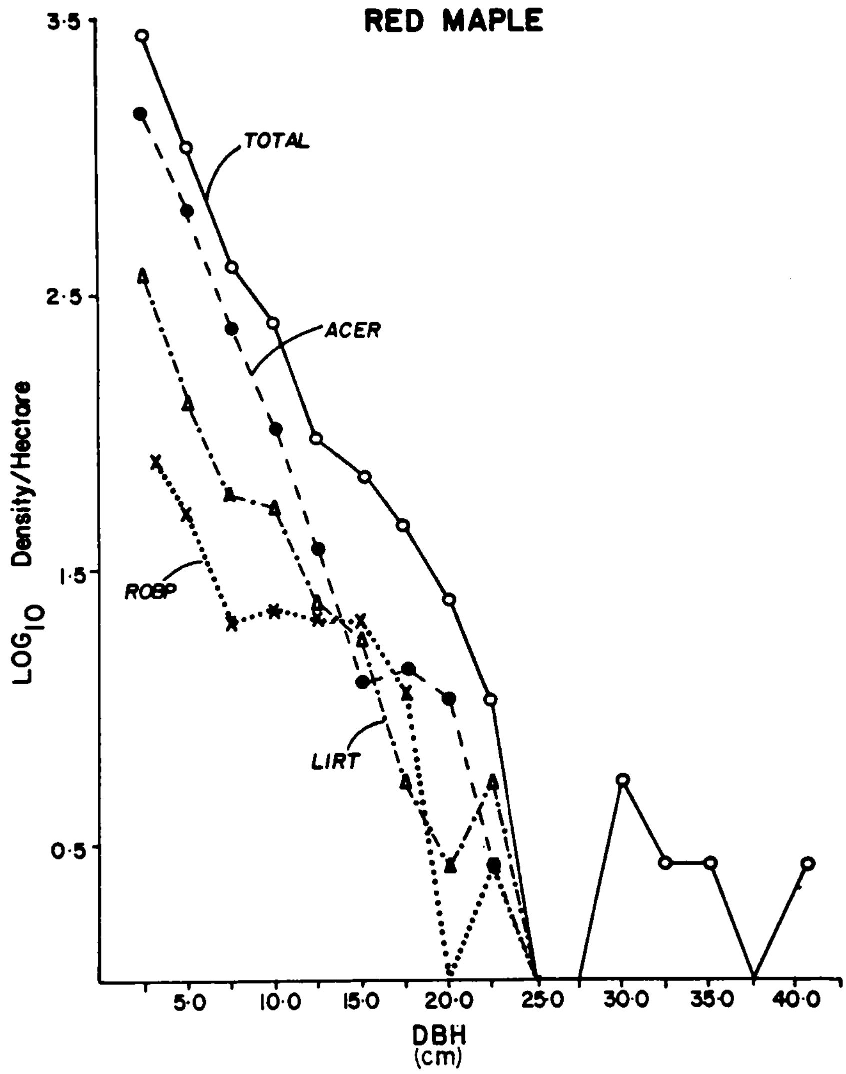

Figure 8. Size Class Distribution of Important Species in Red Maple Canopy Type. ROBP = black locust, ACER = red maple, LIRT = tulip poplar.

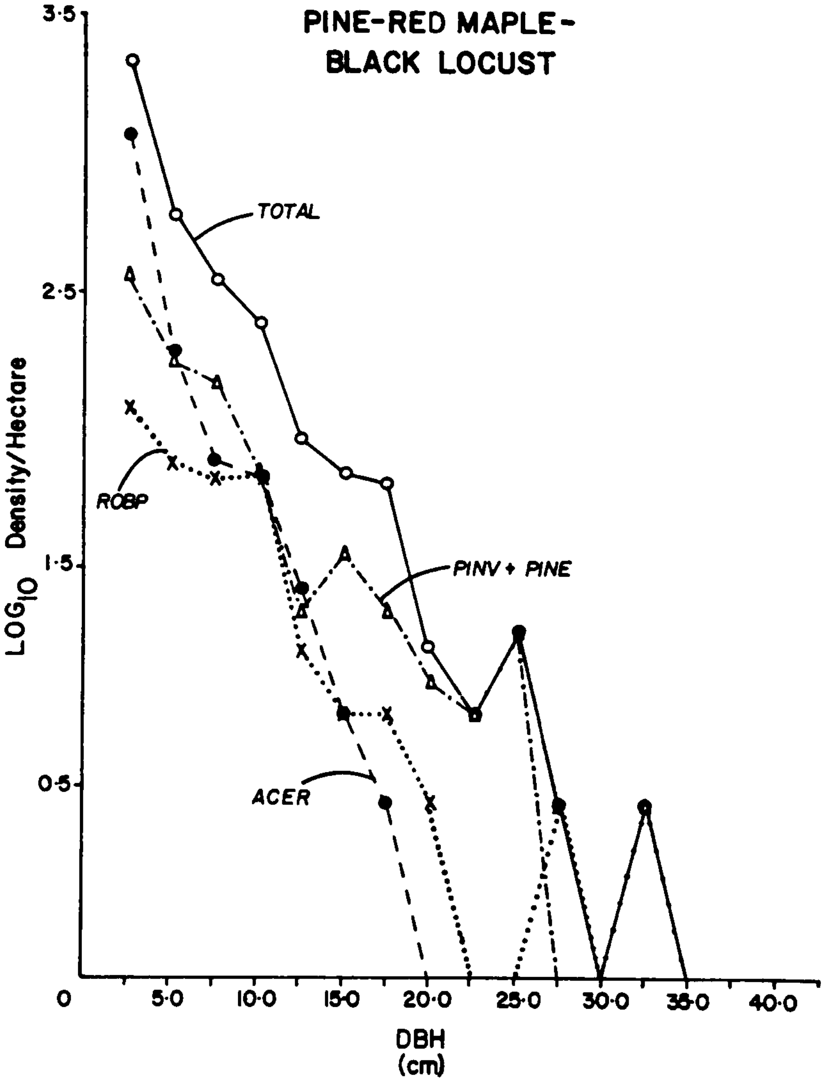

Figure 9. Size Class Distribution of Important Species in Pine-Red Maple-Black Locust Canopy Type. ROBP = black locust, ACER = red maple, PINV = Virginia pine, PINE = shortleaf pine.

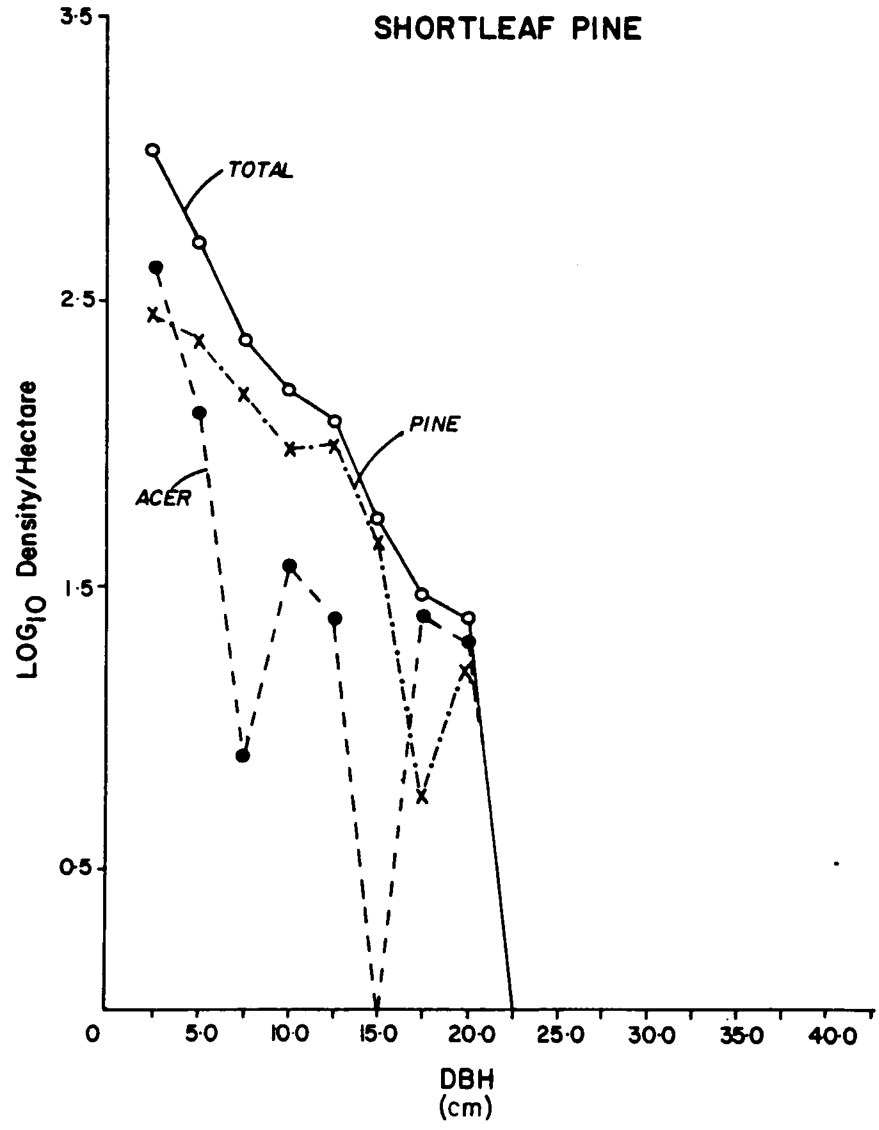

Figure 10. Size Class Distribution of Important Species in the Shortleaf Pine Canopy Type. ACER = red maple, PINE = shortleaf pine.

generally smaller) although the mean number of years since mining of this type is not significantly different from the other types.

Diversity

The diversity indices are summarized by stand type in Table 3, page 42. Not surprisingly, the TU type had the highest richness and equitability and the lowest dominance concentration of the woody data set. This indicated that this type has the most even distribution of resources among woody species and supported the greatest number of species per area sampled. The SLP type had the lowest index of richness and equitability and the highest index of dominance concentration, indicating concentration of available resources among a few species. The remaining canopy types were similar in all measures.

The indices based on the ground cover data set summarized by canopy type include herbs and grasses as well as woody species. The SLP type again had the highest dominance concentration and the lowest equitability and richness. The BL and TU types had the highest richness values while the TU and PIRMBL types had the lowest dominance concentration. Equitability did not vary greatly between types but the TU type had the highest value.

Ordination

Detrended correspondence analysis of the canopy data set was similar to the reciprocal averaging ordination, so the latter was used for interpretation. The sample ordination (Figure 11) illustrates the relationship of the cluster analysis results with those of the ordination, the number next to each sample position corresponding to one of the five types. Members of types derived from the cluster

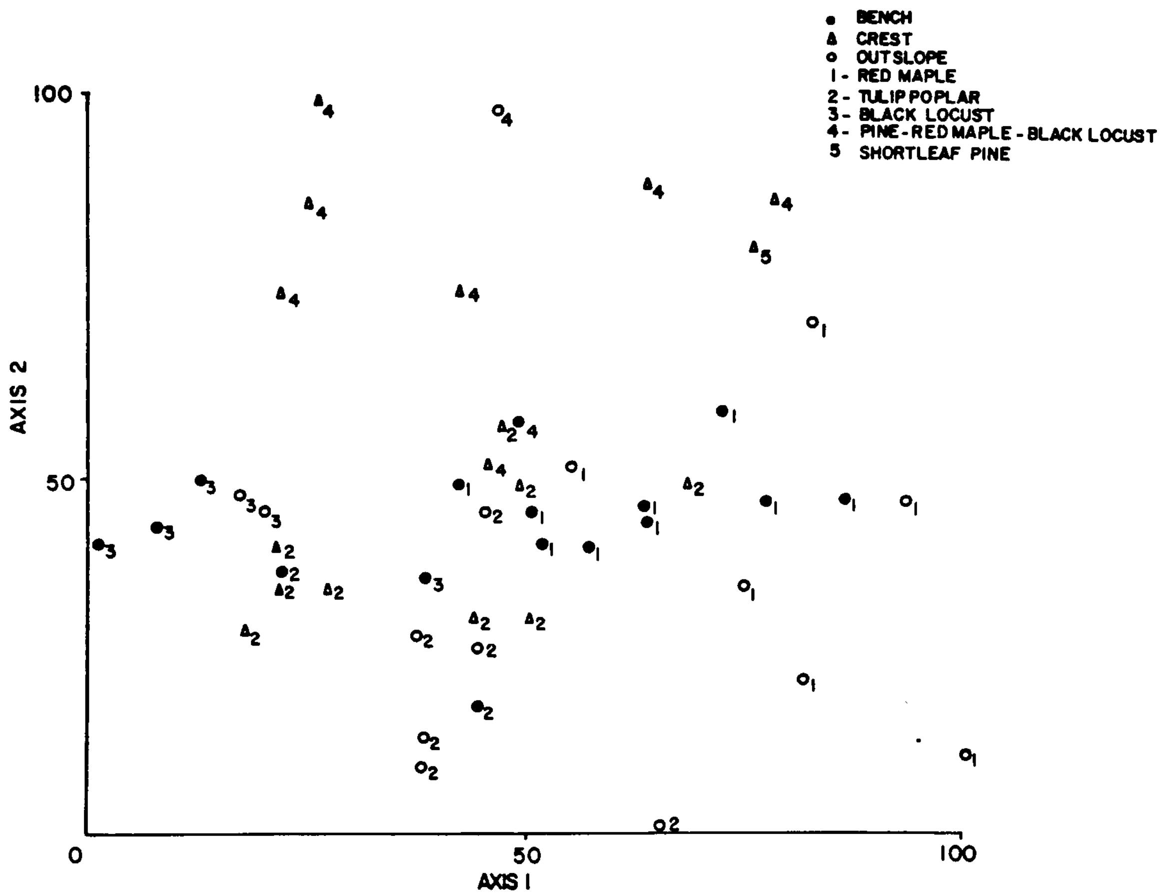

Figure 11. Reciprocal Averaging Sample Ordination of Canopy Data Set Excluding Outliers.

analysis are found in the same area of the ordination graph, although little clustering is evident. The species ordination shows little clustering, either (Figure 12, Table 4), but those species most likely to be found together in the same stand occur in the same area of the ordination graph and correspond to species characteristic of a particular cluster type. For example, tulip poplar, white ash, flowering dogwood, white oak and the hickories form a group characteristic of the TU type while red maple, blackgum, sourwood, sassafras and black oak form a group characteristic of the RM type. Thus, the ordination confirms the integrity of the groups derived from the cluster analysis while illustrating that no sharp boundaries occur between the types.

The first axis of the reciprocal averaging ordination explained 15.1% of the total variance while the second axis explained 14.5% of the total variance.

Environmental interpretation of axis one and two was carried out first by plotting a variety of sample environmental values in the sample position of the ordination graph. Those continuous variables which showed a trend were tested against sample position using simple linear regression. This approach was undertaken to help relativize the degree to which the sample order along the axis could be explained by either increasing or decreasing trends in the environmental variables. The significance tests were simply used to provide a convenient cut-off point for those variables which should be considered. The r^2 helped to relativize the importance of the environmental variables when more than one was significant along a given axis.

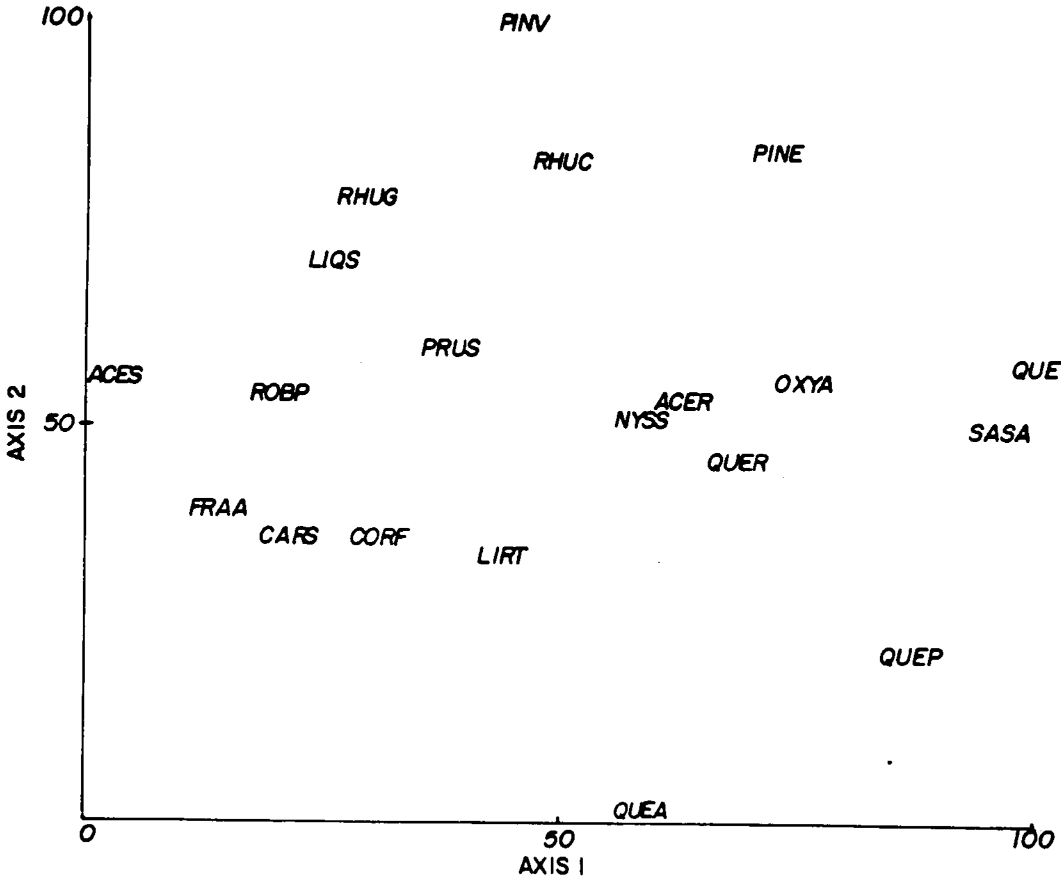

Figure 12. Reciprocal Averaging Species Ordination of the Canopy Data Set Excluding Outliers. See Table 4 for explanation of species code.

Table 4. Corresponding Names for Species Codes in Figure 12.

Code	Name
ACER	*Acer rubrum*
ACES	*A. saccharum*
CARS	*Carya spp.*
CORF	*Cornus florida*
FRAA	*Fraxinus americana*
LIQS	*Liquidambar styraciflua*
LIRT	*Liriodendron tulipifera*
NYSS	*Nyssa sylvatica*
OXYA	*Oxydendrum arboreum*
PINE	*Pinus echinata*
PINV	*P. virginiana*
PRUS	*Prunus serotina*
QUEA	*Quercus alba*
QUEP	*Q. prinus*
QUER	*Q. rubra*
QUEV	*Q. velutina*
RHUC	*Rhus copallina*
RHUG	*R. glabra*
ROBP	*Robinia pseudo-acacia*
SASA	*Sassafras albidum*

Along axis one, pH showed the clearest relationship to sample position (Figure 13) and the linear regression proved to be significant ($P \leq .001$, $r^2 = .339$). Spoil pH varied negatively with sample position; hence the BL type, found left-most on the ordination graph, should have the highest pH values while the RM type found right-most on the graph should have the lowest pH with the remaining types intermediate. This is exactly the relationship which is evident from Table 5 which shows the means and significance tests of pH by canopy types. The BL mean pH is significantly higher than all other types and the RM mean is significantly lower than the BL and TU pH.

Two variables, relief position and slope angle perpendicular to the contour, showed a clear trend along axis two. Outslope relief positions are most common on the lower portion of the sample ordination (Figure 10, page 50), bench positions in the middle and crest positions in the upper portions. Relating this trend to the classification types: the TU type is most common on outslope and crest positions, the RM type is restricted to bench and outslope positions and the PIRMBL type is most common on the crest position (see also Table 5). In addition, the SLP type, not included in the ordination, is restricted to crest and outslope positions. Table 5 shows that the BL type is restricted to the bench and outslope positions but this is apparently the result of sampling design and the small sample size of this type. Areas which reflected high levels of disturbance since mining were avoided during sampling for reasons discussed above; several areas on the tops of spoil banks which were obviously dominated by black locust were not sampled because of more recent disturbance.

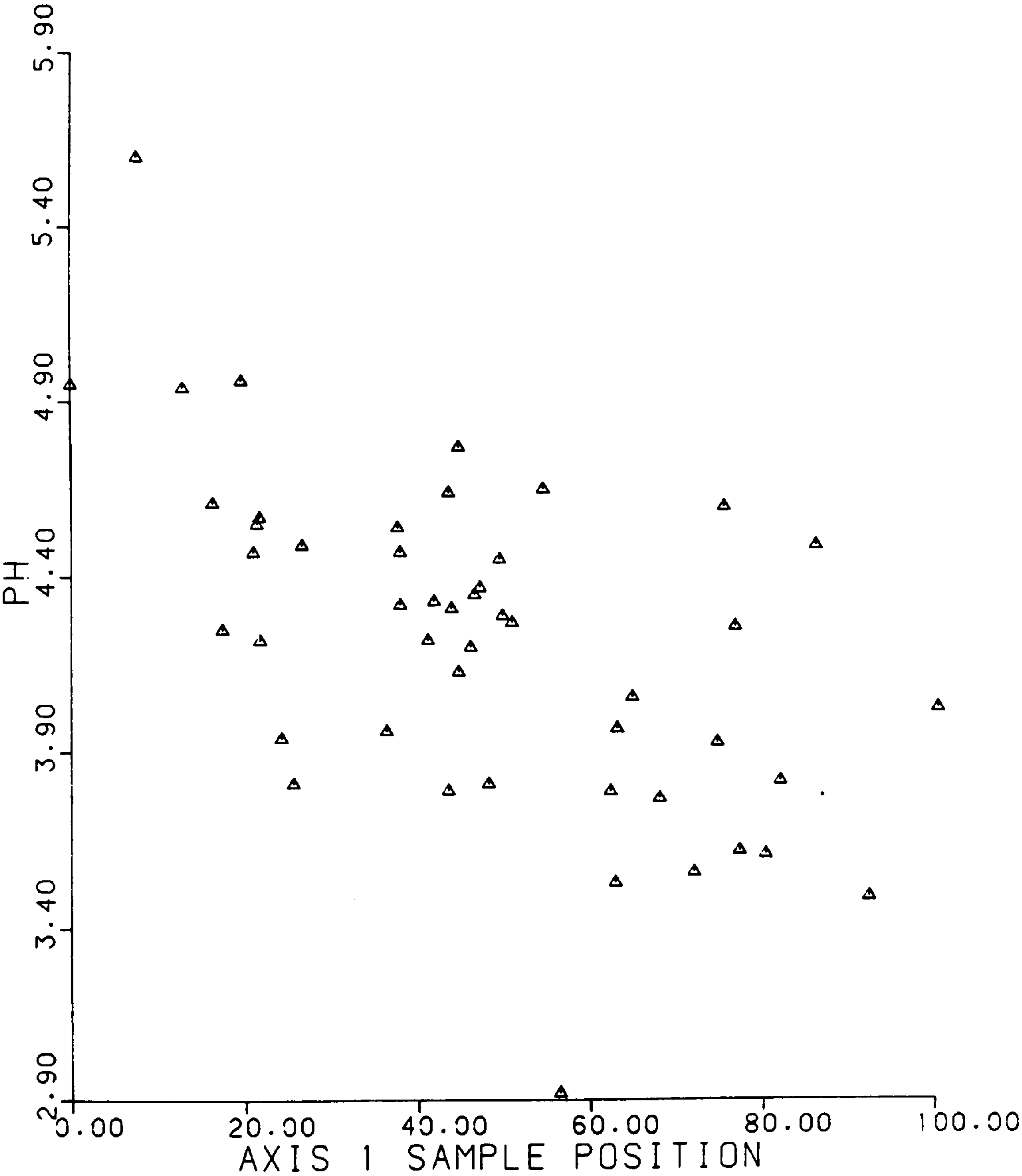

Figure 13. Trend of Decreasing pH with Canopy First Axis Sample Ordination Position. $P \leq .001$, $r^2 = .339$, D.F. = 1,46.

Table 5. Means of Selected Environmental Variables by Canopy Type Used in Discriminant Analysis[a] and Significance Tests.

Variable	Canopy Type[b]					Canonical Coef.[c]	
	BL	TU	PIRMBL	RM	SLP	AXIS 1	AXIS 2
% Spoil < 2 mm	50.3 (9.1)	40.5 (11.9)	43.9 (15.9)	41.2 (11.2)	41.3 (8.2)		
% Clay	17.4 (6.7)	19.6 (8.3)	19.8 (8.6)	21.6 (7.0)	26.1 (9.3)		
% Spoil 2 - 6.35 mm	16.1 (7.7)	16.3 (7.3)	20.7 (8.8)	19.4 (11.7)	14.5 (3.9)		
Color Chroma of Dry Spoil	3.0 (0.7)	2.9 (0.7)	2.8 (0.9)	2.6 (0.6)	2.7 (0.7)		
pH[d]	4.93 (0.37) A	4.31 (0.31) B	4.03 (0.25) B	3.95 (0.47) C	4.13 (0.34) B C	.3143	-1.0227
Relief:[d,e] (% Plots) Bench	67	11	11	60	0		
Crest	0	44	78	0	60	-.8045	-.7060
Outslope	33	44	11	40	40		
Perpendicular[d,f] Slope Angle (%)	53.8 (13.3) A	41.1 (22.6) A B	24.5 (18.8) B	52.0 (17.6) A	37.6 (22.2) A B	.9560	.9033

Table 5. (continued)

Variable	Canopy Type[b] BL	TU	PIRMBL	RM	SLP	Canonical Coef.[c] AXIS 1	AXIS 2
Parallel[g] Slope Angle (%)	5.2 (2.9)	8.2 (4.0)	8.1 (5.0)	5.5 (2.2)	8.8 (3.9)		
Highwall Height (m)	9.7 (5.0)	9.8 (3.8)	10.2 (3.9)	9.9 (2.7)	9.9 (2.0)		
Seam:[h] (No. Plots) Red Ash	2	6	0	3	1	-.7553	-.0765
Windrock	4	3	1	5	4		
Big Mary	0	9	8	7	0		
Age	18.7 (5.2)	18.4 (3.4)	20.2 (2.1)	18.1 (3.1)	15.0 (0.0)	.5904	-.3486
Aspect	199.5 (17.3)	209.3 (22.7)	205.2 (20.8)	211.9 (24.1)	193.8 (9.1)	.4418	-.3041
Number of Plots	6	18	9	15	5		

[a]Variables measured but not used in discriminant analysis are listed in Appendix F.
[b]Figures in parentheses are standard deviations.
[c]Variables which have no value were not entered into final discriminant functions.
[d]Significant one-way analysis of variance at $P \leq .01$, D.F. = 4,48; numbers underneath values indicate results of Duncan's Multiple Range Test: means with same number are not significantly different (α = .05, D.F. = 48).
[e]Relief positions were coded for analysis: bench=1, crest=2, outslope=3.
[f]Slope measured perpendicular to the contour of the highwall.
[g]Slope measured parallel to the contour of the highwall.
[h]Coal seams were coded for analysis: Red Ash=1, Windrock=2, Big Mary=3.

The second factor important along axis two was slope angle perpendicular to the highwall. Simple linear regression proved significant for this variable ($P \leq .001$, $r^2 = .200$) and showed a negative trend from low to high sample positions (Figure 14). Slope and relief are significantly correlated ($\alpha = .05$, $r = .499$) and it is not surprising that higher slope angles occur toward the end of the sample ordination dominated by outslope plots and the lower slope angles occur toward the end of the ordination dominated by crest plots. By type, the PIRMBL mean perpendicular slope angle was significantly different from the BL and RM mean slope angles (Table 5).

Discriminant Analysis

Discriminant analysis of the five canopy types using environmental variables was performed. Pearson product-moment correlations were calculated for all pairs of environmental variables prior to discriminant analysis (Appendix E) and of those variables with correlation coefficients > .500, one was chosen for inclusion in the analysis and the others were excluded. The environmental variables used in the analysis are listed in Table 5. Those values included in the final step of the stepwise discriminant analysis (F-to-Enter = 1.50) are listed with their standardized canonical coefficients. Environmental variables measured but not used are listed by canopy type in Appendix F.

Slope angle perpendicular to the contour, relief position and coal seam were the most important discriminators along discriminant axis one. Spoil pH, slope angle perpendicular to the contour and relief position were the three most important discriminators along the

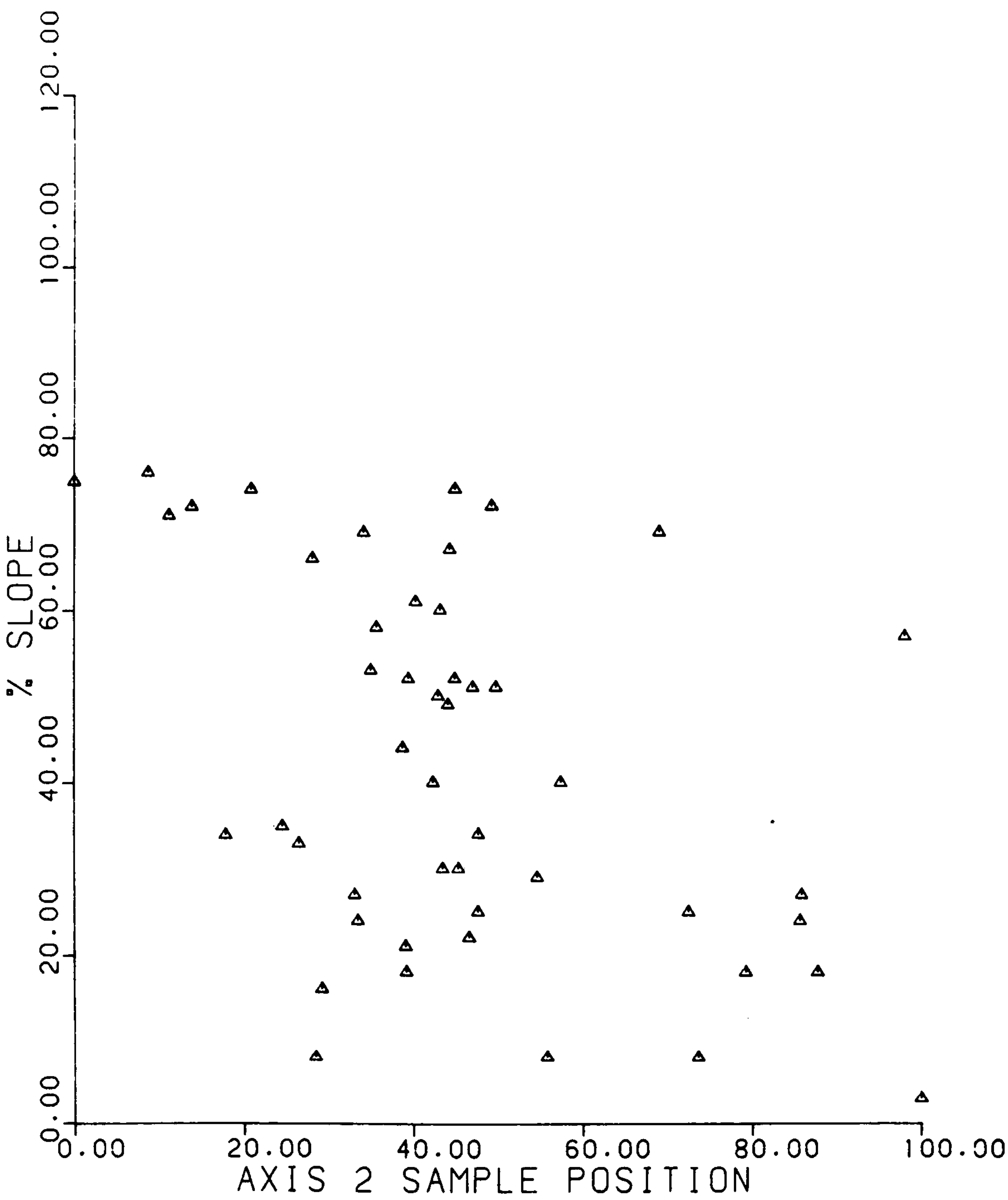

Figure 14. Trend of Decreasing Perpendicular Slope Angle with Canopy Second Axis Sample Ordination Position. $P \leq .001$, $r^2 = .200$, D.F. = 1,46.

second axis. These first two axes explained 82.9% of the variance accounted for by the four significant axes.

It is evident that the discriminant analysis gave results similar to the interpretation of the reciprocal averaging ordination, the first discriminant axis corresponding to slope angle and relief as did the second ordination axis and the second discriminant axis corresponding to pH as did the first ordination axis. In addition, coal seam was one of the factors considered important along discriminant axis one. The eight mine sites studied were located on three different coal seams (Appendix B, Table 17). Two of the types, the SLP type and the PIRMBL type, were each restricted primarily to one seam, the Windrock and the Big Mary, respectively (Table 5). It may be that coal seam is a factor in segregation of these types but the sample in this study is too small to place much confidence in the significance of this observation. Consider, for example, that the Windrock coal seam has nearly equal representation by type with the exception of the PIRMBL type. The lack of representation of the PIRMBL type on this coal seam and the restriction of the SLP type to this seam may be the result of the relatively small number of sites studied and not a reflection of differences in the coal seams.

The percent correct classification of this discriminant analysis was 52.8 as compared with 84.9 based on species variables (see Appendix G, Tables 26 and 27, for the classification and F-matrix tables). This lower classification success indicated that, based on the environmental variables measured in this study, the groups are more heterogeneous environmentally than they are biologically. This relationship can be readily seen in a comparison of plots of group cases and centroids for the discriminant analysis based on species variables (Figure 5, page 38) and the analysis based on environmental variables (Figure 15). Note the higher degree of overlap between types in the environmental discriminant analysis. As will be discussed below, certain key environmental factors which were not directly measured such as moisture and spoil nutrient content probably would have increased discrimination.

Discussion

Five canopy types were derived from cluster analysis of the canopy data set: Tulip Poplar, Black Locust, Pine-Red Maple-Black Locust, Red Maple and Shortleaf Pine. The species discriminant analysis and ordination supported the coherence of these types. The sample ordination positions were correlated with the environmental variables spoil pH, relief position and perpendicular slope angle and the environmental discriminant analysis results indicated the importance of these same variables in discriminating between types. Low pH values, as discussed in an earlier section, may indicate low available nutrients (e.g., P, Ca, Mg) or toxic levels of heavy metals (e.g., Fe, Al, Mn) or, in the case of very low pH, the direct effect of high H ion concentrations. Of course, all of these factors may be acting simultaneously to affect the distribution of the vegetation.

What are some of the characteristics of relief position which have caused it to be a good discriminator between types? One-way analysis of variance of a number of environmental variables measured in this study showed that slope angle perpendicular to the contour and slope angle parallel to the contour were the only variables which

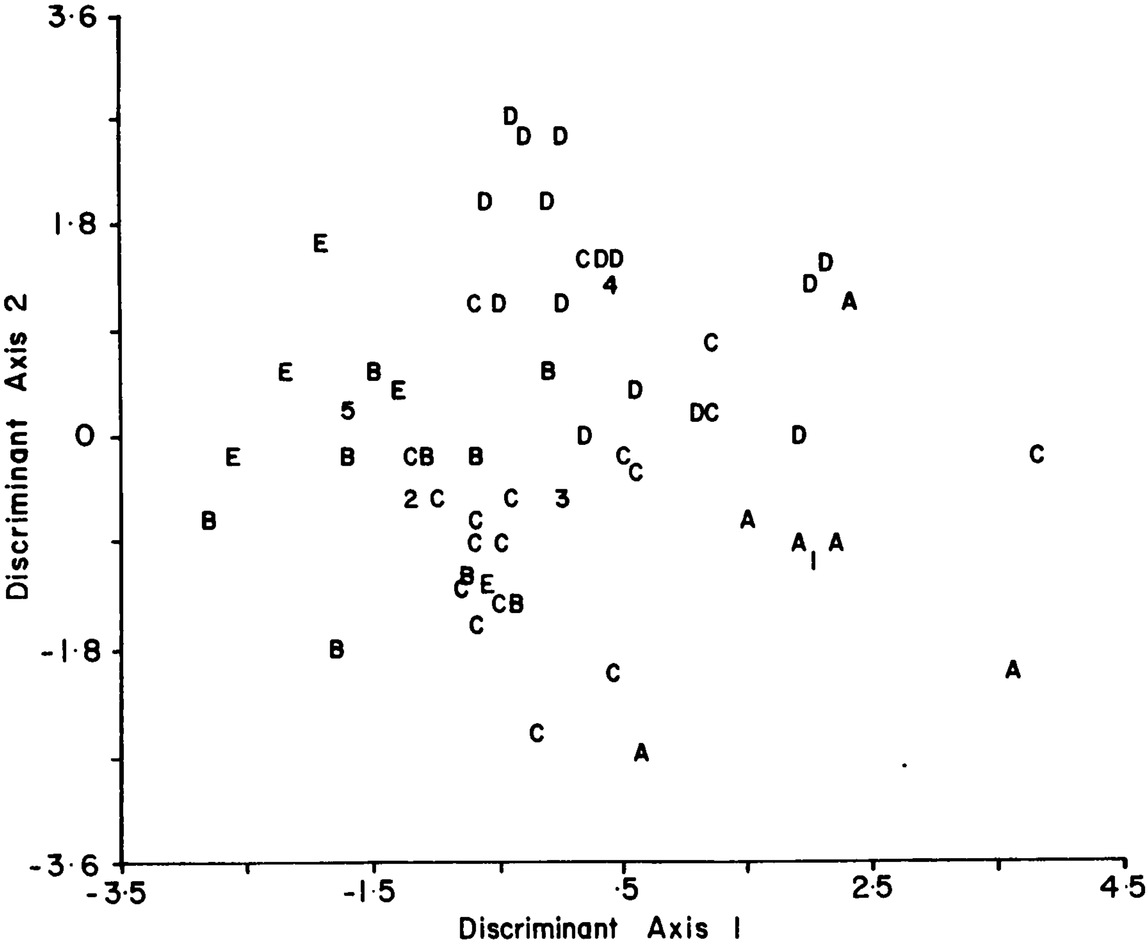

Figure 15. Canopy Environmental Discriminant Analysis. The 1 and A refer to the group centroid and cases for the Black Locust type, respectively; 2 and B, Pine-Red Maple-Black Locust; 3 and C, Tulip; 4 and D, Red Maple; 5 and E, Shortleaf Pine.

varied significantly with relief position (Table 6). Other factors which were tested but did not vary significantly were percent spoil > 6.35 mm, percent spoil 2 mm - 6.35 mm, percent spoil < 2 mm, spoil pH, H ion concentration, spoil color (chroma and value), and spoil texture (percent clay and percent sand).

Factors which are integrated by relief position but were not directly measured in this study are spoil depth, percent soil mixed with spoil, spoil element content and surface temperatures. The first two factors are related to moisture availability. The bench plots are likely to have the shallowest substrate, a factor contributing to low moisture availability. On the other hand, this position may benefit locally from drainage from above the mine, but may also, then, be poorly drained because of the impermeable layer of shale beneath the colluvium. The spoil depth of the crest position varies with the method used to move the spoil during the mining operation. Sometimes the spoil was piled quite high (as high as 10 m) while at other times, the spoil was pushed over the edge of the mountain and only a shallow pile remains at the edge of the bench. This difference probably relates to the type of equipment used in moving spoil, the deeper piles resulting from the use of power shovels and the flatter, shallower piles from the use of bulldozers. It is assumed that the depth of the spoil would have a direct effect on available moisture.

The depth of the spoil on the outslope position is proportional to the steepness of the underlying terrain, the amount of spoil removed and the height of the spoil bank. The outslope spoil is likely to contain most of the soil removed during mining and buried soil

Table 6. Means of Significant Environmental Variables by Relief Position.[a]

Variable	Relief			
	Outslope	Crest	Bench	P ≤
Perpendicular Slope Angle (%)	65.1 (10.5) A	22.3 (10.4) B	38.7 (15.7) C	.001
Parallel Slope Angle (%)	7.2 (4.3) A	8.7 (3.6) A B	5.2 (2.4) B	.01

[a]Analysis of variance (D.F. = 2,52) and Duncan's multiple range test of difference between means (D.F. = 52).

[b]Figures in parentheses are standard deviations; means with different letters are significantly different at $P \leq .05$.

would be available to deep rooted species. The presence of the soil may increase the water holding capacity of the spoil. The outslope spoil is also likely to benefit from drainage through the spoil bank from the highwall direction; in addition, this position is probably well-drained because of its steep slope.

Thus, while slope angle perpendicular to the contour may indicate a decreasing rank of moisture availability from crest to bench to outslope, other mitigating factors may cause the order to be reversed.

The nutrient content of the spoil may vary with relief position because of uneven distribution of soil mixed with spoil (presumably greatest on the outslope), and because of uneven distribution of the toxic strata associated with the coal, which is most likely to be dumped on top of the spoil bank in the crest position. Availability of endomycorrhizal spores may be influenced by the percent soil mixed with the spoil since these spores are not wind disseminated (Marx 1975).

The crest position is the most exposed to wind and solar insolation. The outslope plots are protected from wind and intense insolation by the presence of a mature undisturbed canopy downslope which offers protection to these south to west facing slopes during the hottest part of the day.

With these properties of the relief positions in mind and knowledge of the other environmental variables which may control the distribution of vegetation on the mine, the well-known attributes of the species characterizing each vegetation type will be used to clarify their relationship to the environment of the orphan mine.

The potentially important factor of seed source will be discussed in a later section.

In this study, tulip poplar dominates stands which are found predominately on the top of the spoil bank and on the outslope relief positions, and on areas with relatively high pH values. In locations undisturbed by mining, best tulip poplar growth has been correlated with sites characterized by moist, deep, well-drained, fertile soils with a relatively high pH (> 4.5) (Auten 1945, Tryon et al. 1960, Della-Bianca and Olson 1961, Martin 1966, Hinkle 1975, 1978). Tulip poplar has not been extensively planted on surface mines but a few studies indicate that spoil of pH > 4.5 and lower slopes and well-drained bottoms will promote good growth of this species (Finn 1958, Boyce and Merz 1959, Limstrom 1960). The 95% confidence interval of the spoil pH of the TU type is 4.1-4.4. This is below the level recommended by Limstrom (1960) for areas to be planted to tulip poplar. This discrepancy may be explained by the fact that field test kits, often used in the above cited studies, may read pH values .2-.5 higher than determinations made with glass electrodes (from discussion, Miles et al. 1969). In any case, tulip poplar appears to be sensitive to spoil pH as well as moisture regime as expressed by its preference for the crest and outslope relief positions. As discussed above, it is likely that the outslope may be the most favorable spot on the mine for moisture and nutrients. The crest of the outslope, if the spoil pH is favorable and spoil deep enough, provides suitable habitat for tulip poplar and its associated species. Although empirical data were not collected concerning the association between spoil depth of the crest position and occurrence of individual tulip trees, field observations indicate that this species does have a preference for the deeper spoils.

Red maple dominated areas with high acidity located on the bench and outslope relief positions. This species can accommodate a variety of conditions. It is a common understory species of many vegetation types of the Cumberland Plateau and Mountains (Safley 1970, Hinkle 1975, 1978) and dominates stands on poorly drained swales and heads of streams on the uplands of the Cumberland Plateau (Hinkle 1978). On spoil banks, it is tolerant of very low pH, ranging as low as pH 3.0 (Sturm 1973, Fowler and Adkisson 1980). It is also tolerant of very low spoil concentrations of P, K, Ca and Mg (Sturm 1973). This information supports the findings of this study. The RM type was found on areas of very low pH, the lower 95% confidence interval being 3.4 and on the bench (possibly poorly drained) and outslope positions (adequate moisture but well drained) where acidity was generally too high for species such as black locust and tulip poplar.

Black locust is planted extensively on eastern coal mines and planted seedlings will survive pH as low as 3.8 (Miles et al. 1969) but its growth and survival are severely affected below pH values of approximately 4.5 by increased locust borer damage, decreased nodulation, chlorosis due to Mn toxicity, and possibly restricted root growth due to heavy metal toxicity (Brown and Tryon 1960, Brown 1962, Mellinger et al. 1966, Berg and Vogel 1968, 1969, Rothwell 1969, Ruffner 1978). The significantly higher pH of the BL type was noted above, indicating that this type may be restricted by black locust's decreased growth at low pH values. Lawrey (1977b) found that black locust dominated surface mine habitats in Ohio have higher pH values than bare or pine dominated areas.

Shortleaf pine commonly occurs on upper to middle slopes and ridges on soils of low water holding capacity in the Cumberland Mountains and on the Plateau (Safley 1970, Hinkle 1978). On surface mines, planted shortleaf pine showed good survival on spoil with pH < 4.5 in Pennsylvania (Miles et al. 1969) and was established successfully on upper slopes and ridges of area surface mines in Western Kentucky (Boyce and Merz 1959). The pH of this type is not significantly lower than that of the TU or significantly higher than that of the PIRMBL type (Table 5, page 58), although it is found on the same relief position (crest and outslope) as the TU type. Based on slope angle, pH, and relief, this type is not different from the TU type. Vegetationally, however, it is obvious how different these two types are. The environmental difference probably lies in a severe deficiency of an essential nutrient such as P or a toxic quantity of a metal such as Al, Fe, or Mn. It is interesting that 4 of the 5 plots making up this type were from the same mine, suggesting a condition peculiar to a local area.

Virginia pine occurs as a dominant only in the PIRMBL type which is found predominately on the crest position in areas of moderately low pH values. On the Cumberland Plateau and Mountains, Virginia pine is characteristic of upper slopes and ridges with thin soils and low water holding capacity (Hinkle 1978, Martin 1966, Safley 1970). On surface mines it is tolerant of very low pH (< 4.0) (Stiver 1949, Ruffner 1978) and will grow on the drier areas of the mine (Boyce and Merz 1959). It is also tolerant of very low levels of P and low levels of N (Fowells and Krauss 1959). It may be that this type occurs on those crest plots of shallower spoil depth but no direct evidence for this exists from this study.

Direct measurement of spoil moisture, depth and nutrient concentration would probably have yielded higher coefficients of determinations (r^2) between the sample ordination axes positions and the environmental variable under consideration. However, it is likely that the pattern of distribution of vegetation could never be fully explained even with perfect knowledge of the environment of the plants. This is because in recently colonized stands such as these stochastic events relating to seed rain and variable weather cause "noise" in the vegetational response to the environment. Segregation of species in response to the environment over time would be expected to lessen the effect of this noise and increase the amount of variance in the distribution of the vegetation which could be explained by knowledge of the environment.

CHAPTER VI

UNDERSTORY

Cluster Analysis

The understory data set was analyzed independent of the canopy. Cluster analysis based on RD revealed a 4-group structure at the 50% dispersion level, 5 groups at the 45% level and 6 groups at the 40% level (Figure 16). Discriminant analysis of the respective groups at each level resulted in a total percent correct classification of 64.2, 58.5 and 67.9. The last level was chosen for further analysis on the basis of its total percent correct classification.

A brief description of the six types follows. Constancy and mean RD of the understory species by understory type are given in Table 7. See Appendix D for mean density by understory type.

The Tulip Poplar type (TU) is very small (n=3) but is defined by the large relative density of tulip poplar (RD = 46.0). Also notable in this type is red maple (RD = 27.2).

The Red Maple-Liana type (RMLI) is characterized by co-dominance of red maple with a variety of woody vines: *Smilax glauca* and *S. rotundifolia*, *Lonicera japonica*, *Parthenocissus quinquefolia* and *Rhus radicans*. Red maple is the only other clear dominant (RD = 21.6). The other species mentioned above are presented in Table 7 by small mean relative densities although each co-dominates a few plots.

The Red Maple type (RM) is clearly dominated by red maple (RD = 56.3) with tulip poplar also important (RD = 12.4).

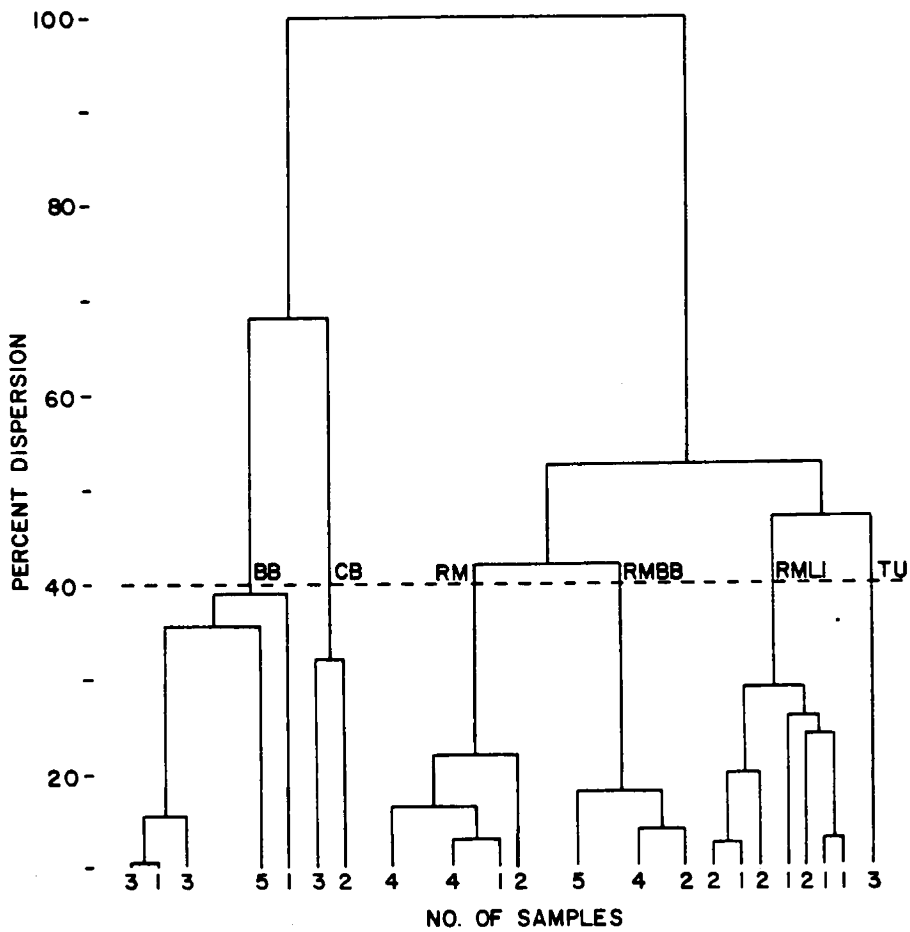

Figure 16. Dendrogram Resulting from Cluster Analysis of Understory Data Set. BB = Blackberry, CB = Catbrier, RM = Red Maple, RMBB = Red Maple-Blackberry, RMLI = Red Maple-Liana, TU = Tulip Poplar.

Table 7. Constancy and Mean Relative Density of Understory Species by Understory Type.

Species	Constancy	Understory Types: Relative Density TU	RMLI	RM	RMBB	BB	CB
Acer rubrum	98.1	27.2	21.5	56.3	39.2	11.1	8.5
A. saccharum	18.9		2.2		0.7	0.8	0.1
Aesculus octandra	1.9		0.1				
Amelanchier spp.	13.2	0.2		0.6	0.1	0.1	0.1
Betula lenta	1.9		0.3				
Carya spp.	17.0		0.7	0.4	0.2	0.1	
Cercis canadensis	3.8		0.1	0.2			
Cornus florida	37.7	1.8	5.9	0.6	1.2	0.8	0.3
Diospyros virginiana	9.4	0.2	0.1	0.1	0.3		
Euonymus americanus	3.8			1.5	0.1		
Fraxinus americana	34.0	2.9	2.5	0.5	0.9	0.8	
Hydrangea arborescens	1.9		0.3				
Juglans nigra	3.8	0.1			0.1		
Juniperus virginiana	5.7		0.2	0.1		0.1	
Kalmia latifolia	9.4	0.3		0.9		0.5	1.0
Liquidambar styraciflua	9.4		0.4	0.3	0.3	0.2	
Liriodendron tulipifera	88.7	46.0	8.0	12.4	8.6	2.5	0.9
Lonicera japonica	13.2		7.1		0.3	2.2	
Magnolia acuminata	7.5	1.0	0.1				
Malus pumila	1.9					0.2	
Nyssa sylvatica	56.6	5.2	6.4	1.5	2.8	1.6	1.0
Oxydendrum arboreum	37.7	4.7	1.0	3.9	0.7	0.4	1.9
Parthenocissus quinquefolia	17.0		4.9		0.3	0.4	
Pinus echinata	34.0			4.0	1.1	5.0	3.9
P. virginiana	37.7		4.3	2.2	3.3	0.6	3.9
Prunus serotina	28.3	0.3	0.9	0.7	0.7		

Table 7. (continued)

Species	Constancy	Understory Types Relative Density					
		TU	RMLI	RM	MRBB	BB	CB
Quercus alba	13.2		0.1	0.2	0.4	0.4	
Q. coccinea	3.8					0.1	0.1
Q. prinus	24.5		0.1	0.8	2.5	0.8	0.2
Q. rubra	35.9	1.0	2.4	1.1	0.7	0.4	0.5
Q. velutina	22.6	0.3	0.2	0.3	0.3	0.2	0.1
Rhododendron spp.	5.7	0.2	0.1			0.1	
Rhus copallina	7.5		1.3	0.3		0.8	
R. glabra	24.5		0.5	0.1	0.2	1.4	0.7
R. radicans	7.5		2.3			0.3	
Robinia pseudo-acacia	50.9		1.9	1.6	0.9	2.4	0.6
Rosa spp.	3.8				1.8	0.1	
Rubus spp.	77.3	4.2	2.7	1.8	18.2	54.7	18.0
Sambucus canadensis	26.4	0.7	3.3	1.3	0.5	2.5	
Sassafras albidum	9.4			0.1	0.3	1.8	
Smilax glauca	50.9		9.4	3.0	7.5	2.1	52.8
S. rotundifolia	34.0	1.9	4.5	1.0	4.0	0.9	2.3
Ulmus americana	1.9						0.1
U. rubra	5.7	0.8	0.1	0.2			
Vaccinium spp.	18.9	0.5	1.1	0.2	0.1		2.4
Viburnum acerifolium	5.7				0.8		0.1
Vitis spp.	35.8	0.7	2.6	1.5	0.7	3.4	0.6

The Red Maple-Blackberry type (RMBB) is dominated by red maple (RD = 39.2) with Rubus having considerable mean relative density (RD = 18.2).

The Blackberry type (BB) is clearly dominated by Rubus spp. (RD = 54.7). Red maple is also important (RD = 11.1).

The Catbrier type (CB) is dominated by Smilax glauca (RD = 52.8) with Rubus spp. (RD = 18.0) and red maple (RD = 8.5) also important.

The discriminant analysis classification table (Table 8) of the six types illustrates the level of heterogeneity within the types, especially the loose structure of the RMLI type which achieved only a 30% correct classification. The plot of group centroids and members shows good separation, however (Figure 17). See Appendix G, Table 28, for the F-matrix table.

Ordination

Detrended correspondence analysis again failed to improve noticeably the reciprocal averaging ordination. The sample reciprocal averaging ordination (Figure 18) illustrates the level of separation between the BB and CB types and the overlap between the remaining four types. The TU, RM, RMLI and RMBB types are not well segregated. They are, however, generally arrayed along the first axis in the following order: TU, RM, RMLI, RMBB, followed by the CB and BB types. The only good separation along the second axis is between the CB type and all other types.

The first axis of the ordination explained 11.4% of the total variance and the second axis explained 11.6% of the total variance.

Table 8. Jackknifed Classification Success from Discriminant Analysis of Understory Types Using Species Relative Density.

Type	Percent Correct	Number of Cases Classified into Type					
		BB	CB	RM	RMBB	RMLI	TU
BB	76.9	10		1		1	1
CB	80.0		4			1	
RM	72.7			8	2		1
RMBB	81.8				9	1	1
RMLI	30.0	1	1	1	2	3	2
TURM	66.7					1	2
Total	67.9						

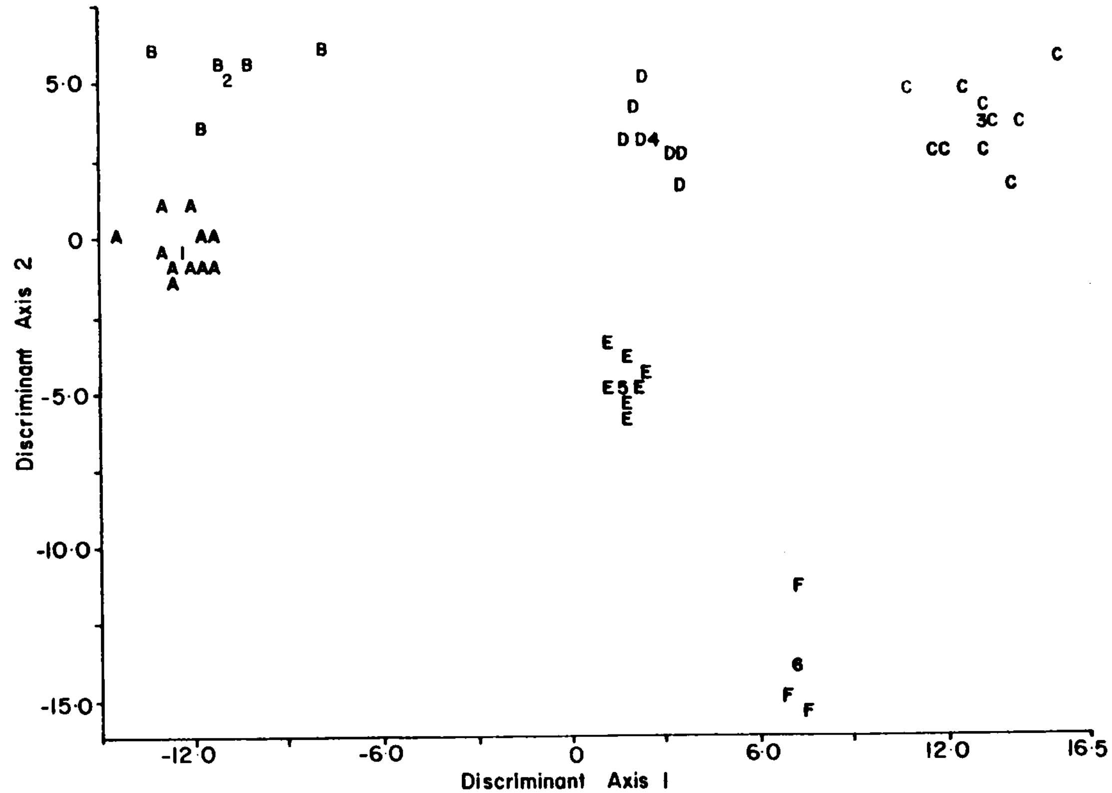

Figure 17. Understory Species Discriminant Analysis. The 1 and A refer to the group centroid and cases for the Blackberry-Red Maple type, respectively; 2 and B, Catbrier; 3 and C, Red Maple; 4 and D, Red Maple-Blackberry; 5 and E, Red Maple-Liana; 6 and C, Tulip.

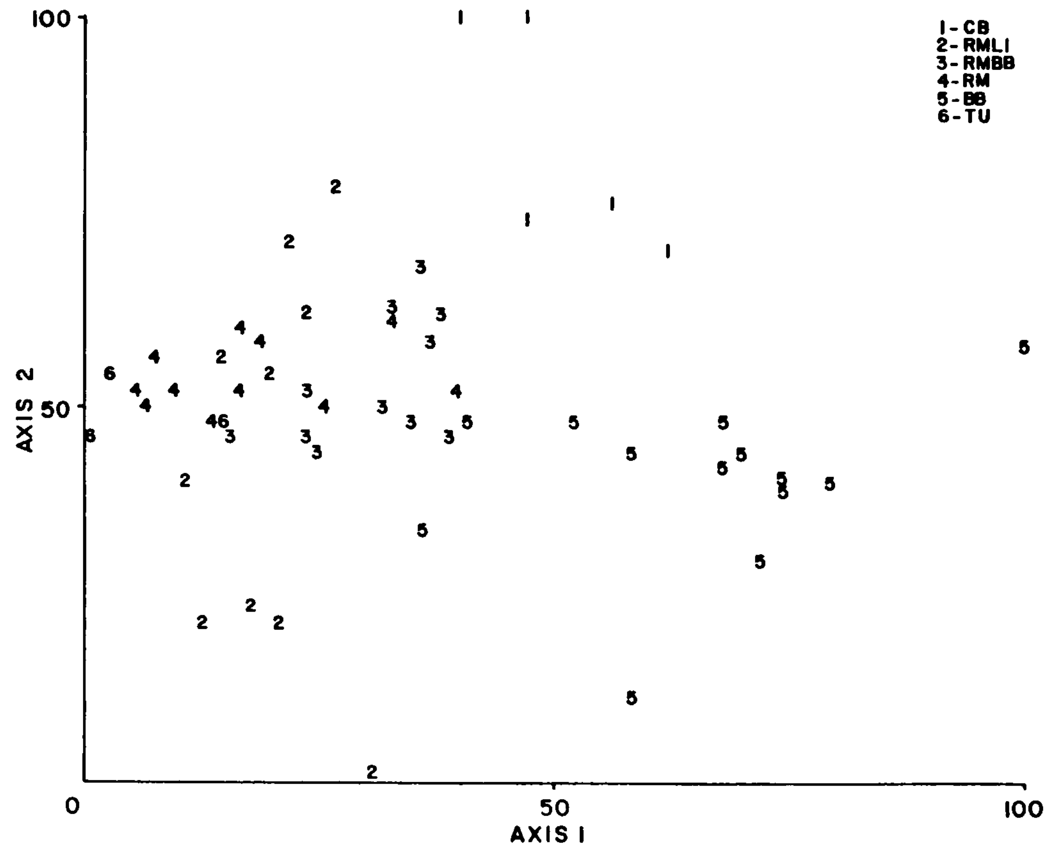

Figure 18. Reciprocal Averaging Sample Ordination of Understory Data Set.

Environmental interpretation of the ordination was approached as in the interpretation of the canopy ordination. The variable showing the clearest trend along the first axis was percent canopy closure (Figure 19). The linear regression was significant ($P \leq .001$, $r^2 = .409$). Percent canopy closure decreased as sample position increased, toward the BB end of the first axis.

Inspection of the species ordination (Figure 20, Table 9) shows a distribution along the first axis of such species as slippery elm, cucumber magnolia, tulip poplar and Parthenocissus quinquefolia at the TU and RM end of the ordination to smooth sumac, Rubus spp., sassafras and shortleaf pine at the BB end of the ordination. The species at the TU and RM end are generally more mesophytic as well as more shade tolerant than those species toward the BB end. Based on this species distribution and on the trend in percent canopy closure along the first ordination axis, a successional-moisture gradient is suggested as strongly influencing the sample and species order of the ordination first axis.

Along the second ordination axis, spoil pH was the only environmental variable measured which showed a significant relationship ($P \leq .01$, $r^2 = .111$) to sample position (Figure 21). Examination of the species ordination supports the interpretation of the second axis as a pH (or nutrient) axis. Ericads, such as Vaccinium spp., sourwood, Kalmia latifolia and Rhododendron spp. are arrayed toward the acidic end of the gradient, and species associated with less acidic soil, such as white ash, sugar maple and Parthenocissus quinquefolia, are arrayed toward the less acidic end of the gradient.

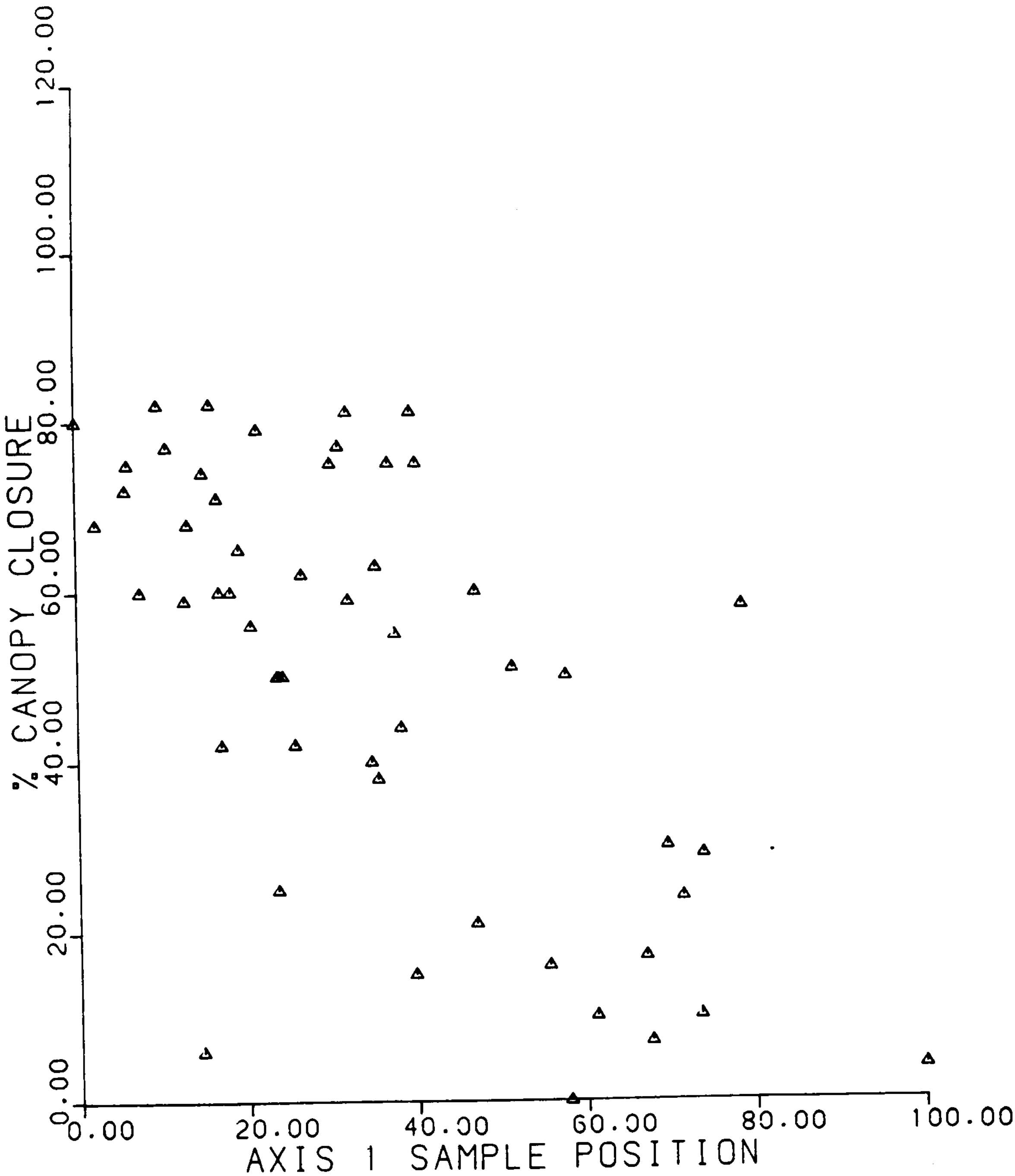

Figure 19. Trend of Decreasing Canopy Closure with Understory First Axis Sample Ordination Position. $P \leq .001$, $r^2 = .409$, D.F. = 1,50.

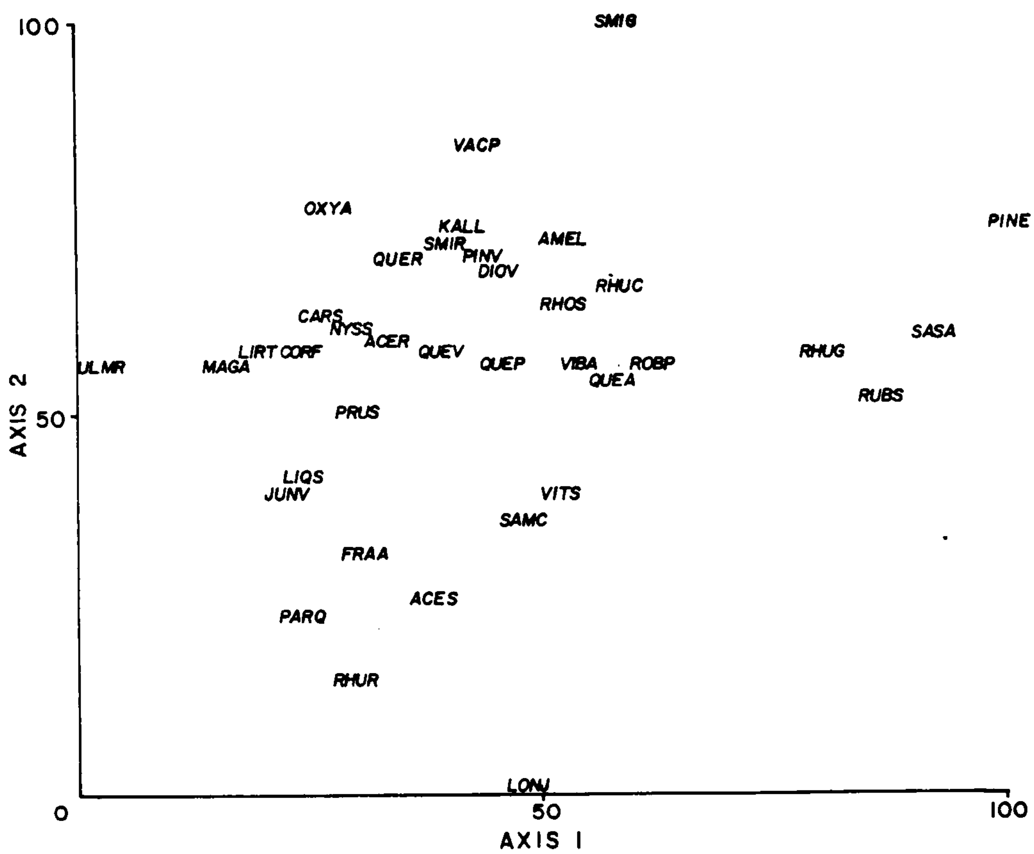

Figure 20. Reciprocal Averaging Species Ordination of Understory Data Set. See Table 9 for corresponding species names.

Table 9. Corresponding Names for Species Codes in Figure 20.

Code	Name
ACER	*Acer rubrum*
ACES	*A. saccharum*
AMEL	*Amelanchier spp.*
CARS	*Carya spp.*
CORF	*Cornus florida*
DIOV	*Diospyros virginiana*
FRAA	*Fraxinus americana*
JUNV	*Juniperus virginiana*
KALL	*Kalmia latifolia*
LIQS	*Liquidambar styraciflua*
LIRT	*Liriodendron tulipifera*
LONJ	*Lonicera japonica*
MAGA	*Magnolia acuminata*
NYSS	*Nyssa sylvatica*
OXYA	*Oxydendrum arboreum*
PARQ	*Parthenocissus quinquefolia*
PINE	*Pinus echinata*
PINV	*P. virginiana*
PRUS	*Prunus serotina*
QUEA	*Quercus alba*
QUEP	*Q. prinus*
QUER	*Q. rubra*
QUEV	*Q. velutina*
RHOS	*Rhododendron spp.*
RHUC	*Rhus copallina*
RHUG	*R. glabra*
RHUR	*R. radicans*
ROBP	*Robinia pseudo-acacia*
RUBS	*Rubus spp.*
SAMC	*Sambucus canadensis*
SASA	*Sassafras albidum*
SMIG	*Smilax glauca*
SMIR	*S. rotundifolia*
ULMR	*Ulmus rubra*
VACP	*Vaccinium spp.*
VIBA	*Viburnum acerifolium*
VITS	*Vitis spp.*

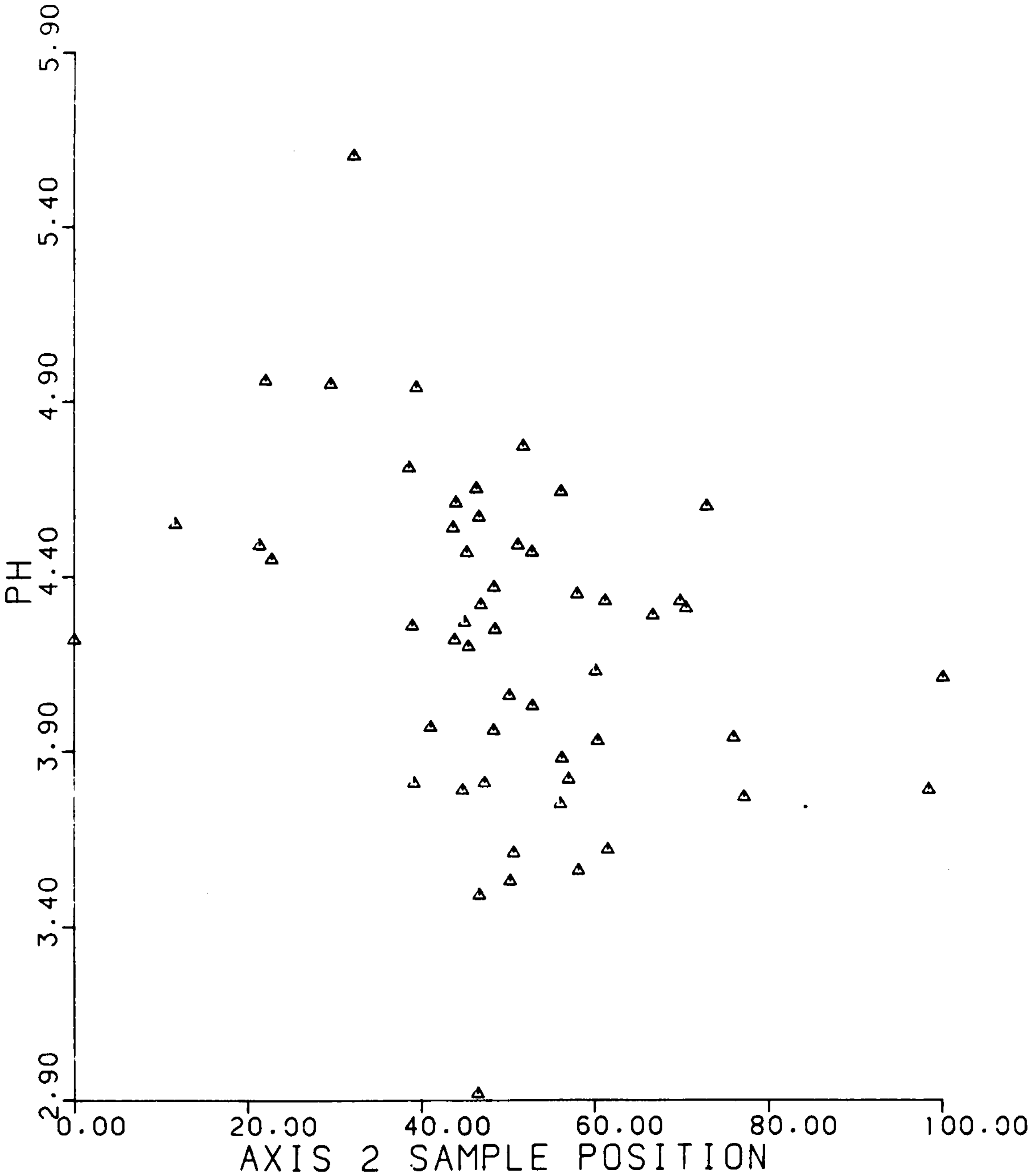

Figure 21. Trend of Decreasing pH with Understory Second Axis Sample Position. $P \leq .05$, $r^2 = .111$, D.F. = 1,51.

Discriminant Analysis

The total percent correct classification of the environmental discriminant analysis was 37.7. This low value and the plot of group centroids and their members illustrates the degree of environmental overlap between types (Figure 22). See Appendix G, Tables 29 and 30, for the classification and F-matrix tables. Reasons for the low percent correct classification may lie in two areas: poor initial classification based on the species variables and/or lack of sufficient environmental data. Although the groups were well separated along axis one and two of the species discriminant analysis (Figure 17, p. 78), the percent correct classification was only 67.9 and a great degree of overlap could be seen between some groups in the reciprocal averaging ordination. This indicates that the initial classification may not have been totally satisfactory. The first two discriminant axes explained 93.2% of the variance explained by the three significant axes.

The variable in the discriminant analysis most important along the first axis is chroma (Table 10). Although there are significant differences between mean chroma values by understory types, it is difficult to interpret exactly what this means. High chroma in spoil (≥ 3) may be indicative of highly weathered material, free of pyrites and their associated acidity. Low chroma (< 2) may indicate potentially high levels of pyrite (Grube et al. 1973, Sobek et al. 1978). Spoil pH, important along the ordination second axis, and chroma are significantly correlated ($\alpha = .05$, $r = .387$) but the ordering of groups along the first discriminant function is in no way similar to the ordering of samples along the second ordination axis. If chroma

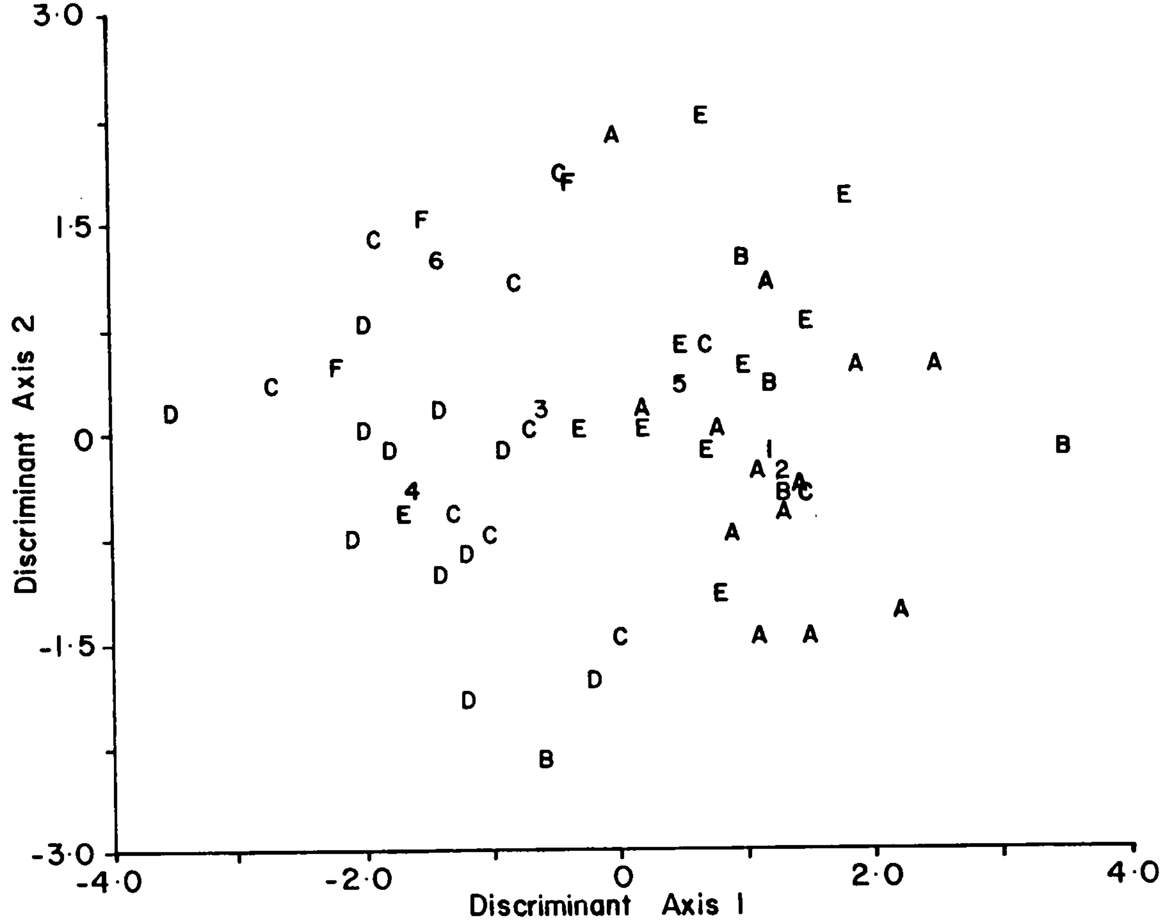

Figure 22. Understory Environmental Discriminant Analysis. The 1 and A refer to the group centroid and cases for the Blackberry-Red Maple type, respectively; 2 and B, Catbrier; 3 and C, Red Maple; 4 and D, Red Maple-Blackberry; 5 and E, Red Maple-Liana; 6 and C, Tulip.

Table 10. Means, Canonical Coefficients and Significance Tests[a] of Environmental Variables Entered into the Final Discriminant Function in Discriminant Analysis of Understory Types.[b]

Variable	Understory Type[c]						P ≤	D.F.	Canonical Coefficient	
	TU	RMLI	RM	RMBB	BB	CB			Axis 1	Axis 2
Color Chroma	2.9 (0.6) A B	3.1 (0.6) A B	2.7 (0.6) B	2.0 (0.3) C	3.2 (0.5) A	3.1 (0.9) A B	.001	5,47	.9510	.5492
Perpendicular Slope Angle (%)	73.0 (2.6)	36.0 (18.5)	44.4 (22.5)	45.3 (20.2)	41.5 (22.1)	29.6 (20.1)	NS	5,47	-.6057	.3064
Canopy Closure (%)	74.0 (6.0) A	57.1 (21.5) A B	60.4 (18.4) A B	58.6 (18.9) A B	32.8 (21.6) C	37.6 (31.2) B C	.01	5,46	-.6141	.6143
Number of Plots	3	10	11	11	13	5				

[a]Analysis of variance and Duncan's multiple range test of difference between means. (D.F.=47,47, 46 for chroma, slope and canopy closure, respectively).

[b]Other variables used in discriminant analysis but not entered into final function: % spoil < 2mm, % clay, pH, relief, parallel slope, highwall height, seam, age, aspect, and canopy type.

[c]Figures in parentheses are standard deviations; means with different letters are significantly different at $\alpha = .05$.

is indicative of a nutrient axis, it does not appear to be related to the nutrient axis of the ordination second axis.

Perpendicular slope angle was important along the first discriminant axis, also. However, the analysis of variance of this variable across the types failed to be significant. The discriminant analysis was supportive of the ordination interpretation, in that percent canopy closure was the most important variable along the second discriminant axis, corresponding to the first ordination axis.

Relationship to Canopy Types

The relationship between the understory and overstory classifications was quantified using a measure of association (or similarity index) presented by Goodman and Kruskal (1954). This analysis is outlined by McCarthy (1976) and has been used by Grigal and Goldstein (1971) and McCarthy in comparing classifications. The measure, G, has a value of + 1 when perfect correspondence between classifications occurs, a value of 0 when the classifications are totally independent. The similarity index between the understory and overstory classification is G = .065. This indicated very little association between the two strata.

Discussion

The environmental discriminant analysis was not very successful in distinguishing between understory types in terms of classification success or in ease of interpretation of the discriminant functions. As mentioned above, even the classification success of the species discriminant analysis was not impressive. Certain key environmental variables, as mentioned previously, were not measured directly in this study (i.e., moisture and element content of the spoil). Inclusion of these variables and, perhaps, a more satisfactory initial classification would have improved discrimination.

On the other hand, the reciprocal averaging ordination proved relatively interpretable in terms of environmental gradients; so, those results are taken to be a more trustworthy representation of the distribution of understory species on the mine. The first axis was interpreted as a successional-moisture gradient; the second axis was related to a pH or indirectly, a nutrient axis.

The understory consists primarily of tree species which also occur in the canopy. A shrub layer is not well developed. Of the shrub species, only the *Rubus spp*. are common (constancy = 77%). Of the woody vines, only the *Smilax spp*. are common (*S. glauca* constancy = 51%, *S. rotundifolia* constancy = 34%). Given the abundance of *Rubus spp*., it is not surprising that their environmental preference for high light conditions helped define one of the environmental gradients along which species and types were distributed along the first ordination axis. Other species in the understory which are particularly sensitive to light conditions and that were found in the species ordination graph with *Rubus spp*. were smooth sumac and shortleaf pine. Of course, these species are also adapted to dry conditions.

The lack of association between the canopy and understory classification can be partially explained by the fact that the understory, while responding to moisture and nutrients as did the canopy, also responded to the gradient produced by canopy closure.

Canopy closure was significantly correlated to age of the mine (α = .05, r = .335). However, the canopy closure also relates to growth conditions within the mine. For example, the bench plots were slower to colonize because a suitable substrate was not available for plant growth until a certain minimal amount of colluvium had formed at the base of the highwall. The vegetation which colonized this area has also been subject to disturbance as new colluvium formed. Thus, vegetation development on these areas was delayed relative to the crest or outslope relief positions which provided a suitable substrate very soon, if not immediately, after mining. Another area on the mine, not sampled in this study, which is slow to colonize is the "pit" area, the area between the colluvium of the highwall and the spoil bank, which is essentially an exposed unconsolidated and often very toxic shale substrate. The presence of this pit between the highwall and spoil bank allows the continuance of high light conditions after colonization of the crest and bench relief conditions through the effects of side-lighting. It is not surprising that 85% of the BB plots occurred on either the bench or crest plots. The Rubus spp. seemed able to tolerate a wide range of nutrient and moisture conditions, judging by its abundance in all the canopy types (Table 2, page 40) with the exception of the canopy TU type which had a significantly higher percent canopy closure than the other types (Table 3, page 42).

CHAPTER VII

GROUND COVER

Results and Discussion

Reciprocal averaging ordination was performed on the ground cover data set using cover as the species value. After elimination of species with less than 10% constancy in the mine plots and elimination of one sample outlier, the data set consisted of 58 species and 52 plots. The average number of species per plot was 17.2 $\pm$ 5.8 S.D. and the average total percent cover was 43.2 $\pm$ 3.3 S.D. The percent constancy and overall mean percent cover are presented for species with at least 5% constancy in Table 11. An examination of this table shows the preponderance of wind dispersed species, a large number of which are members of the Asteraceae.

The reciprocal averaging ordination was severely affected by the arch effect common to data sets of high beta diversity, rendering the second axis uninterpretable. Detrended correspondence analysis gave an ordination not noticeably affected by arching (Figure 23) and therefore interpretation was based on this analysis. The rescaling option of detrended correspondence analysis was not invoked, leaving the first detrended axis identical to that of the first reciprocal averaging axis. The first axis explained 14.1% of the total variance; the second axis explained 9.4% of the total variance.

A plot of spoil pH versus first axis sample position revealed that pH was correlated with first axis sample ordering (Figure 24).

Table 11. Constancy and Mean Percent Cover of Ground Cover Species in Mine Plots.[a]

Species	Constancy	Cover
Acalypha virginica	13.2	1.3
Acer rubrum	92.5	4.0
Agrostis spp.	20.7	1.2
Ambrosia artemisiifolia	18.9	1.3
Amelanchier spp.	5.7	1.0
Andropogon virginicus	37.7	2.3
Anemonella thalictroides (L.) Spach -F,G	5.7	1.0
Aster cordifolius	9.4	1.8
A. divaricatus	18.9	2.9
A. lateriflorus	41.5	1.6
A. surculosus	5.7	2.3
A. spp.	52.8	1.1
A. undulatus	15.1	1.1
Bidens vulgata	32.1	1.1
Campanula divaricata	18.9	1.6
Carex spp.	15.1	1.1
Chimaphila maculata	9.4	1.0
Clematis virginiana	13.2	5.6
Coreopsis major	30.2	1.9
Cornus florida	11.3	1.5
Cunila origanoides	5.7	1.3
Danthonia spicata	24.5	1.7
Desmodium spp.	9.4	1.2
Erechtites hieracifolia	41.5	1.1
Eupatorium purpureum	41.5	3.7
E. rugosum	56.6	8.1
E. serotinum	9.4	1.4
E. spp.	13.2	1.7
Fraxinus americana	11.3	1.5
Gillenia trifoliata	5.7	1.3
Helianthus microcephalus	32.1	3.8
Impatiens pallida	5.7	10.7
Lactuca floridana	34.0	1.2
Lespedeza intermedia	5.7	1.3
Linum striatum	5.7	1.0
Liriodendron tulipifera	54.7	2.4
Lonicera japonica	17.0	4.8
Lysimachia quadrifolia	9.4	1.6
Microstegium vimineum	20.7	21.3
Muhlenbergia schreberi	5.7	1.0
M. tenuiflora	9.4	1.0
Nyssa sylvatica	20.7	1.1
Oxydendrum arboreum	13.2	1.7
Panicum boscii	13.2	1.3
P. clandestinum	9.4	4.2

Table 11. (continued)

Species	Constancy	Cover
P. commutatum	28.3	1.1
P. dichotomum	35.8	1.4
P. lanuginosum	7.5	1.5
P. spp.	20.7	1.0
Parthenocissus quinquefolia	54.7	3.2
Phytolacca americana	60.4	2.4
Pinus echinata	20.7	1.6
Pinus spp.	15.1	1.1
Pinus virginiana	9.4	1.4
Polygonum spp.	24.5	1.1
Polystichum acrostichoides	9.4	1.2
Potentilla simplex	11.3	4.0
Prenanthes altissima	11.3	1.0
Prunus serotina	7.5	1.0
Pycnanthemum incanum	5.7	1.0
Quercus alba	11.3	1.3
Q. prinus	20.7	1.6
Q. rubra	15.1	1.6
Q. velutina	22.6	1.5
Rhododendron spp.	9.4	1.2
Rhus radicans	32.1	4.6
Robinia pseudo-acacia	13.2	1.3
Rubus spp.	96.2	2.7
Sambucus canadensis	18.9	2.0
Senecio spp.	9.4	1.4
Smilax glauca	71.7	2.2
S. rotundifolia	49.0	1.4
Solidago arguta	9.4	2.0
S. caesia	52.8	4.4
S. canadensis v. scabra (Muhl.) T.&G.	5.7	1.7
S. flaccidifolia Small-G	15.1	5.4
S. spp.	32.1	1.5
S. sphacelata	7.5	1.3
Vaccinium spp.	20.7	1.4
Viola spp.	28.3	1.3
Vitis spp.	9.4	2.2
Unknown Asteraceae	13.2	1.3
Unknown Fabaceae	11.3	1.3
Unknown Gramineae	28.3	1.1

[a]See Appendix H for list of species with < 5% constancy in mine plots.

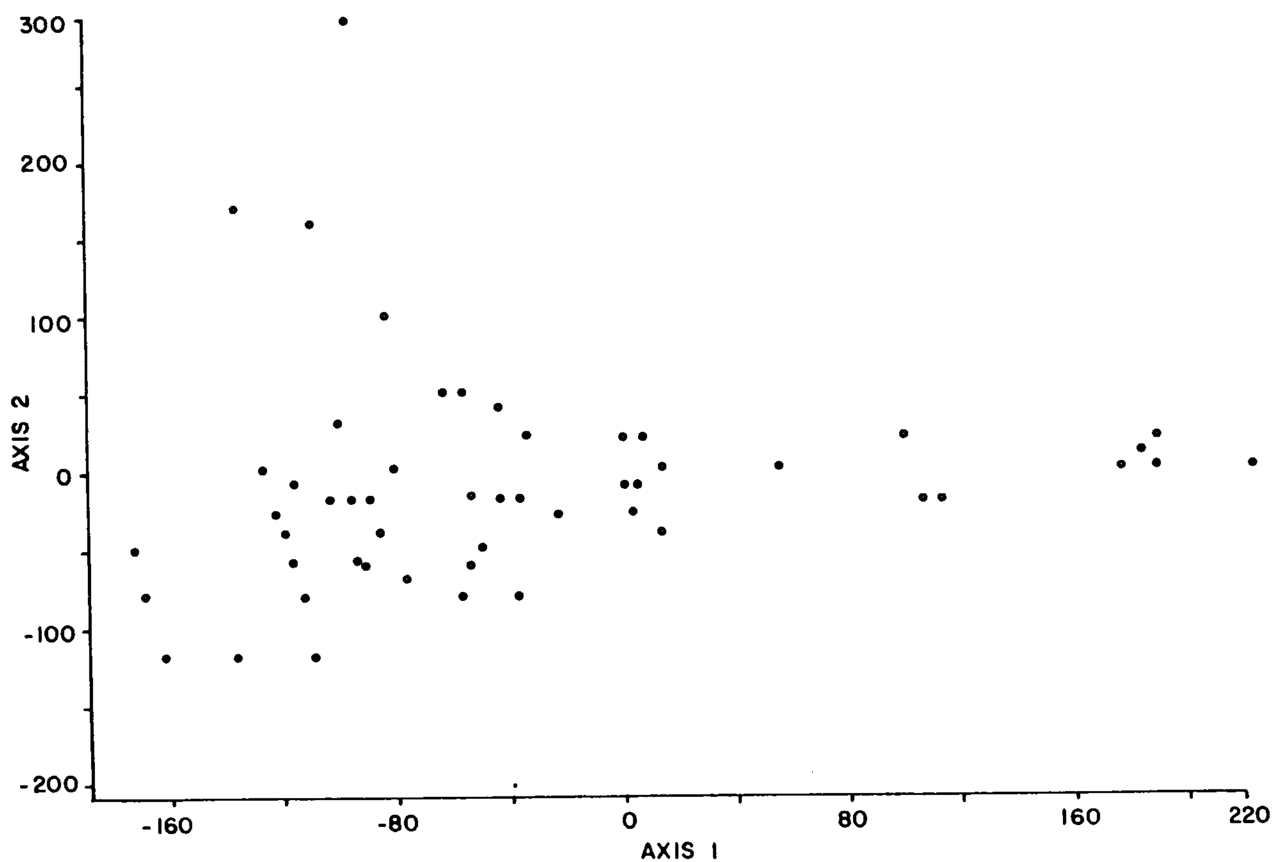

Figure 23. Sample Detrended Correspondence Analysis of Ground Cover Data Set.

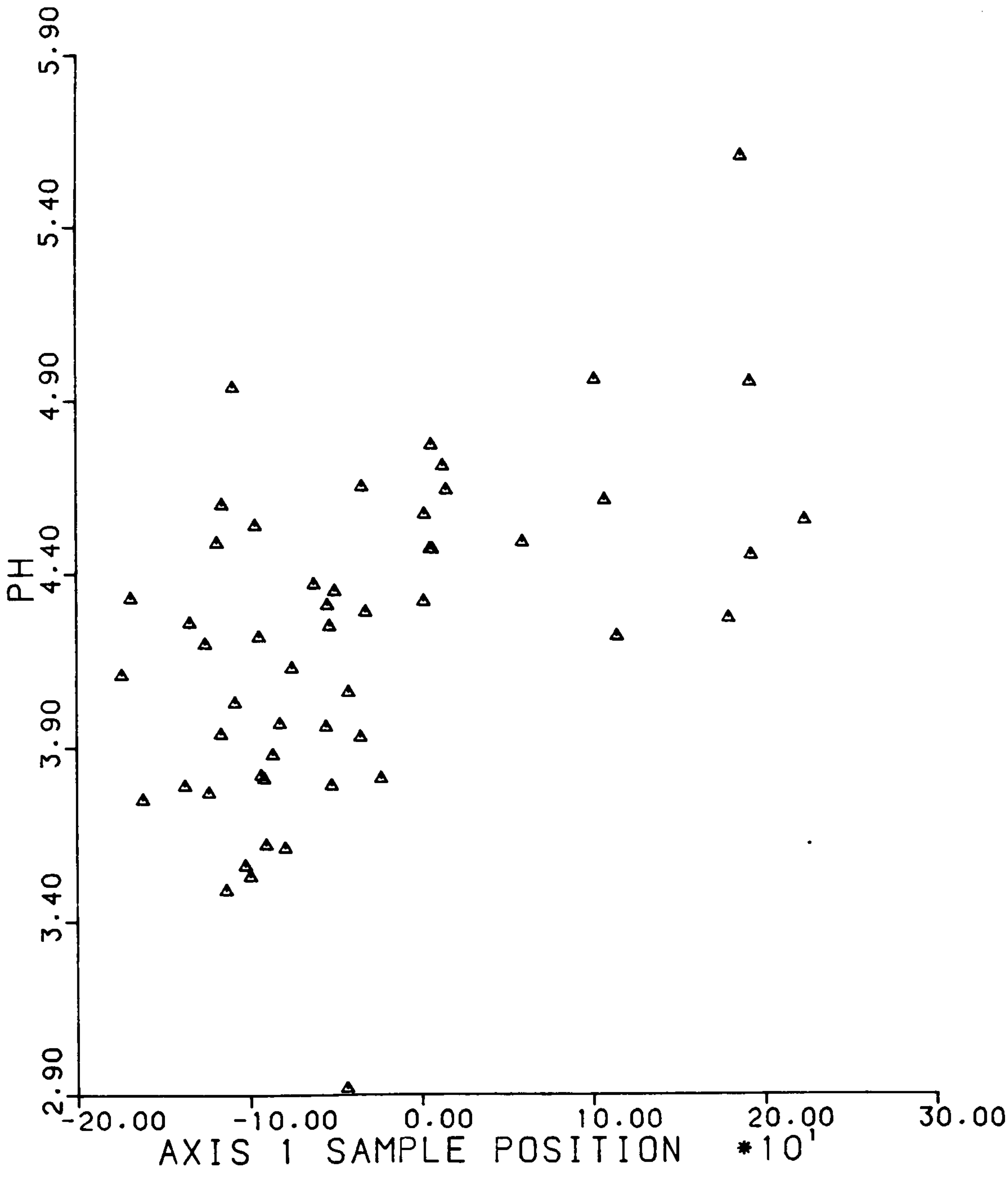

Figure 24. Trend of Increasing pH with Ground Cover First Axis Sample Ordination Position. $P \leq .001$, $r^2 = .278$, D.F. = 1,50.

Simple linear regression of pH on sample first axis position was significant ($P \leq .001$, $r^2 = .278$). Based on species environmental preferences the first axis also appears to be partially related to moisture (Figure 25, Table 12). Species such as Microstegium vimineum and Clematis virginiana have a distinct preference for the more moist sites and are located at opposite ends of the first axis of the species ordination from species such as Andropogon virginicus, Panicum commutatum and sourwood which here are dry site species tolerant of low pH.

The second axis was more difficult to interpret even though detrended. Spoil pH was slightly although significantly dependent on second axis sample order ($P \leq .05$, $r^2 = .076$) (Figure 26) but no other environmental gradients could be discerned on the basis of either environmental variable relationships to sample position or species-site preferences.

When canopy types were plotted on the ground cover sample ordination, a relationship between canopy type and ground cover position became apparent. Simple linear regressions were performed between the IV of the major canopy species (red maple, Virginia and shortleaf pine, tulip poplar and black locust) and the sample position on the first and second axes. Only positive values of the species were entered in the analysis. This revealed a positive significant relationship between black locust and sample position on both axes (Figures 27 and 28) and a negative relationship between shortleaf pine and sample position on both axes (Figures 29 and 30). Based on these relationships, it is probable that the ground cover component of the vegetation responds to the same environmental gradients as the canopy, i.e., moisture and nutrients, and

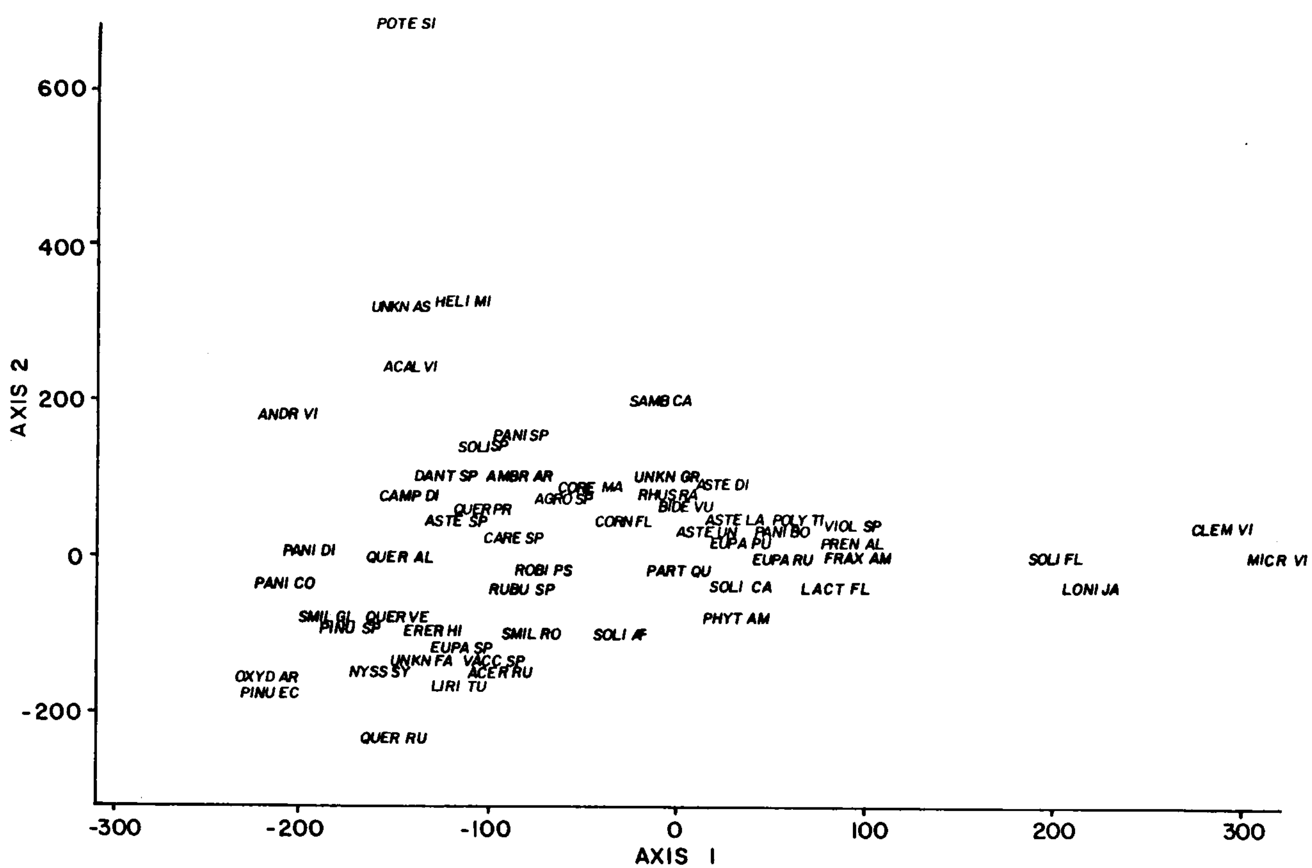

Figure 25. Species Detrended Correspondence Analysis of Ground Cover Data Set. See Table 12 for corresponding names.

Table 12. Corresponding Names for Species Codes in Figure 25.

Code	Names	Code	Names
ACAL VI	Acalypha virginica	PANI CO	P. commutatum
ACER RU	Acer rubrum	PANI DI	P. dichotomum
AGRO SP	Agrostis spp.	PANI SP	P. spp.
AMBR AR	Ambrosia artemisiifolia	PART QU	Parthenocissus quinquefolia
ANDR VI	Andropogon virginicus	PHYT AM	Phytolacca americana
ASTE DI	Aster divaricatus	PINU EC	Pinus echinata
ASTE LA	A. lateriflorus	PINU SP	P. spp.
ASTE SP	A. spp.	POLY TI	Polygonum spp.
ASTE UN	A. undulatus	POTE SI	Potentilla simplex
BIDE VU	Bidens vulgata	PREN AL	Prenanthes altissima
CAMP DI	Campanula divaricata	QUER AL	Quercus alba
CARE SP	Carex spp.	QUER PR	Q. prinus
CLEM VI	Clematis virginiana	QUER RU	Q. rubra
CORE MA	Coreopsis major	QUER VE	Q. velutina
CORN FL	Cornus florida	RHUS RA	Rhus radicans
DANT SP	Danthonia spicata	ROBI PS	Robinia pseudo-acacia
EREC HI	Erechtites hieracifolia	RUBU SP	Rubus spp.
EUPA PU	Eupatorium purpureum	SAMB CA	Sambucus canadensis
EUPA RU	E. rugosum	SMIL GL	Smilax glauca
EUPA SP	E. spp.	SMIL RO	S. rotundifolia
FRAX AM	Fraxinus americana	SOLI CA	Solidago caesia
HELI MI	Helianthus microcephalus	SOLI FL	S. flaccidifolia
LACT FL	Lactuca floridana	SOLI SP	S. spp.
LIRI TU	Liriodendron tulipifera	SOLI AF	S. spp. 2
LONI JA	Lonicera japonica	VACC SP	Vaccinium spp.
MICR VI	Microstegium vimineum	VIOL SP	Viola spp.
NYSS SY	Nyssa sylvatica	UNKN AS	Unknown Asteraceae
OXYD AR	Oxydendrum arboreum	UNKN FA	Unknown Fabaceae
PANI BO	Panicum boscii	UNKN GR	Unknown Gramineae

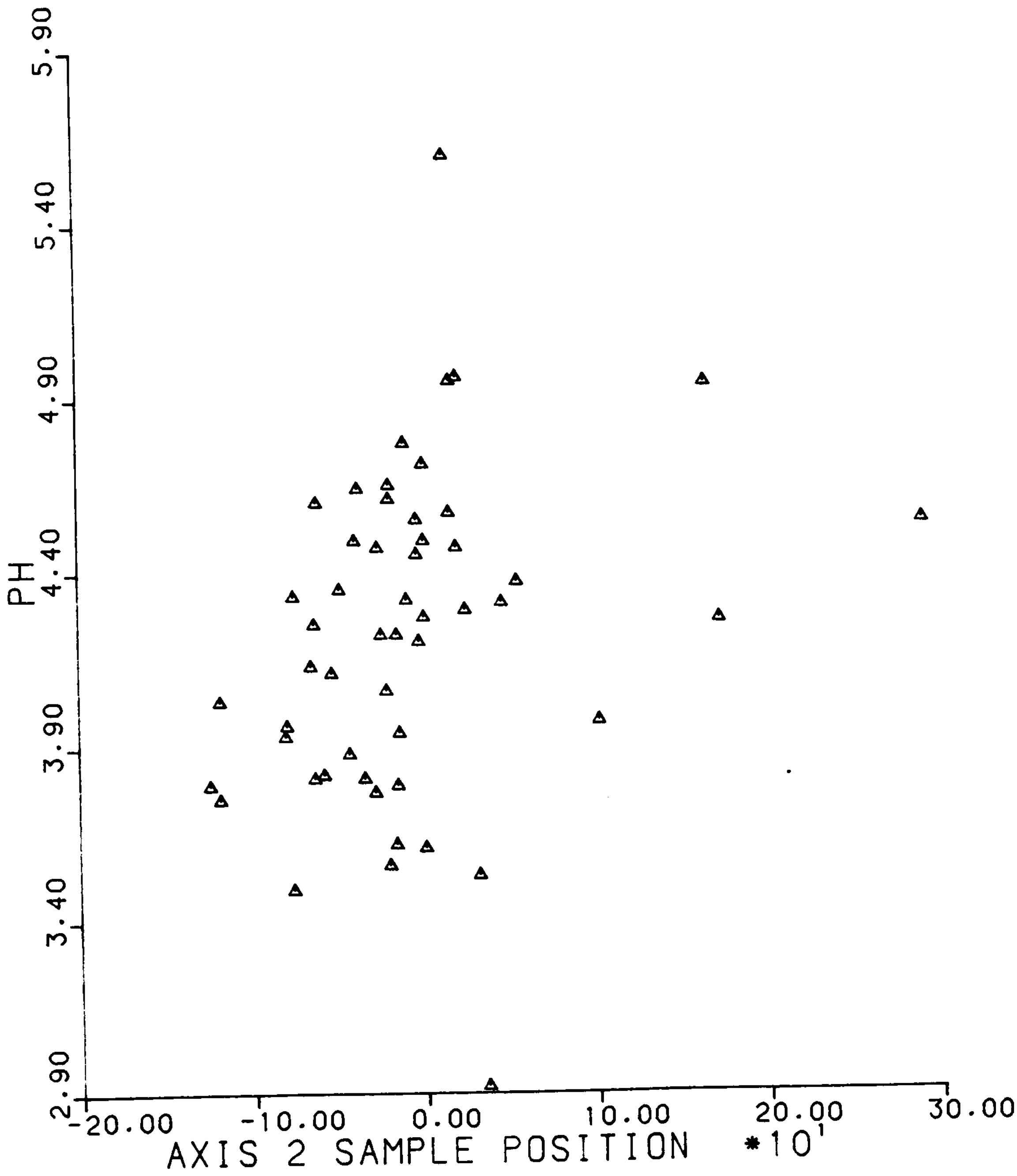

Figure 26. Trend of Increasing pH with Ground Cover Second Axis Sample Ordination Position. $P \leq .05$, $r^2 = .076$, D.F. = 1,50.

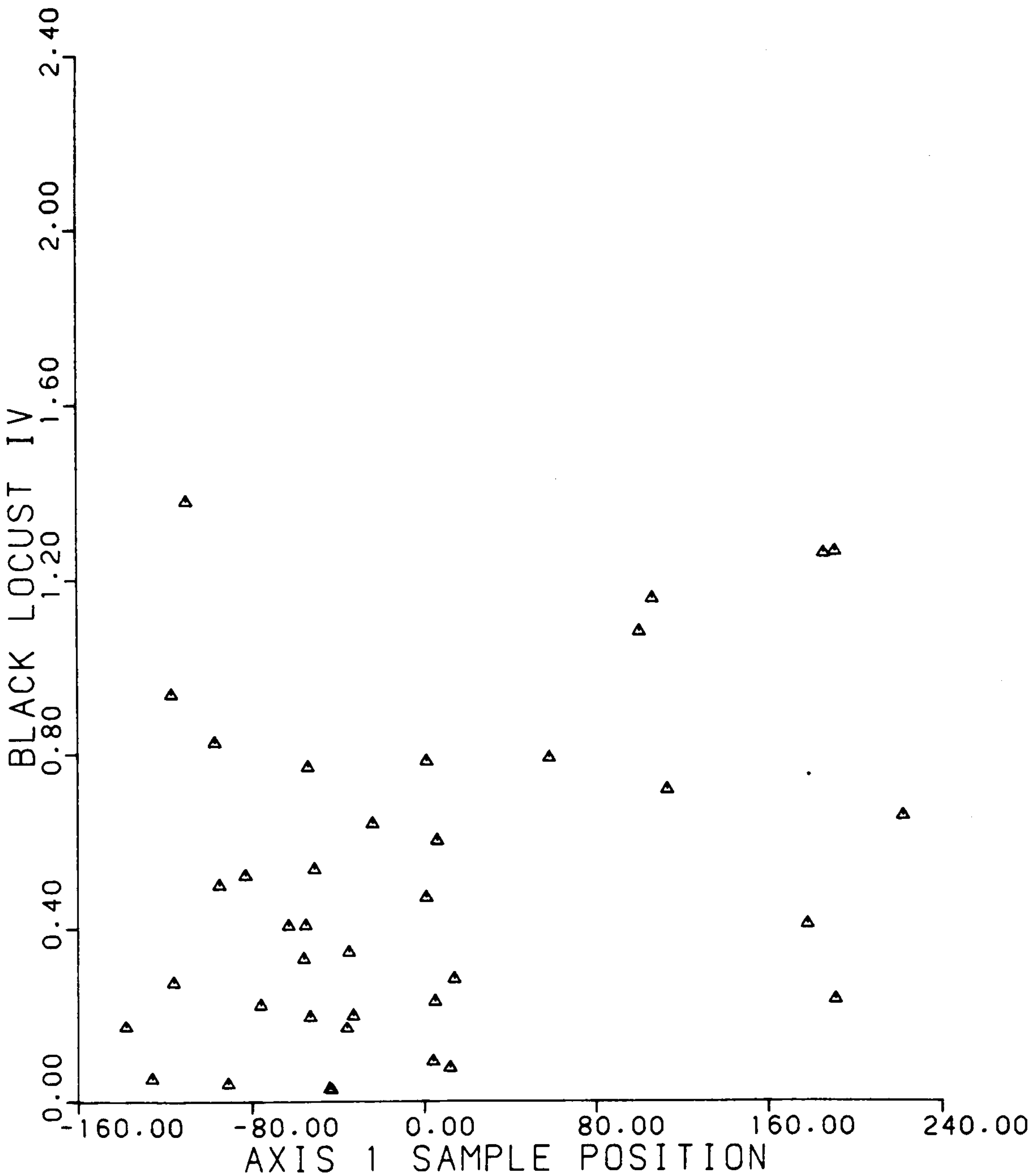

Figure 27. Trend of Increasing Canopy Black Locust IV with Ground Cover First Axis Sample Ordination Position. $P \leq .05$, $r^2 = .133$, D.F. = 1,36.

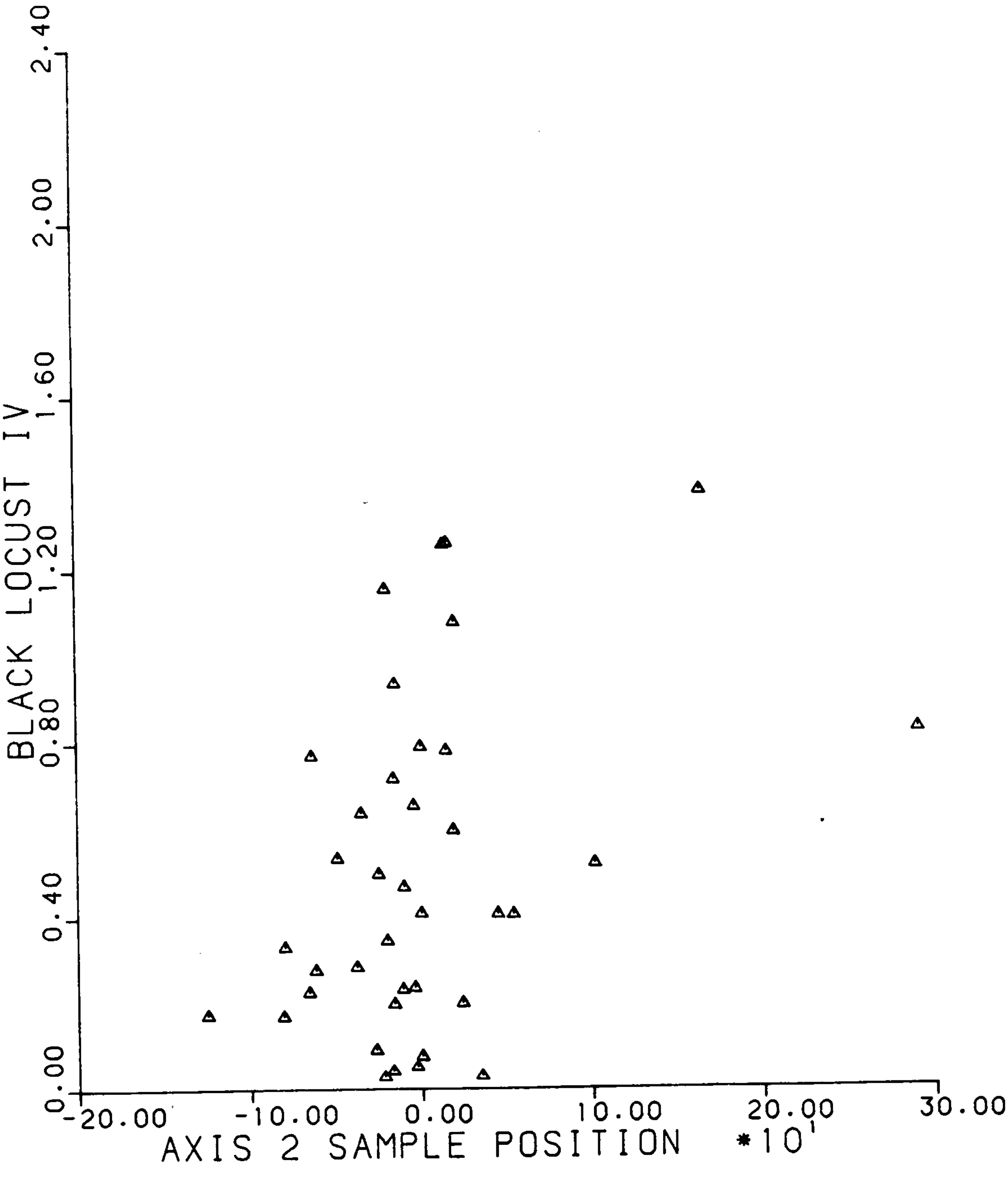

Figure 28. Trend of Increasing Canopy Black Locust IV with Ground Cover Second Axis Sample Ordination Position. $P \leq .05$, $r^2 = .139$, D.F. = 1,36.

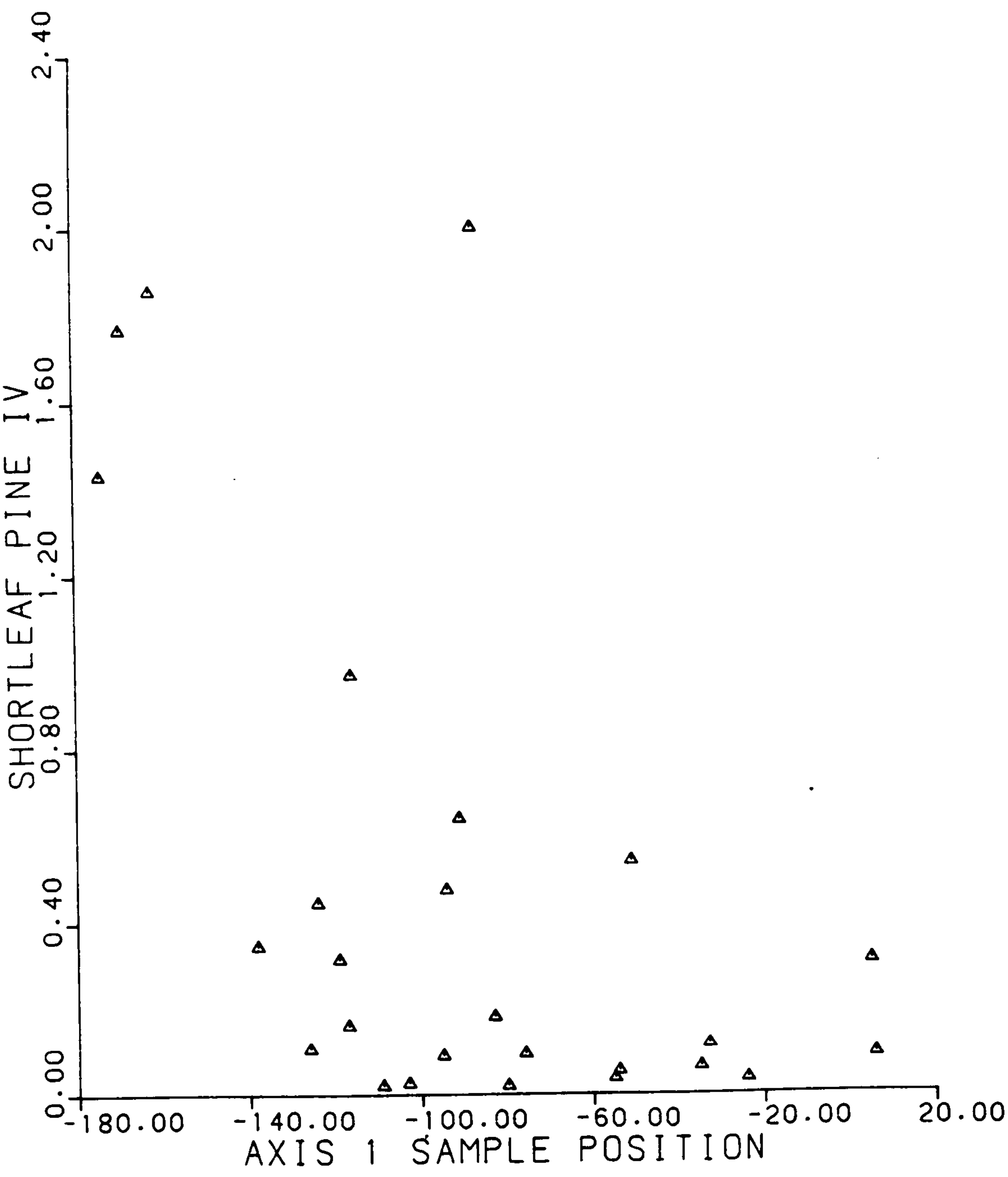

Figure 29. Trend of Decreasing Canopy Shortleaf Pine IV with Ground Cover First Axis Sample Ordination Position. $P \leq .01$, $r^2 = .294$, D.F. = 1, 24.

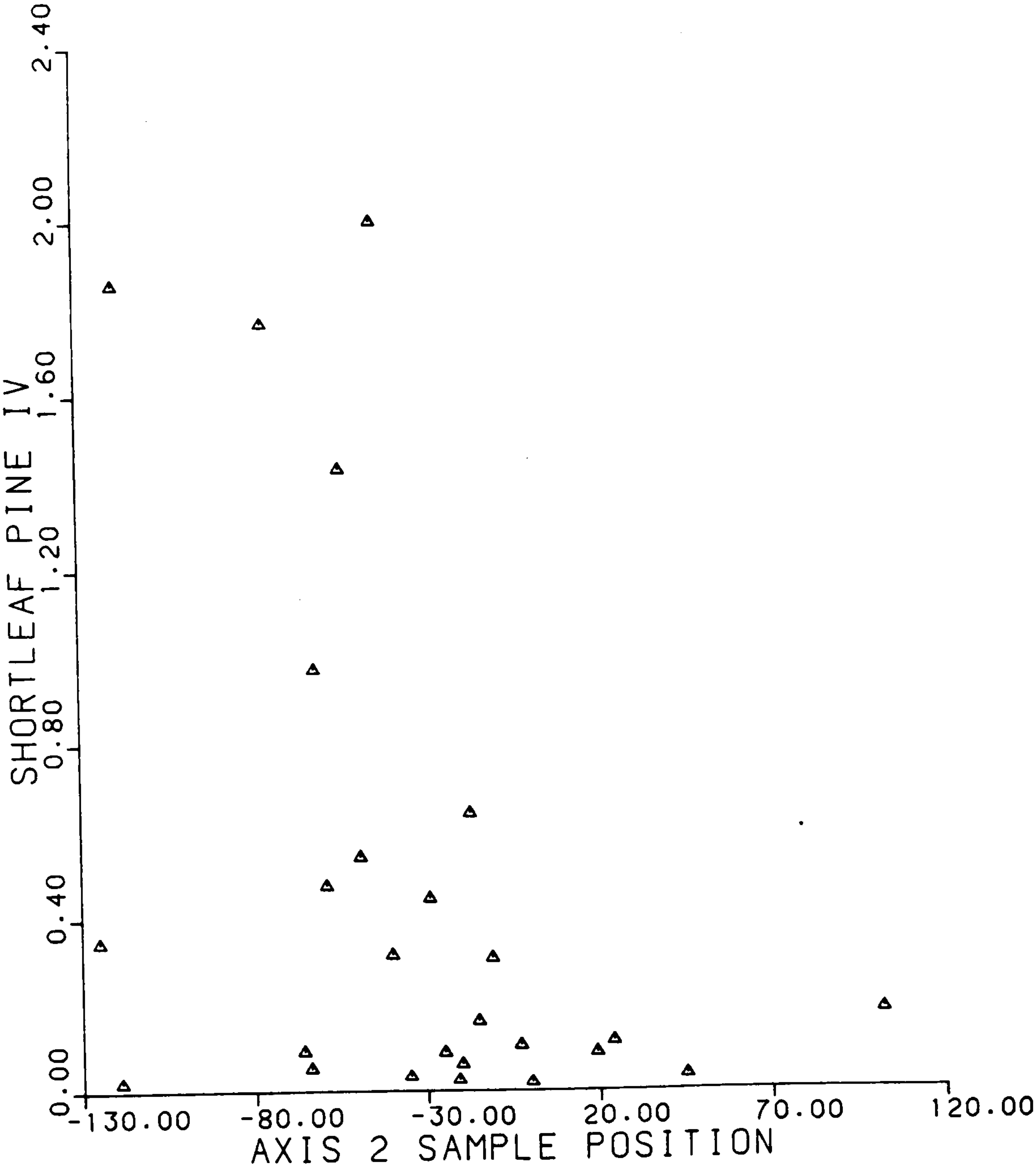

Figure 30. Trend of Decreasing Canopy Shortleaf Pine IV with Ground Cover Second Axis Sample Ordination Position. $P \leq .05$, $r^2 = .161$, D.F. = 1,24.

in addition may be responding to environmental conditions contributed by the canopy itself. However, it is interesting to note that no clear trend could be seen between canopy closure and either axis. Thus, the ground cover does not appear to respond to one of the major environmental factors correlating with the understory vegetation.

CHAPTER VIII

RELATIONSHIP OF MINE VEGETATION TO UNDISTURBED VEGETATION

Character of Undisturbed Vegetation

The most common stand type encountered in the undisturbed vegetation was one dominated by chestnut oak. This species occurred in 23 of the 27 undisturbed samples (85%) with an overall mean IV of 50.4, based on all stems > 2.5 cm DBH. Red maple was important in nearly all stands with a mean IV of 55.8 and constancy of 100%. Several stands were dominated by tulip poplar. This species occurred in 61% of the samples, with a mean IV of 14.6. Black locust and the pines were not as commonly encountered and their abundance was limited. The mean densities and constancy of the woody species encountered in the sampling of the undisturbed vegetation are listed in Table 13. A comparison of the species lists in Table 13 with those of Table 7, page 74, reveals that only species found infrequently on the mine or infrequently in the undisturbed vegetation were not found in both types of vegetation. Examples of species which were sampled on the mine but not in the undisturbed vegetation are hackberry, black walnut and red cedar; species not sampled on the mine which were sampled in the undisturbed vegetation were striped maple, basswood and chestnut.

The recent disturbance history of the undisturbed vegetation was documented by the presence of stumps and double trunked trees indicating selective logging (30% plots), fire scars and charred wood indicating

Table 13. Mean Density and Constancy of Woody Species in Undisturbed Vegetation.

Species	Constancy (%)	Density (stems/ha)
A. pensylvanicum	7.4	2
Acer rubrum	100.0	1371
A. saccharum	48.1	220
Aesculus octandra	11.1	3
Amelanchier spp.	51.9	86
Betula lenta	11.1	3
Carya spp.	85.1	71
Castanea dentata	3.7	1
Cercis canadensis	18.5	52
Cornus florida	88.9	533
Crataegus spp.	3.7	1
Diospyros virginiana	3.7	2
Euonymous americanus	3.7	1
Fraxinus americana	51.9	60
Hydrangea arborescens	3.7	15
Kalmia latifolia	18.5	370
Liquidambar styraciflua	3.7	12
Liriodendron tulipfera	70.4	136
Magnolia acuminata	14.8	10
Morus rubra	7.4	5
Nyssa sylvatica	92.6	655
Oxydendrum arboreum	77.8	274
Parthenocissus quinquefolia	25.9	66
Pinus echinata	22.2	42
P. virginiana	18.5	10
Prunus serotina	33.3	24
Quercus alba	59.3	35
Q. coccinea	25.9	20
Q. prinus	85.2	523
Q. rubra	88.9	124
Q. velutina	48.1	34
Rhododendron spp.	40.7	160
Rhus glabra	18.5	14
R. radicans	3.7	4
Robinia pseudo-acacia	29.6	71
Rubus spp.	7.4	19
Sambucus canadensis	3.7	1
Sassafras albidum	18.5	20
Smilax glauca	44.4	78
S. rotundifolia	63.0	602
Tilia heterophylla	3.7	1

Table 13. (continued)

Species	Constancy (%)	Density (stems/ha)
Ulmus alata	11.1	18
Vaccinium spp.	66.7	406
Viburnum acerifolium	44.4	452
Vitis spp.	40.7	95

fire disturbance (63% plots), and tip-ups and damaged trees indicating wind damage (11% plots). Thus, although not disturbed by mining these stands surrounding the mines have a disturbance history which would promote the patchy distribution of species adapted to relatively long distance dispersal of seed. Of course, the present day forests only approximate the composition and the size class distribution of the forest at the time of mining 12-23 years before sampling.

Table 14 shows selected species' mean size class distributions based on the total number of undisturbed samples. Note the preponderance of red maple in the smaller size classes and the relatively low density of this species in the larger, seed producing size classes. By contrast, chestnut oak has the highest density in the larger size classes. Black locust and Virginia pine are conspicuously absent from the larger size classes.

Ordination

The reciprocal averaging ordination of the total woody data set illustrates the overall relationship between the species composition of of the mine and the undisturbed vegetation. This data set was transformed to presence/absence mode for comparison of the mine and undisturbed vegetation. Detrended correspondence analysis did not appreciably change the reciprocal averaging order of samples or species; therefore, interpretation was based on reciprocal averaging. The first axis explained 11.6% of the total variance, the second axis explained 10.3% of the total variance.

The sample ordination shows that the major separation of mine and undisturbed samples occurs along the second axis (Figure 31).

Table 14. Mean Size Class Distribution of Selected Species from Undisturbed Samples (N=27).

Species	Diameter Size Classes (cm)											
	0-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	> 55
Acer rubrum	943	282	71	33	5	9	4	5	3			
A. saccharum	174	29	6	3	3			1				
Carya spp.	43	4	2	2		5	4	1	1			1
Cercis canadensis	46	6										
Fraxinus americana	53	3										
Lirodendron tulipfera	67	31	14	4	7		4	6			3	1
Nyssa sylvatica	578	27	6	3	2	2	1				1	
Oxydendron arboreum	206	48	9	6	1	1						
Pinus echinata	12	9	4	6	3	6	1					
Pinus virginiana	6											
Quercus alba	12	11	2		2	5	2	6			1	1
Q. coccinea	11	1	2		2	1	2	2				
Q. prinus	278	79	40	28	15	19	19	8	8	2		5
Q. rubra	84	12	6	3	2	4	3	4	3			
Q. velutina	17	6	4	1	3		2		1			
Robinia pseudo-acacia	45	21	2	1			1					

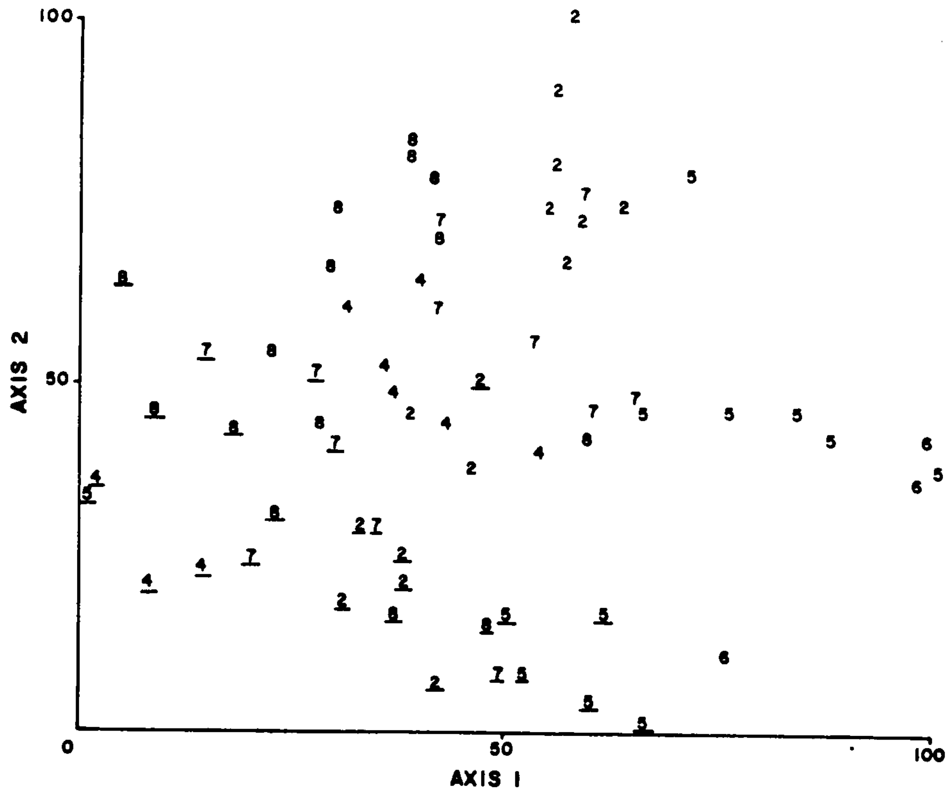

Figure 31. Sample Reciprocal Averaging Ordination of the Total Woody Species Data Set. Numbers refer to the mine on which the sample was taken; those underlined are undisturbed samples.

As would be expected, the species ordination (Figure 32, Table 15) illustrates a preponderance of widely dispersed species at the far end of the second species axis. These include the pines, smooth sumac, persimmon, *Rubus* *spp*. and *Lonicera japonica*. At the other extreme occur species such as buckeye and hickories which do not occur in great abundance in these stands, and whose seeds are less widely dispersed and whose germination requirements are perhaps more exacting. Species such as the oaks, black gum, ash and *Rhododendron* are concentrated in the center of the second axis indicating approximately equal presence (but not abundance) in both the mine and undisturbed areas. This illustrates the close relationship in the species composition between the mine and the surrounding undisturbed vegetation.

Distribution of species along the first axis suggests a gradient in species' affinity for acid soil but this hypothesis cannot be directly tested because soils were not analyzed in the undisturbed vegetation samples.

Both the mine and undisturbed samples from mine 5 and 6 are located at the far end of the first axis (because mine 6 was located immediately above mine 5, with little intervening undisturbed vegetation, the undisturbed samples labeled "5" in the ordination characterized the undisturbed vegetation for both mines). This indicates a similarity in composition between the mine and its immediate seed source which may be a response to seed availability or a similarity in environment which promotes the growth of the same species both on and off the mine. As mentioned above, these mines differed from all others studied in being located at approximately 670 m on a mountain reaching a total elevation of 980 m. This change in slope position significantly changed the

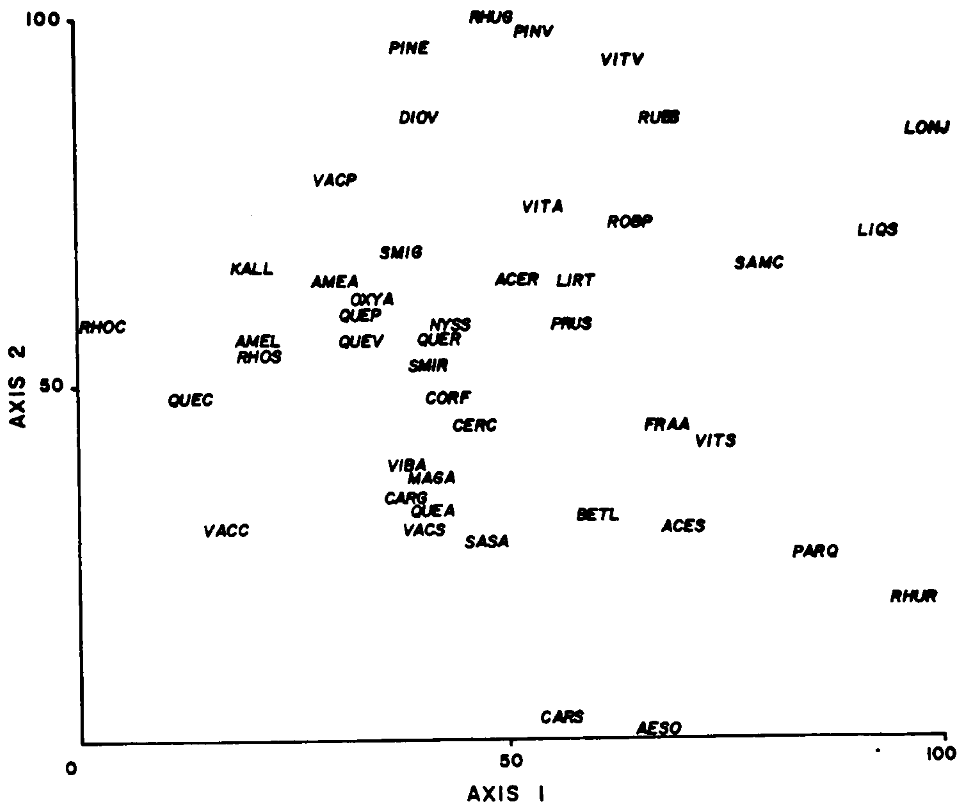

Figure 32. Species Reciprocal Averaging Ordination of the Total Woody Species Data Set. See Table 15 for corresponding species names.

Table 15. Corresponding Names for Species Codes in Figure 32.

Code	Name
ACER	Acer rubrum
ACES	A. saccharum
AESO	Aesculus octandra
AMEA	Amelanchier arborea
AMEL	A. laevis
BETL	Betula lenta
CARG	Carya glabra
CARS	C. spp.
CERC	Cercis canadensis
CORF	Cornus florida
DIOV	Diospyros virginiana
FRAA	Fraxinus americana
KALL	Kalmia latifolia
LIQS	Liquidambar styraciflua
LIRT	Liriodendron tulipifera
LONJ	Lonicera japonica
MAGA	Magnolia acuminata
NYSS	Nyssa sylvatica
OXYA	Oxydendrum arboreum
PARQ	Parthenocissus quinquefolia
PINE	Pinus echinata
PINV	P. virginiana
PRUS	Prunus serotina
QUEA	Quercus alba
QUEC	Q. coccinea
QUEP	Q. prinus
QUER	Q. rubra
QUEV	Q. velutina
RHOC	Rhododendron cumberlandense
RHOS	R. spp.
RHUG	Rhus glabra
RHUR	R. radicans
ROBP	Robinia pseudo-acacia
RUBS	Rubus spp.
SAMC	Sambucus canadensis
SASA	Sassafras albidum
SMIG	Smilax glauca
SMIR	S. rotundifolia
VACC	Vaccinium constablaei
VACP	V. spp.
VACS	V. stamineum
VIBA	Viburnum acerifolium
VITA	Vitis aestivalis
VITS	V. spp.
VITV	V. vulpina

character of the upslope vegetation. This was noticed especially in the increase in relatively more mesic species such as the hickories, sugar maple, white oak and buckeye. However, at the same time the seed source character is changing, these mines also exhibited some of the highest spoil pH values encountered, a factor already shown to be indicative of factors contributing to vegetation pattern on the mines.

The undisturbed vegetation of mine 3 was not sampled because of severely limited access to the area due to active mining operations. This mine had an estimated total percent cover very much less than that encountered on any other mine in this study. The crest and outslope position samples of this mine made up most of the SLP canopy type, characterized by low stem density and few species. It is unlikely that seed source accounts for much of the difference of this type when compared to the types found on other mines. Although not sampled, the undisturbed vegetation was transversed during the sampling of the mine vegetation and was found to be similar to the stands described above, dominated by chestnut oak and northern red oak. Shortleaf pine was noted in the upslope vegetation.

Discussion

Colonization of a primary surface is restricted to those species whose seeds reach the mine. The importance of this rather obvious factor in primary succession has been recognized by numerous authors (Cooper 1939, Hall 1957, Flaccus 1959, Molyneaux 1963, Sigafoos and Hendricks 1969). The exclusion of significant vegetative reproduction and buried seed reproduction makes the pattern of succession on the surface mine substantially different from what would be expected in the same area after logging, fire, plowing or other disturbances which do not completely destroy the seed bank and vegetative propagules. In the terms of Grubb (1977), the most common plants on a surface mine would have a "regeneration niche" consisting of moderate production of seed every year (thus retaining the ability to colonize quickly), production of seed widely dispersed in space, and the ability to germinate and become established in high light, low moisture and infertile conditions. The five woody tree species whose abundance defines the canopy types in this study presumably meet these requirements. Of course, the abundance of any of these species in the surrounding vegetation will influence the probability that the species will express its ability to germinate and become established (Grubb 1977).

Where seed sources are available, late successional species can become established on primary surfaces such as surface mines. My field observations of newly created wildcat mines indicate that many species, early and late successional, are able to colonize the spoil banks in the first growing season after completion of mining. Other primary surfaces upon which this observation has been made are glacial moraines (Cooper 1923, 1939; Lawrence 1958; Sigafoos and Hendricks 1969), landslides (Flaccus 1959) and volcanic surfaces (Heath 1967).

An example of the effect of local seed source on species composition may be illustrated with an examination of the distribution of _Kalmia latifolia_ in this study. This species' seeds are small and slightly winged (Schopmeyer 1974) and are probably distributed relatively short distances by wind. It is found in the understory of five mine samples, on each of two mines. In each case, _K. latifolia_ was also found in a sample in the upslope undisturbed vegetation surrounding the mine, indicating its proximity as a seed source. It seems probable that the distribution of this species was limited by availability of seeds. This situation probably existed for many of the species found on the mine sites whose abundance was somewhat limited in the surrounding vegetation. A few species, such as red maple and tulip poplar, abundant in the surrounding vegetation as well as adapted to wind dispersal can be assumed to have had an abundance of seed reaching the mines, making their distribution more likely to be a pure response to the environment. Even a species such as chestnut oak whose seeds are not adapted to long distance dispersal, if present in great enough quantities (especially in overhanging positions above the mine which facilitates the dispersal of its large seeds by gravity) can be present with surprising constancy (32%). The pines and black locust were not abundant in the offsite vegetation. The presence of a few nearby seed trees would provide seed locally for these long distance dispersed species, but it is possible that their distribution on the mine was locally restricted due to the lack of available seed. Seed rain data on similar areas would help to elucidate the importance of seed availability in natural revegetation of surface mines.

Diversity indices calculated for the undisturbed samples, taken together, show that these sites had greater species richness (6.118 $\pm$ 1.435 S.D.) and equitability (.8873 $\pm$ .1066 S.D.) and lower dominance concentration (.1940 $\pm$ .0663 S.D.) than the mine canopy trees (Table 3, page 42). The difference may be related to the discussion, above, of the effect of seed availability on the composition of the mine. Relatively few of the proximally located species have seeds adapted to long distance dispersal. These species would tend to dominate the sites for a period of time after mining, concentrating resources among a few species and lowering equitability. However, the effect of the mine environment is also important as illustrated by the differences in the indices among the mine canopy types, the SLP type and the TU type defining the extremes.

CHAPTER IX

CONCLUSIONS

The primary objectives of this study were to describe the vegetation of selected surface mines and to relate the distribution of the vegetation to environmental patterns using multivariate numerical techniques. In a vegetation study of this kind, causal relationships should not be inferred from correlation between environmental pattern and vegetation pattern without benefit of supportive experimental investigations. The conclusions of this study should be viewed in the light of their possible predictive value and their value in hypothesis generation.

Of the multivariate techniques used to describe the several data sets, reciprocal averaging ordination proved most effective in elucidating the correlation of the vegetation to the environmental pattern. Cluster analysis and multiple discriminant analysis facilitated description and interpretation of the distribution of the canopy species but was less helpful for the understory trees, shrubs and vines. Detrended correspondence analysis scarcely improved the ordination of the ground cover data set. Although the reciprocal averaging arch was removed, the detrended second axis remained uninterpretable.

On a gross level, the vegetation of the mines was reflective of the undisturbed vegetation surrounding the mine, being dominated by tree species common in the surrounding forests which were adapted to long distance seed dispersal (especially red maple and tulip poplar), and presumably adapted to germination and establishment under relatively harsh conditions. "Late" succession species such as oaks and hickories were also found on the mines where seed sources were proximate. Presumably, species not adapted to long distance dispersal were limited not only by differential response to the environmental gradients of the mine, but also by seed availability. Distribution of species adapted to long distance seed dispersal (e.g., black locust and pines) may have been limited by their patchy distribution in the undisturbed vegetation. Field observations and a review of pertinent literature indicated the ability of traditional "late" succession species (e.g., oaks) to germinate and establish very early on the mine.

The canopy species on the mine were found to correlate primarily with gradients described by spoil pH and topographic position. The measurement of pH presumably integrated the effects of low nutrients and/or high heavy metal concentration as well as H ion concentration. Moisture relationships were proposed as the major factor responsible for correlation of the canopy species to relief (topographic) position. This conclusion was reached on the basis of the complex structure of the mines and on well-known species characteristics. Spoil depth and drainage may be the most important structural factors in explaining the relationship of relief position to spoil moisture. The direct measure of spoil moisture and spoil nutrient and heavy metal concentrations would, of course, have facilitated interpretation of these patterns. Although not considered in this study, field observation indicated that slope azimuth (presumably reflecting complex moisture relationships) has a significant effect on vegetation pattern.

The distribution of the understory species, dominant among these being Rubus and red maple, was found to correlate with canopy closure and spoil pH. The well-known site preferences of the species in the understory sample suggested that soil moisture was also important. The correlation between sample ordination position and canopy closure was probably a reflection of the abundance of Rubus on the mine and the strong response of Rubus to decreasing light conditions. Ground cover species correlated with spoil pH and the presence of dominant tree species and, based on species' site preferences, to spoil moisture conditions. Whether the ground cover species are responding to the presence of canopy trees or covarying with the canopy along similar environmental gradients is not clear.

Because of the current reclamation practice of establishing a rapid and stabilizing cover with exotic grasses and legumes, conditions for natural revegetation on reclaimed mines is expected to differ considerably from that of orphan mines. This difference may affect the type of natural vegetation which develops as well as the rate of development of the natural vegetation. Use of native species in reclamation efforts may enhance the development of stands which are characteristic of the surrounding vegetation. Based on the findings of this study, it is evident that species such as red maple and Rubus spp. are adapted to many conditions found on surface mines and should be considered for use in reclamation efforts in the Cumberland Mountains. Tulip poplar also has great potential if planted on sites characterized by moist, well-drained and nontoxic spoil. Smilax glauca may be desirable for its ability to grow on toxic spoil as well as for its wildlife potential. Among the grasses and herbs, Andropogon virginicus, Panicum commutatum, P. dichotomum, Danthonia spicata and Campanula divaricata may be successful on dry, acid sites while Aster divaricatus, A. lateriflorus, Solidago caesia, Eupatorium rugosum and E. purpureum have potential on less acid, more moist sites.

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APPENDICES

APPENDIX A

WEATHER STATION LOCATIONS

AND CLIMATIC SUMMARY

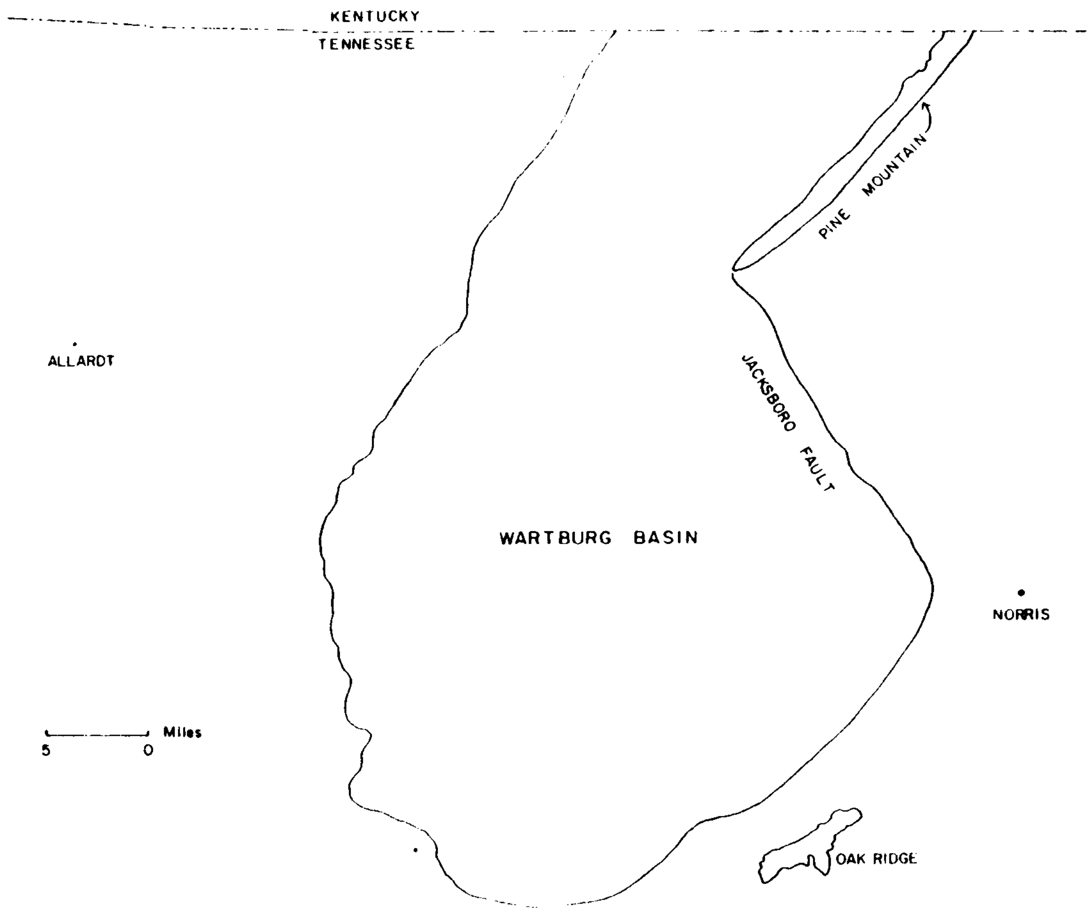

Figure 33. Location of Weather Stations.

Table 16. Climatic Data from Three Nearby Weather Stations.[a]

Variables		Norris[b]	Oak Ridge[b]	Allardt[c]
Precipitation (cm):				
January:	Mean	12.4		12.2
	Minimum	4.3		3.8
	Maximum	29.6		34.4
July:	Mean	11.4		12.9
	Minimum	3.2		3.9
	Maximum	35.6		32.5
Temperature (°C):				
January:	Mean		3.4	3.8
	Minimum		1.6	2.6
	Maximum		8.4	8.5
July:	Mean		25.0	23.1
	Minimum		19.1	16.8
	Maximum		30.6	29.5

[a]United States Department of Agriculture Weather Bureau 1960. Climatic Summary of the U.S. - Eastern Tennessee 1951-1960. U.S. Department of Commerce Weather Bureau. 1961-1965. Climatological Data - Tennessee Annual Summaries 66-70. U.S. Department of Commerce Environmental Sciences Administration. 1966-1970. Climatological Data 71-75. U.S. Department of Commerce National Oceanic and Atmospheric Administration. 1971-1978. Climatological Data 76-83.

[b]30 year averages.

[c]Precipitation values and January and July averages based on 28 years; January and July minimum and maximum based on 10 years.

APPENDIX B

MAPS OF STUDY SITE LOCATIONS AND SEAM, AGE AND POSITIONS SAMPLED ON THE EIGHT STUDY SITES

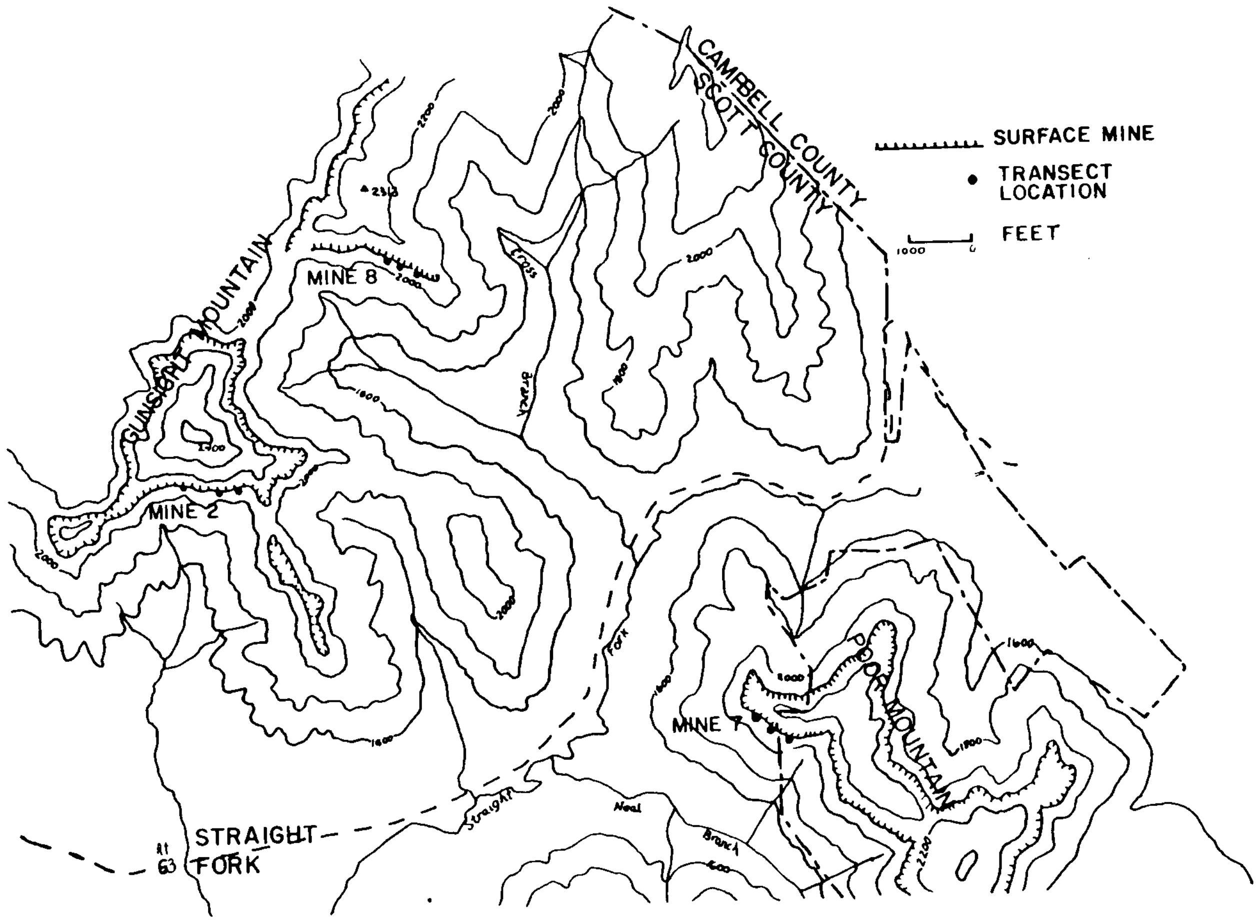

Figure 34. Location of Study Sites 2, 7, and 8 on the Pioneer Quadrangle.

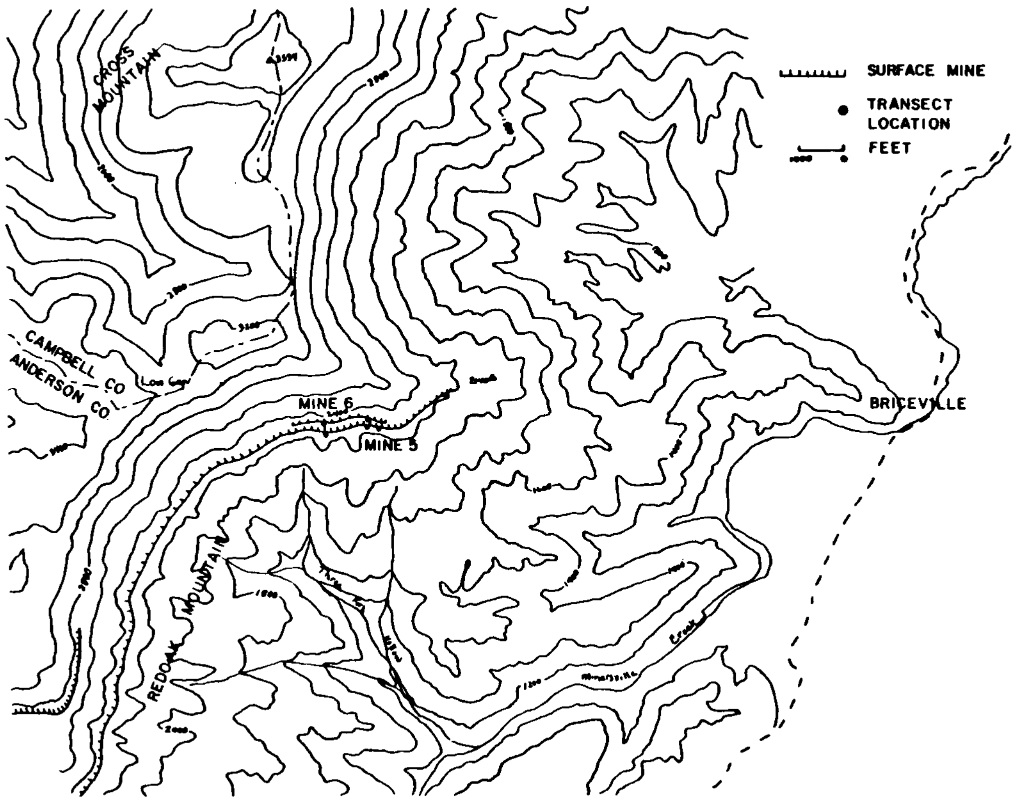

Figure 35. Location of Study Sites 5 and 6 on the Lake City Quadrangle.

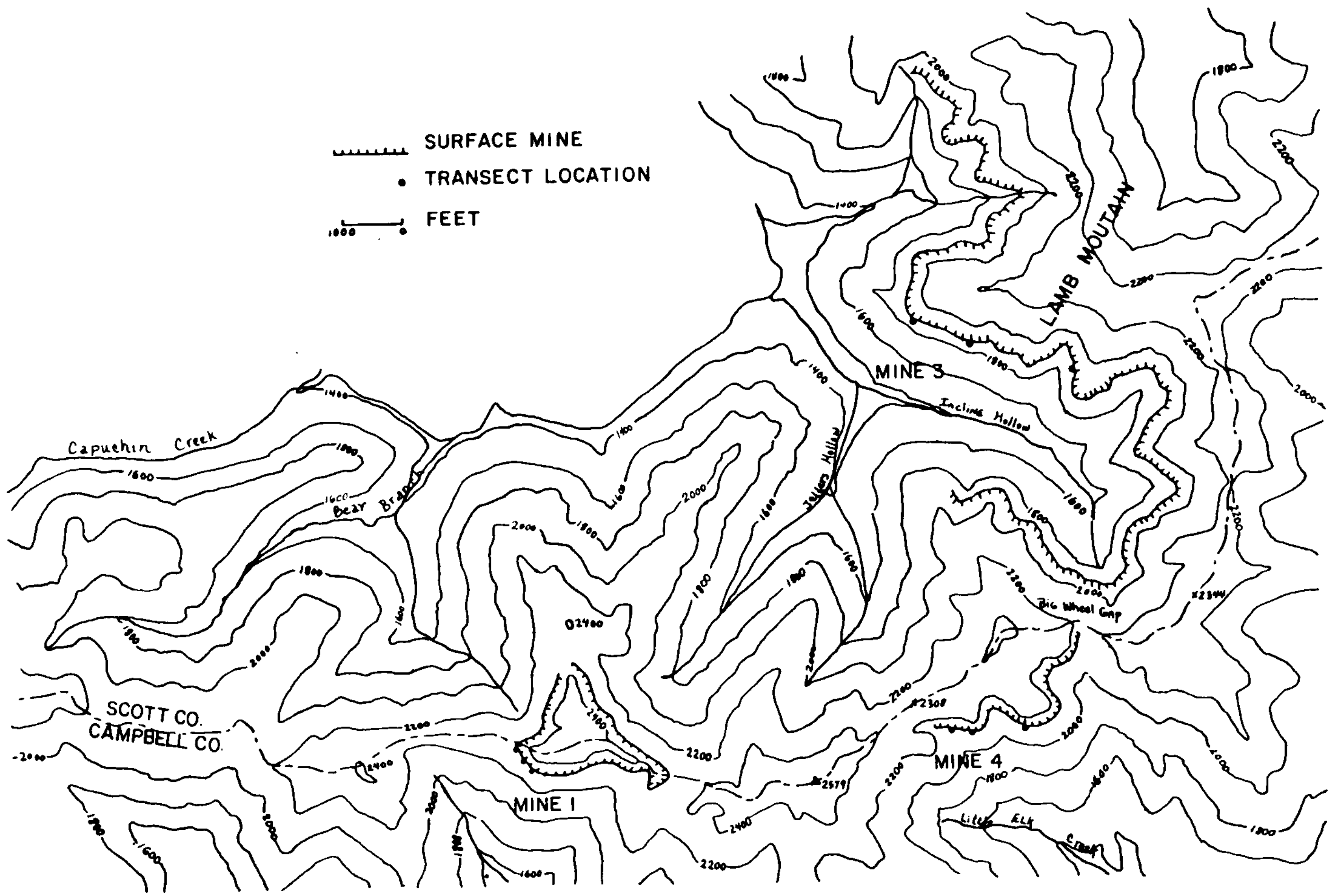

Figure 36. Location of Study Sites 1, 3, and 4 on the Ketchen Quadrangle.

Table 17. Seam, Age and Sampling Distribution on the Eight Study Sites.

Site #	1	2	3	4	5	6	7	8
[a]Seam	RA	BM	WR	RA	WR	WR	BM	BM
[b]Age	12	21	15	15	22	22	18	21
Positions Sampled								
Bench	2	2	3	2	3	1	0	3
Crest	2	3	3	3	0	2	3	3
Outslope	0	3	3	3	3	0	3	3

[a]RA:Red Ash; BM:Big Mary; WR:Windrock.

[b]At time of sampling.

APPENDIX C

SCIENTIFIC AND COMMON NOMENCLATURE

Table 18. Common and Scientific Names of Tree Species Referenced in Text

Common Name	Scientific Name
Basswood	Tilia heterophylla
Birch	Betula spp.
Black gum	Nyssa sylvatica
Black locust	Robinia pseudo-acacia
Black oak	Quercus velutina
Black walnut	Juglans nigra
Buckeye	Aesculus octandra
Chestnut	Castanea dentata
Chestnut oak	Quercus prinus
Cottonwood	Populus spp.
Cucumber magnolia	Magnolia acuminata
Flowering dogwood	Cornus florida
Hackberry	Celtis occidentalis
Hickory	Carya spp.
Northern red oak	Quercus rubra
Persimmon	Diospyros virginiana
Red cedar	Juniperus virginiana
Red maple	Acer rubrum
Sassafras	Sassafras albidum
Shortleaf pine	Pinus echinata
Slippery elm	Ulmus rubra
Smooth sumac	Rhus glabra
Sourwood	Oxydendrum arboreum
Striped maple	Acer pensylvanicum
Sugar maple	A. saccharum
Sweetgum	Liquidambar styraciflua
Tulip poplar	Liriodendron tulipifera
Virginia pine	Pinus virginiana
White ash	Fraxinus americana
White oak	Quercus alba
Wild black cherry	Prunus serotina
Winged sumac	Rhus copallina

APPENDIX D

DENSITY AND BASAL AREA OF CANOPY AND UNDERSTORY SPECIES BY TYPE

Table 19. Mean Basal Area of Canopy Species by Canopy Type.

Species	Canopy Types m^2/ha				
	BL	TU	PIRMBL	RM	SLP
Acer rubrum	1.94	1.78	1.37	3.37	1.22
A. saccharum	0.02	0.03	0.02		
Betula lenta		0.03			
Carya spp.	0.03	0.59			
Celtis occidentalis	0.01				
Cercis canadensis		0.05			
Cornus florida	0.03	0.09			0.01
Diospyros virginiana					
Fraxinus americana	0.05	0.10	0.01		
Juglans nigra		0.01			
Liquidambar styraciflua	0.06		0.05	0.05	
Liriodendron tulipifera	1.24	7.35	1.04	1.57	0.03
Magnolia acuminata					
Malus pumila		0.01			
Nyssa sylvatica	0.05	0.15	0.17	0.25	0.09
Oxydendrum arboreum	0.03	0.05	0.05	0.26	0.01
Paulownia tomentosa	0.01				
Pinus echinata		0.86	0.99	0.41	3.66
P. virginiana		0.49	3.03	0.30	0.07
Populus grandidentata					0.17
Prunus serotina	0.03	0.01	0.32	0.01	
Quercus alba	0.01	0.43		0.01	
Q. coccinea				0.17	
Q. prinus	0.13	0.36	0.02	1.60	0.12
Q. rubra		0.13	0.03	0.08	
Q. velutina			0.16	0.10	
Rhus copallina			0.01	0.10	
R. glabra		0.04	0.08		0.01
Robinia pseudo-acacia	9.90	3.61	1.60	1.11	0.23
Sambucus canadensis			0.01		
Sassafras albidum		0.03			
Ulmus rubra				0.02	
Vitis spp.	0.08	0.03		0.01	

Table 20. Mean Density of Canopy Species by Canopy Type.

Species	Canopy Types stems/ha				
	BL	TU	PIRMBL	RM	SLP
Acer rubrum	390	400	373	1054	220
A. saccharum	13	22	18		
Betula lenta		4			
Carya spp.	10	31			
Celtis occidentalis	13				
Cercis canadensis		13			
Cornus florida	10	64		3	8
Diospyros virginiana		2			
Fraxinus americana	13	39	9	3	
Juglans nigra		2			
Liquidambar styraciflua	20	2	10	13	
Liriodendron tulipifera	123	857	123	294	14
Magnolia acuminata				3	
Malus pumila		2			
Nyssa sylvatica	18	44	13	63	31
Oxydendrum arboreum	10	20	40	132	8
Paulownia tomentosa	7				
Pinus echinata		67	129	37	650
P. virginiana		29	379	77	25
Populus grandidentata					8
Prunus serotina	13	2	22	5	
Quercus alba	7	13		6	
Q. coccinea				11	
Q. prinus	31	20	13	81	22
Q. rubra		31	22	24	
Q. velutina			13	21	
Rhus copallina			9	9	
R. glabra		31	31		8
Robinia pseudo-acacia	568	330	257	147	111
Sambucus canadensis			4		
Sassafras albidum		20		2	
Ulmus rubra				3	
Vitis spp.	33	27		3	

Table 21. Mean Density of Understory Species by Understory Type.

Species	Understory Type stems/ha					
	TU	RMLI	RM	RMBB	BB	CB
Acer rubrum	1182	825	1840	1642	593	659
A. saccharum		119	3	15	28	8
Aesculus octandra		4				
Amelanchier spp.	13		22	4	5	16
Betula lenta		8				
Carya spp.		36	11	7	6	
Cercis canadensis		4	4			
Cornus florida	106	395	18	64	45	24
Diospyros virginiana		8	9	4	12	
Euonynus americanus			33	4		
Fraxinus americana	66	131	13	25	28	
Hydrangea arborescens		24				
Juglans nigra		4		4		
Juniperus virginiana		8	4		3	
Kalmia latifolia	13		55		40	88
Liquidambar styraciflua		24	7	18	6	
Liriodendron tulipifera	1939	406	440	350	118	66
Lonicera japonica		398		22	73	
Magnolia acuminata	66	4			3	
Malus pumila					6	
Nyssa sylvatica	252	178	43	105	107	78
Oxydendrum arboreum	239	46	139	43	28	169
Parthenocissus quinquefolia		127	3	11	12	
Pinus echinata			94	56	61	256
P. virginiana		43	75	139	47	159
Prunus serotina	27	36	15	33	3	

Table 21. (continued)

Species	Understory Type stems/ha					
	TU	RMLI	RM	RMBB	BB	CB
Quercus alba		8	4	26	23	
Q. coccinea					4	6
Q. prinus		9	22	117	47	16
Q. rubra	53	64	25	31	14	30
Q. velutina	13	8	10	11	7	6
Rhododendron spp.	13	4			5	
Rhus copallina		80	23		67	
R. glabra		24	4	7	98	56
R. radicans		76			12	
Robinia pseudo-acacia		96	46	53	118	25
Rosa spp.				62	3	
Rubus spp.	319	116	58	840	2931	991
Sambucus canadensis	53	60	25	16	116	
Sassafras albidum			5	22	56	
Smilax glauca		419	142	384	99	3843
S. rotundifolia	146	240	35	229	77	146
Ulmus americana						6
U. rubra	13	4	4			
Vaccinium spp.	27	64	7	7		207
Viburnum acerifolium			3	52		8
Vitis spp.	53	139	25	27	141	48

APPENDIX E

ENVIRONMENTAL VARIABLE CORRELATIONS

Table 22. Significant (α=.05) Correlations (Pearson Product-Moment) Between Environmental Variables.

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. % spoil > 19 mm																		
2. % spoil 6.35-19 mm	.277																	
3. % spoil 2-6.35 mm	-.410	-.318																
4. % spoil < 2 mm	-.588	-.623																
5. % clay	.261																	
6. % sand					-.849													
7. Color value	.287	.321	-.310		.480	-.519												
8. Color chroma						-.387	.678											
9. Spoil pH							.304	.387										
10. Mine		-.349		.360														
11. Relief																		
12. Perpendicular slope angle (%)											.499							
13. Parallel slope angle																		
14. Highwall height (m)								.344		.405								
15. Plot distance from highwall (m)			-.276								.862	.448		.293				
16. Seam						.293	-.452		-.461	.352				.437				
17. Age (yr)		-.263			-.322	.383	-.273			.529				.280		.584		
18. Slope aspect			.289						-.422							.261		
19. % Canopy closure										.471	.367						.335	

APPENDIX F

SUMMARY OF ENVIRONMENTAL VARIABLES NOT USED IN DISCRIMINANT ANALYSIS

Table 23. Mean Environmental Variables in Canopy Types Not Entered into Discriminant Analysis.

Variables	Canopy Type BL	TU	PIRMBL	RM	SLP
% Spoil > 19 mm	9.9 (8.8)	11.2 (9.1)	7.9 (7.6)	11.7 (9.2)	11.9 (6.7)
% Spoil 6.35-19 mm	23.7 (7.5)	32.0 (7.2)	27.4 (9.7)	27.7 (7.1)	32.4 (6.2)
Color Value	6.5 (0.5)	6.4 (0.9)	5.7 (1.3)	6.4 (0.8)	6.6 (1.1)
% Sand	51.4 (11.8)	49.4 (15.2)	51.5 (17.8)	48.5 (10.3)	42.6 (17.9)
Plot Distance from Highwall (m)	28.8 (39.5)	25.6 (16.7)	19.6 (11.4)	14.9 (19.3)	31.5 (11.0)

APPENDIX G

DISCRIMINANT ANALYSIS TABLES

Table 24. Jackknifed Classification Success from Discriminant Analysis of Canopy Types Using Species Importance Values.

Type	Percent Correct	Number of Cases Classified into Type				
		BL	PIRMBL	TU	RM	SLP
BL	100.0	6				
PIRMBL	66.7		6		3	
TU	88.9	1		16	1	
RM	80.0	2		1	12	
SLP	100.0					5
Total	84.9					

Table 25. F-Values from Discriminant Analysis of Canopy Types Using Species Importance Values.[a]

Type	BL	PIRMBL	TU	RM
PIRMBL	4.59			
TU	4.62	11.31		
RM	3.63	6.50	8.59	
SLP	8.76	11.07	10.74	10.33

[a]The overall F of 7.45 (D.F.=80,117) is significant at $P \leq .001$; for values within the table, the $F_{20,29,.001}$.

Table 26. Jackknifed Classification Success from Discriminant Analysis of Canopy Types Using Environmental Variables.

Type	Percent Correct	Number of Cases Classified into Type				
		BL	PIRMBL	TU	RM	SLP
BL	50.0	3		2	1	
PIRMBL	55.6		5	3	1	
TU	33.3	2	5	6	4	1
RM	66.7	1		3	10	1
SLP	80.0			1		4
Total	52.8					

Table 27. F-values from Discriminant Analysis of Canopy Types Using Environmental Variables.[a]

Type	BL	PIRMBL	TU	RM
PIRMBL	6.32			
TU	3.52	2.26		
RM	5.40	5.45	4.75	
SLP	6.59	2.18	3.44	4.43

[a]The overall F of 4.09 (D.F.=24,151) was significant at P $\leq$ .001; for values within the table, $F_{6,43,.001} = 4.68$, $F_{6,43,.01} = 3.27$, $F_{6,43,.05} = 2.33$.

Table 28. F-values from Discriminant Analysis of Understory Types Using Species Relative Density.[a]

Type	BB	CB	RM	RMBB	RMLI
CB	3.13				
RM	24.96	14.02			
RMBB	9.61	5.14	4.23		
RMLI	11.75	7.51	9.75	4.26	
TU	10.15	9.74	6.45	6.34	6.36

[a]The overall F-value of 5.05 (D.F.=185,60) is significant at $p \le .001$; for values within the table, $F_{37,11,.001} = 6.57$, $F_{37,11,.01} = 4.58$, $F_{37,11,.05} = 2.54$.

Table 29. Jackknifed Classification Success from Discriminant Analysis of Understory Types Using Environmental Variables.

Type	Percent Correct	Number of Cases Classified into Type					
		BB	CB	RM	RMBB	RMLI	TU
BB	38.5	5	3	1		3	1
CB	0.0	2			1	2	
RM	9.1	1	1	1	3	2	3
RMBB	63.6			2	7		2
RMLI	50.0	2	1	1	1	5	
TU	66.7				1		2
Total	37.7						

Table 30. F-values from Discriminant Analysis of Understory Types Using Environmental Variables.

Type	BB	CB	RM	RMBB	RMLI
CB	0.44				
RM	6.86	3.96			
RMBB	15.91	9.28	2.75		
RMLI	2.69	1.14	2.19	9.22	
TU	6.92	6.12	1.87	2.63	4.14

[a]The overall F-value of 4.54 (D.F.=15,124) is significant at $P \leq .001$; for values within the table, the $F_{3,45,.001} = 6.49$, $F_{3,45,.01} = 4.27$, $F_{3,45,.05} = 2.82$.

APPENDIX H

GROUND COVER SPECIES WITH LESS

THAN 5% CONSTANCY

Table 31. Ground Cover Species with Less than 5% Constancy in Mine Plots

Species	
Acer saccharum	*Lactuca canadensis*
Agrimonia rostellata	*L. scariola*
Agrostis hyemalis	*L. spp.*
A. perennans	*Lespedeza cuneata*
Ailanthus altissima	*L. hirta*
Allium spp.	*L. repens*
Ambrosia trifida	*Lycopodium flabelliforme*
Amphicarpa bracteata	*L. obscurum* v. obscurum
Andropogon scoparius	*Monarda clinopodia*
Apocynum cannabinum	*Panicum lanuginosum* v. lindheimeri
Arctium minus	*P. polyanthes*
Arisaema triphylla	*P. sphaerocarpon*
Aristolochia serpentaria	*Paronychia canadensis*
Ascyrum hypericoides L. -S,F,G	*Passiflora lutea*
Bidens aristosa	*Physalis virginiana*
Botrychium spp.	*Prunella vulgaris*
Carya cordiformis	*Rhus copallina*
Carya spp.	*R. glabra*
Cercis canadensis	*Rudbeckia fulgida*
Cypripedium acaule	*Rumex acetosella*
Daucus carota	*Sanicula canadensis*
Desmodium paniculatum	*S. spp.*
Diospyros virginiana	*Sassafras albidum*
Erigeron spp.	*Scutellaria ovata*
Euonymus americanus	*Sericocarpus asteroides* (L.) BSP.-S,F
Eupatorium fistulosum	*Solidago altissima*
E. pilosum	*S. bicolor*
Euphorbia corollata	*S. gigantea*
Festuca elatior	*S. nemoralis*
F. obtusa	*S. odora*
Fragaria virginiana	*Taenidia integerrima*
Galactia spp.	*Taraxacum officinale*
Galium triflorum	*Trifolium pratense*
G. spp.	*Ulmus rubra*
Geum spp.	*Uvularia perfoliata*
Heterotheca mariana	*Vaccinium constablaei*
Heuchera americana	*V. stamineum*
Hieracium paniculatum	*V. vacillans*
Houstonia purpurea	*Vernonia spp.*
Hystrix patula	*Viburnum acerifolium*
Juncus spp.	*Vitis aestivalis*
Kalmia latifolia	*V. vulpina*

VITA

Anne Smith Stocum was born in Rome, New York on October 24, 1953. She attended elementary schools in that city and graduated from Rome Catholic High School in June 1971. The following August she entered The State University of New York College at Geneseo on a Regent's Scholarship where she received a Bachelor of Arts degree in Biology in May 1975, graduating summa cum laude.

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The author is a member of the Ecological Society of America and the Association of Southeastern Biologists.