A Comparison of Trees and Tree Growth on Unreclaimed 1949 Indiana Coal Spoil Banks in 1964 and 1981

John Richard Schrock
Association of Systematics Collections
Museum of Natural History
University of Kansas
Lawrence, Kansas 66045
and
Jack R. Munsee
Department of Life Science
Indiana State University
Terre Haute, Indiana 47809

Introduction

Over 95,000 acres of Indiana land were stripmined before modern reclamation laws were in place (5). While Indiana has a long history of coal stripmine reclamation research, nearly all of the early research was directed at reforestation techniques, primarily the survival of tree plantings, and spoil amendments. Research since 1970 has been solely on the ecology of sites re-topsoiled and re-contoured under the new reclamation requirements. The considerable acreage of early barren spoils abandoned to develop a new topsoil and revegetate by natural processes have been left unstudied. This is probably because 1) there is no current commercial incentive to study the abandoned sites as an applied problem and 2) as a pure science problem, the succession on spoil banks is too slow to yield results in one person's doctoral program.

In 1964, Munsee (25) studied the ecology of ants on relatively barren unreclaimed Indiana spoil banks originally deposited in 1949-51. In 1981, Schrock (31) repeated the methodology at the same 21 sites, now mostly revegetated. While the primary focus of both studies was the surface-active insect populations (32), extensive samplings of both the soil and vegetation at each site were used in analyses to explain the distribution of selected insects. Of these major factors studied by Munsee and Schrock—soils, herbaceous vegetation, trees, and insects—this paper summarizes the tree data. These studies, 17-years apart, constitute the first and probably the last possible real-time comparison of changes on unreclaimed humid Midwestern spoil banks over a substantial period of time.

Some studies have assumed that successional changes over time could be studied at one point in time on a series of multi-aged spoil banks, but this approach has been shown to be very limited by short-distance variation in spoils and microclimate (18, 32).

Bauer (2) observed that trees appearing on excavated mines in Germany were ". . .a chance combination of species without regard to natural plant associations. . ." and ". . .competition begins to play a role in the determination of the final association. . .after the vegetational cover is closed or after the microclimate has changed due to shading by trees."

Neumann (26, 27) defined this importance of trees in altering spoilbank microclimate in his study of succession of soil fauna on West German reclaimed coal dumps. Neumann's sites were actively reforested and developed a closed canopy between the 7th and 11th year. Using continuous recording equipment, he measured temperature, relative humidity and cumulative evaporation. The peak daily temperature dropped dramatically between sites of these ages. Relative humidity no longer fell drastically through the stressful afternoon hours under the closed canopy, but the younger, open 7-year plantation closely resembled the spoils. Soil moisture remained depressed through the seventh year, but by the eleventh year had risen to the general level of the undisturbed forests. Neumann found that populations of millipedes and isopods dramatically increased with canopy closure and there was a switch in the ground beetle population from open to woodland species. Although food supply and migration distances were also involved, he proposed that microclimate was the controlling factor in the observed invertebrate succession on reclaimed spoilbanks.

In another study by Van der Aart (36), spider populations on a dune area were studied for correlations with environmental factors twice, ten years apart. Both times, the 12 species at 28 sites distributed themselves according to a main environmental factor described by principal components analysis. Of 26 environmental characteristics, the amount of light penetrating the vegetation came closest to approximating this main environmental factor.

In contrast, Vogel and Berg (37) found that plant competition did exist between black locust seedlings and dense herbaceous vegetation and also used treatments to confirm that tree growth was held back by lack of N and P in coal spoils.

Methods

In 1964, Munsee selected an ecological study area in the old Sunspot Mines. The location of the stripmines is south of Centenary in Vermillion County, Indiana, in Township 14N, Section 24 (10) and physical site descriptions are detailed in Schrock & Munsee (32). According to Lindsey et al. (19), the sites would have been classified as beech-maple forest in pre-settlement Indiana.

The spoilbanks resulted from surface coal mining by Ayrshire Colleries from 1949 to 1951. Ayrshire sold about 300 acres of the spoilbanks to the Clinton Chapter of the Isaac Walton League. The protection provided by the League and the relative inaccessibility of the research site prevented disturbance of the research site over the past 41 years. All seed dispersal is therefore natural.

Site Descriptions

Twenty-one research sites, 19 on mined spoilbanks and two in an adjacent unmined area, were selected by Munsee in 1964 with guidance from Dr. Leland Chandler from Purdue University. The plots were selected to provide an assortment of exposures and slopes (32).

The size and shape of plots varied due to topography (Figure 1). Plots were oriented to avoid problematic areas and sampled a variety of tops, slopes and bases of ridges.

Site Designation

In 1964, Munsee designated his research sites by letters, beginning with "Site A" in the south end of the area and working north along the mined ridges and west to east when sites cut across ridges. "Site A" was an unmined site and later, Munsee added an unmined woodland site, "Site W", south of site A. Therefore, sites labelled by letters close together in the alphabet are physically closer together on the research area, with the exception of site W which is off the spoilbanks from site A. Therefore, tabular data are presented in the order "W, A, B, C, D. . .T."

Tree Survey

In 1964, Munsee tallied all trees greater than 2.54 cm (one inch) diameter measured at 137 cm (4.5 ') height (=dbh) at each site. Note that not all plot sizes are the same in area or dimensions (Figure 1). There were no stems that qualified by these standards on sites B, D, I, L-O, P, Q and T in 1964. Of the 149 stems counted on the

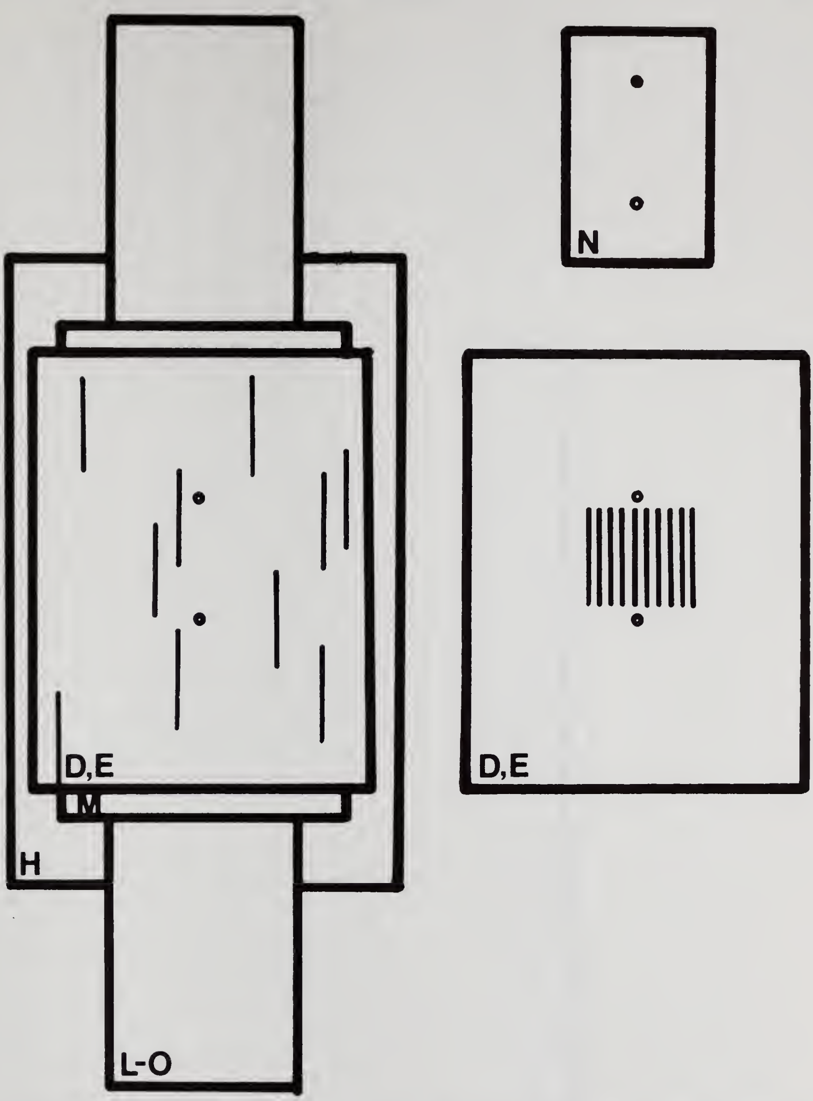

FIGURE 1. Variation in size of representative vegetation and tree plots in 1964, repeated in 1981 with a change in vegetation sampling pattern only. The smallest plot was at site N (upper right) and the longest was site L-O (left background).

other sites, two-thirds were on the unmined sites W and A. By 1981, all mined sites harbored trees within the 1964 defined plots.

In 1964, Munsee used both a folding yardstick as calipers and a tape to measure tree diameters, depending on the tree size. In 1981, all diameters were taken from tape measures of circumference. Diameter values were converted to basal area in square feet using Munns' forestry tables (23) both years. For multiple-stemed trunks, Munsee

TABLE 1. Number of trees with dbh of 2.54 cm (one inch) or greater at each of 20 research sites in 1964.

	W	A	B	C	D	E	F	G	H	I	J	K	L-O	M	N	P	Q	R	S	T	%
Acer negundo L. (Boxelder)	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	1
Acer saccharinum L. (Silver Maple)	—	—	—	—	—	1	1	—	2	—	3	1	—	—	—	—	—	—	—	—	5
Carya ovata (Mill.) K.Koch (Shagbark Hickory)	8	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6
Carya spp. (Hickories)	3	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3
Cornus spp. (Dogwoods)	7	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6
Crataegus spp. (Hawthorns)	—	22	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	15
Fraxinus americana L. (White Ash)	—	7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5
Fraxinus pennsylvanica Marsh. (Red Ash)	—	—	—	2	—	2	6	1	1	—	3	1	—	—	1	—	—	—	—	—	11
Gleditsia tricanthos L. (Honey Locust)	—	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3
Juglans nigra L. (Black Walnut)	1	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3
Malus spp. (Wild Crabapple)	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1

Pinus banksiana Lamb. (Jack Pine)	—	—	—	—	—	1	—	1	—	—	1	2	—	—	—	—	—	1	1	—	5
Pinus virginiana Mill (Scrub Pine)	—	—	—	—	—	2	—	1	2	—	2	—	—	—	—	—	—	—	—	—	5
Platanus occidentalis L. (Sycamore)	—	—	—	—	—	—	—	—	3	—	—	—	—	—	1	—	—	4	1	—	6
Populus deltoides Marsh. (Cottonwood)	—	—	—	—	—	—	1	—	—	—	—	—	—	1	—	—	—	—	—	—	1
Prunus serotina Ehrh. (Wild Black Cherry)	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
Quercus alba L. (White Oak)	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
Quercus imbricaria Michx. (Shingle Oak)	4	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3
Quercus velutina Lam. (Black Oak)	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
Sassafras albidum (Natt.) (Sassafras)	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
Ulmus americana L. (American Elm)	—	18	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	12
Ulmus rubra Muhl. (Red Elm)	1	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3
Vitis spp. (Grape)	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
Site Total:	30	68	0	2	0	6	8	4	8	0	9	4	0	1	2	0	0	5	2	0	

TABLE 2. Number of trees with dbh of 2.54 cm (one inch) or greater at each of 20 research sites in 1981.

	W	A	B	C	D	E	F	G	H	I	J	K	L-O	M	N	P	Q	R	S	T	%
Acer negundo L. (Boxelder)	—	—	—	—	—	—	—	2	1	—	—	—	—	—	—	—	—	—	—	—	1
Acer saccharinum L. (Silver Maple)	—	—	3	—	3	—	1	—	6	—	3	1	—	—	—	—	—	2	—	—	6
Carya ovata (Mill.) K.Koch (Shagbark Hickory)	2	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
Carya spp. (Hickories)	2		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
Celtis occidentalis L. (Hackberry)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1
Cercis canadensis L. (Redbud)	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
Cornus spp. (Dogwoods)	6	17	—	1	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	7
Crataegus spp. (Hawthorns)	—	18	1	—	—	—	—	—	—	2	—	1	3	—	—	—	1	2	2	1	9
Fraxinus americana L. (White Ash)	—	2	5	5	—	—	—	5	—	—	—	—	—	—	—	—	—	—	—	—	5
Fraxinus pennsylvanica Marsh. (Red Ash)	—	—	—	—	1	4	7	1	6	10	2	5	4	13	2	4	12	2	—	1	22
Fagus grandifolia Ehrh. (Beech)	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
Gleditsia tricanthos L. (Honey Locust)	—	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
Juglans nigra L. (Black Walnut)	1	6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
Liquidambar styraciflua L. (Sweet Gum)	—	—	—	1	—	—	—	—	—	—	—	—	—	1	—	—	—	1	—	—	1
Liriodendron tulipifera L. (Tulip Poplar)	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1

Malus spp. (Wild Crabapple)	1	1	2	1	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	2
Pinus banksiana Lamb. (Jack Pine)	—	—	2	—	2	1	—	2	—	—	2	—	—	—	—	—	—	3	1	—	4
Pinus resinosa Ait. (Red Pine)	—	—	—	—	1	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	1
Pinus strobus L. (White Pine)	—	—	—	1	—	—	1	—	—	—	—	—	1	1	1	—	—	3	2	—	3
Pinus virginiana Mill (Scrub Pine)	—	—	—	—	5	2	—	1	1	—	3	4	—	1	—	—	—	2	—	—	6
Platanus occidentalis L. (Sycamore)	—	—	—	1	—	—	—	—	3	—	—	—	—	—	1	—	—	5	1	—	3
Populus deltoides Marsh. (Cottonwood)	—	—	2	—	—	—	1	—	—	—	—	—	—	1	—	—	—	—	—	—	1
Prunus serotina Ehrh. (Wild Black Cherry)	—	2	—	—	—	—	—	—	—	5	—	—	—	1	—	—	2	1	1	—	3
Quercus alba L. (White Oak)	2	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
Quercus imbricaria Michx. (Shingle Oak)	3	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
Quercus velutina Lam. (Black Oak)	2	3	3	—	1	—	—	—	—	—	—	—	—	—	—	2	—	—	1	—	3
Robinia pseudoacacia L. (Black Locust)	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
Salix nigra Marsh. (Black Willow)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	12	4
Sassafras albidum (Natt.) (Sassafras)	1	8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3
Ulmus americana L. (American Elm)	—	8	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4
Ulmus rubra Muhl. (Red Elm)	2	5	—	2	—	—	—	2	—	—	—	—	2	—	—	—	—	—	1	—	4
Vitis spp. (Grape)	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
Site Total:	23	83	22	12	13	7	10	13	19	18	10	11	11	20	4	6	15	21	11	15	

TABLE 3. Basal area of trees with dbh of 2.54 cm (one inch) or greater at each of 20 research sites in 1964. Basal areas are in square feet and were calculated from Munns et al. (23). One square foot = 929 square centimeters.

	W	A	B	C	D	E	F	G	H	I	J	K	L-O	M	N	P	Q	R	S	T
Acer negundo L.	—	—	—	—	—	—	—	0.14	—	—	—	—	—	—	—	—	—	—	—	—
Acer saccharinum L.	—	—	—	—	—	0.10	0.03	—	0.30	—	0.80	0.02	—	—	—	—	—	—	—	—
Carya ovata (Mill.) K.Koch	1.40	0.01	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Carya spp.	0.20	0.01	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Cornus spp.	0.30	0.12	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Crataegus spp.	—	0.40	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Fraxinus americana L.	—	0.20	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Fraxinus pennsylvanica Marsh	—	—	—	0.20	—	0.10	0.10	0.05	0.01	—	0.14	0.02	—	—	0.01	—	—	—	—	—
Gleditsia triacanthos L.	—	0.02	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Juglans nigra L.	0.01	0.04	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Malus spp.	—	0.50	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Pinus banksiana Lamb.	—	—	—	—	—	0.01	—	0.01	—	—	0.03	0.02	—	—	—	—	—	—	—	—
Pinus virginiana Mill	—	—	—	—	—	0.10	—	0.01	0.05	—	0.10	—	—	—	—	—	—	—	—	—
Platanus occidentalis L.	—	—	—	—	—	—	—	—	0.10	—	—	—	—	—	0.03	—	—	0.05	0.03	—
Populus deltoides Marsh.	—	—	—	—	—	—	0.10	—	—	—	—	—	—	0.01	—	—	—	—	—	—
Prunus serotina Ehrh.	—	0.10	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Quercus alba L.	1.40	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Quercus imbricaria Michx.	0.30	0.04	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Quercus velutina Lam.	1.50	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Sassafras albidum (Natt.)	0.01	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Ulmus americana L.	—	0.80	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Ulmus rubra Muhl.	0.01	0.10	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Vitis spp.	0.01	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Site Total:	5.14	2.97	0.00	0.20	0.00	0.31	0.23	0.21	0.46	0.00	1.07	0.06	0.00	0.01	0.04	0.00	0.00	0.06	0.04	0.00

noted that ". . .each stem was measured separately and the measurements were grouped so that all basal area values could be taken as one." This was repeated in 1981.

Munsee used Fernald (13) and Harlow (16) as chief references in determining tree species. Schrock used Mohlenbrock (22) and Gleason and Cronquist (15). Some tree leaves from both 1964 and 1981 were deposited with the Indiana State University Herbarium by both researchers.

Quantitative Methods for Trees

In addition to total tree numbers and tree basal areas, an importance value was calculated for each tree at the site. The importance value (I.V.) was defined here as a measure of the influence that each species exerts upon the community. If only one species is present, it comprises 100% of the basal area at the site and 100% of the density. The sum of these relative percentages (each x 100 first) yields an I.V. of 200 for all sites with trees. The following formulae were used in 1964 and 1981:

$$\text{Relative basal area species A} = \frac{\text{basal area of species A}}{\text{basal area of all species}} \times 100$$

$$\text{Relative density of species A} = \frac{\text{density of species A}}{\text{density of all species}} \times 100$$

$$\text{Importance value of species A} = \text{Relative basal area} + \text{Relative density}$$

The ecological value of an abstract "importance value" constructed from precisely partitioned density and basal areas is difficult to show in spite of its extensive use in forest community studies beginning with Curtis and McIntosh (8). However, it may have limited validity here because: 1) by reducing values to proportions, it partially compensates for the varying plot sizes and 2) it is biologically reasonable that because of its size, a single tree on a small plot would influence much of the area if alone but have less influence if among other trees.

Clustering Methods, Correlations and Principal Components Analyses

Chambers (6) defines the serious shortcomings of diversity indices and rank correlations for direct comparisons between communities but finds several similarity indices appropriate and ". . .well-suited for evaluating mined land diversity."

To detect the complex patterns of similarity between sites based on trees, a cluster analysis was performed using each site as a case. For this task, BMDP statistical program P2M was used as modified to run on the Kansas University Computing Center Honeywell DPS-3/E.

The distance between two cases of data is defined as the chi-square test of equality of the two sets of frequencies. The computer program begins by comparing each pair of cases and using this chi-square test, joins the closest two cases. When two cases are joined, a new centroid is formed by averaging each variable. In the next round of searching for the shortest distance, this centroid is compared with other candidates for membership to the next larger cluster. The number of cases (or pseudocases) is reduced by one at each step until all are clustered, forming a dendrogram.

Cluster analyses were performed for the 1964 sites with trees, for all 1981 sites, and for all of these sites taken together. The methodology described above was applied to tree numbers, tree occurrence, tree basal areas and tree importance values.

TABLE 4. Basal area of trees with dbh of 2.54 cm (one inch) or greater at each of 20 research sites in 1981. Basal areas are in square feet and were calculated from Munns et al. (23). One square foot = 929 square centimeters.

	W	A	B	C	D	E	F	G	H	I	J	K	L-O	M	N	P	Q	R	S	T
Acer negundo L.	—	—	—	—	—	—	—	0.09	0.01	—	—	—	—	—	—	—	—	—	—	—
Acer saccharinum L.	—	—	0.30	—	0.02	—	0.08	—	1.86	—	2.55	0.16	—	—	—	—	—	—	0.50	—
Carya ovata (Mill.) K.Koch	1.30	0.40	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Carya spp.	0.60	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Celtis occidentalis L.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.07
Cercis canadensis L.	—	—	—	0.01	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Cornus spp.	0.60	0.50	—	0.01	—	—	—	—	—	—	—	—	0.01	—	—	—	—	—	—	—
Crataegus spp.	—	0.71	0.02	—	—	—	—	—	—	0.05	—	0.02	0.08	—	—	—	0.01	0.08	0.03	0.04
Fraxinus americana L.	—	0.21	0.81	1.45	—	—	—	0.73	—	—	—	—	—	—	—	—	—	—	—	—
Fraxinus pennsylvanica Marsh	—	—	—	—	0.01	1.58	1.70	0.24	1.08	0.40	0.69	0.58	0.51	1.52	0.21	0.32	1.11	0.09	—	0.04
Fagus grandifolia Ehrh.	—	0.10	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Gleditsia tricanthos L.	—	0.40	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Juglans nigra L.	0.03	1.20	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Liquidambar styraciflua L.	—	—	—	—	—	—	—	—	—	—	—	—	—	0.08	—	—	—	0.38	—	—
Liriodendron tulipifera L.	—	0.30	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Malus spp.	0.20	0.05	0.03	0.01	—	—	—	—	—	—	—	—	—	0.02	—	—	—	—	—	—
Pinus banksiana Lamb.	—	—	0.02	—	0.04	0.13	—	0.79	—	—	0.63	—	—	—	—	—	—	0.51	0.08	—
Pinus resinosa Alt.	—	—	—	—	0.02	—	—	—	0.87	—	—	—	—	—	—	—	—	—	—	—
Pinus strobus L.	—	—	—	0.20	—	—	0.29	—	—	—	—	—	0.02	0.11	0.01	—	—	0.07	1.13	—
Pinus virginiana Mill	—	—	—	—	0.22	0.72	—	0.13	0.20	—	1.42	0.53	—	0.11	—	—	—	0.37	—	—
Platanus occidentalis L.	—	—	—	0.67	—	—	—	—	0.77	—	—	—	—	—	0.48	—	—	0.46	0.56	—
Populus deltoides Marsh.	—	—	2.10	—	—	—	0.71	—	—	—	—	—	—	0.66	—	—	—	—	—	—
Prunus serotina Ehrh.	—	2.40	—	—	—	—	—	—	—	0.15	—	—	—	0.16	—	—	0.02	0.07	0.01	—
Quercus alba L.	1.90	5.39	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Quercus imbricaria Michx.	1.61	2.30	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Quercus velutina Lam.	3.10	0.30	0.04	—	0.18	—	—	—	—	—	—	—	—	—	—	0.46	—	—	0.03	—
Robinia pseudoacacia L.	—	0.05	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Salix nigra Marsh.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.02	0.17
Sassafras albidum (Natt.)	0.03	0.90	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Ulmus americana L.	—	0.79	0.30	—	—	—	—	—	—	0.07	—	—	—	—	—	—	—	—	—	—
Ulmus rubra Muhl.	0.05	0.20	—	0.10	—	—	—	0.25	—	—	—	—	0.27	—	—	—	—	—	0.01	—
Vitis spp.	0.02	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Site Totals:	9.44	16.23	3.62	2.45	0.49	2.43	2.78	2.23	4.79	0.67	5.29	1.29	0.89	2.66	0.70	0.78	1.14	2.53	1.87	0.32

TABLE 5. Importance values of trees with dbh 2.54 cm (one inch) or greater at each research site in 1964.

	W	A	B	C	D	E	F	G	H	I	J	K	L-O	M	N	P	Q	R	S	T
Acer negundo L.	—	—	—	—	—	—	—	91.6	—	—	—	—	—	—	—	—	—	—	—	—
Acer saccharinum L.	—	—	—	—	—	48.9	25.5	—	90.2	—	108.0	58.3	—	—	—	—	—	—	—	—
Carya ovata (Mill.) K.Koch	53.8	1.8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Carya spp.	13.9	3.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Cornus spp.	29.1	6.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Crataegus spp.	—	45.8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Fraxinus americana L.	—	17.1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Fraxinus pennsylvanica Marsh	—	—	—	200.0	—	65.6	118.5	48.8	14.7	—	46.4	58.3	—	—	75.0	—	—	—	—	—
Gleditsia tricanthos L.	—	14.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Juglans nigra L.	3.3	19.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Malus spp.	—	18.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Pinus banksiana Lamb.	—	—	—	—	—	19.9	—	29.8	—	—	13.9	83.3	—	—	—	—	—	36.6	75.0	—
Pinus virginiana Mill	—	—	—	—	—	65.6	—	29.8	35.9	—	31.5	—	—	—	—	—	—	—	—	—
Platanus occidentalis L.	—	—	—	—	—	—	—	—	59.2	—	—	—	—	—	125.0	—	—	163.3	125.0	—
Populus deltoides Marsh.	—	—	—	—	—	—	56.0	—	—	—	—	—	—	200.0	—	—	—	—	—	—
Prunus serotina Ehrh.	—	4.8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Quercus alba L.	33.8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Quercus imbricaria Michx.	19.6	2.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Quercus velutina Lam.	35.8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Sassafras albidum (Natt.)	3.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Ulmus americana L.	—	53.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Ulmus rubra Muhl.	3.3	9.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Vitis spp.	3.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

TABLE 6. Importance values of trees with dbh of 2.54 cm (one inch) or greater at each research site in 1981.

	W	A	B	C	D	E	F	G	H	I	J	K	L-O	M	N	P	Q	R	S	T
Acer negundo L.	—	—	—	—	—	—	—	19.3	5.5	—	—	—	—	—	—	—	—	—	—	—
Acer saccharinum L.	—	—	21.8	—	27.2	—	12.9	—	70.4	—	78.2	21.5	—	—	—	—	—	29.3	—	—
Carya ovata (Mill.) K.Koch	22.3	7.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Carya spp.	14.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Celtis occidentalis L.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	28.6
Cercis canadensis L.	—	—	—	8.7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Cornus spp.	32.3	23.6	—	8.7	—	—	—	—	—	—	—	—	10.2	—	—	—	—	—	—	—
Crataegus spp.	—	26.0	5.0	—	—	—	—	—	—	18.6	—	10.7	36.3	—	—	—	7.6	12.7	19.8	19.2
Fraxinus americana L.	—	3.7	45.1	100.8	—	—	—	71.2	—	—	—	—	—	—	—	—	—	—	—	—
Fraxinus pennsylvanica Marsh	—	—	—	—	9.7	122.1	131.2	18.5	54.1	115.3	33.0	90.4	93.7	122.1	80.0	107.7	177.4	13.1	—	19.2
Fagus grandifolia Ehrh.	—	1.8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Gleditsia tricanthos L.	—	6.1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Juglans nigra L.	4.6	14.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Liquidambar styraciflua L.	—	—	—	—	—	—	—	—	—	—	—	—	—	8.0	—	—	—	19.8	—	—
Liriodendron tulipifera L.	—	3.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Malus spp.	6.4	1.5	9.9	8.7	—	—	—	—	—	—	—	—	—	10.8	—	—	—	—	—	—
Pinus banksiana Lamb.	—	—	9.6	—	23.6	19.6	—	50.8	—	—	31.9	—	—	—	—	—	—	34.5	13.4	—
Pinus resinosa Alt.	—	—	—	—	11.8	—	—	—	28.7	—	—	—	—	—	—	—	—	—	—	—
Pinus strobus L.	—	—	—	16.5	—	—	20.4	—	—	—	—	—	11.3	9.1	26.4	—	—	17.1	78.6	—
Pinus virginiana Mill	—	—	—	—	83.4	58.2	—	13.5	9.5	—	56.8	77.5	—	9.1	—	—	—	24.1	—	—
Platanus occidentalis L.	—	—	—	35.6	—	—	—	—	31.9	—	—	—	—	—	93.6	—	—	42.0	39.0	—
Populus deltoides Marsh.	—	—	67.1	—	—	—	35.5	—	—	—	—	—	—	29.8	—	—	—	—	—	—
Prunus serotina Ehrh.	—	17.1	—	—	—	—	—	—	—	50.2	—	—	—	11.0	—	—	15.1	7.6	9.6	—
Quercus alba L.	28.8	35.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Quercus imbricaria Michx.	30.0	15.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Quercus velutina Lam.	41.5	5.4	14.7	—	44.4	—	—	—	—	—	—	—	—	—	—	92.3	—	—	10.7	—
Robinia pseudoacacia L.	—	1.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Salix nigra Marsh.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	19.3	133.1
Sassafras albidum (Natt.)	4.6	15.1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Ulmus americana L.	—	14.5	26.5	—	—	—	—	—	—	16.0	—	—	—	—	—	—	—	—	—	—
Ulmus rubra Muhl.	9.2	7.2	—	20.7	—	—	—	26.6	—	—	—	—	48.5	—	—	—	—	—	9.6	—
Vitis spp.	4.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

In addition, individual trees on each stripmine plot were compared in 1964 and 1981. Annual growth was calculated for trees present both years and this was compared with average growth for the same species from Smith and Shifley's (33) data on Indiana and Illinois trees for the same time period. Since their diameter growth data is cumulative and trees grow slowly at first, it was necessary to calculate the average growth for the final 17-year increment to compare with the observed 1964-81 growth. Trees were then designated as growing faster (+) or slower (−) than trees in forest settings. All stripmine trees were arrayed by species according to the average pH of their plot. Trees present in 1964 but dead or disappeared (D) by 1981 were arrayed by 1964 site pH. Trees new to the site in 1981 (N) were arrayed by 1981 pH.

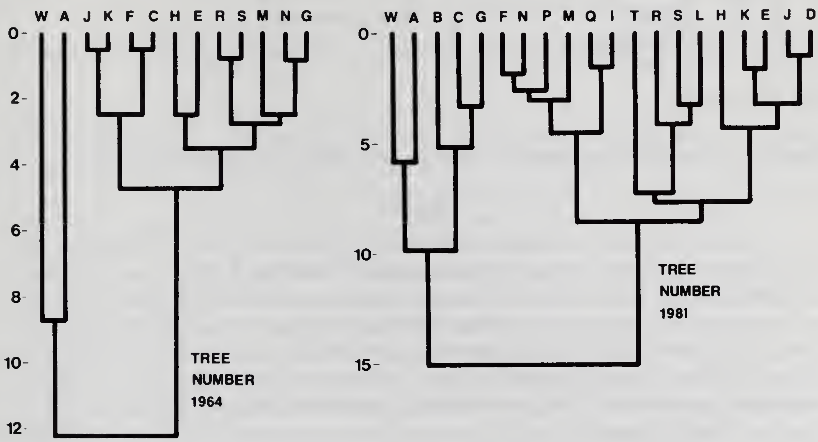

FIGURE 2. Dendrograms clustering sites by tree number in 1964 and 1981.

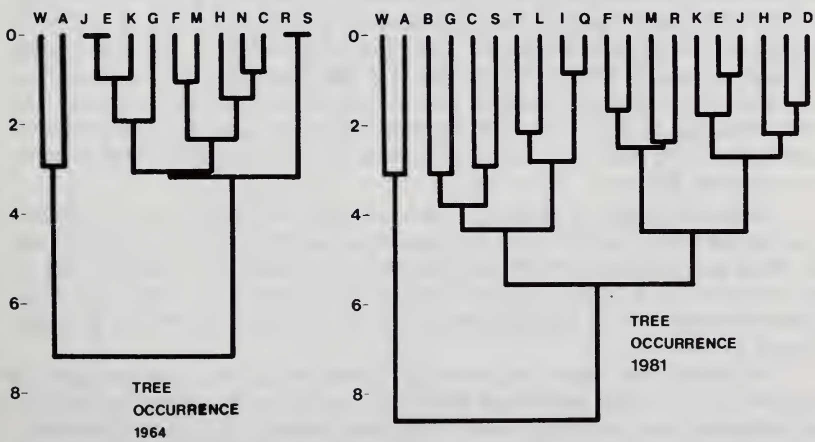

FIGURE 3. Dendrograms clustering sites by presence and absence of trees in 1964 and 1981.

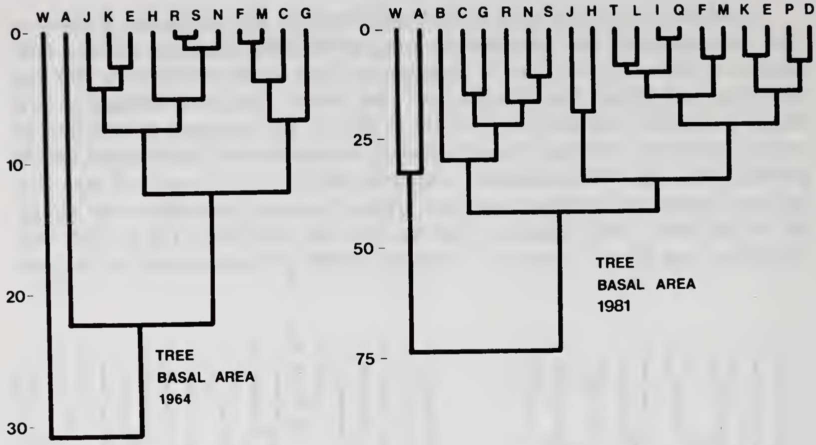

FIGURE 4. Dendrograms clustering sites by tree basal area in 1964 and 1981.

Results

Fully two-thirds of the trees in 1964 were on the unmined sites W and A (Table 1). Hickories, dogwoods and oaks dominated site W while site A was a young woodland of hawthorns, elms and white ash. Red ash, silver maple, jack and Virginia pines and a few sycamores, spotted the spoilbanks with rare occurrences of other species. By 1981, site W was found to still be maturing as reflected by a nearly universal reduction in tree numbers (Table 2) and an increase in basal area (Tables 3 and 4). At site A, white ash, American elm and hawthorns were declining in numbers although hawthorns that survived increased in total basal area. This young woodland still saw additions of stems over 2.54 cm. (1 in.) dbh of white oak, black oak, sassafras, tulip poplar, black walnut and shagbark hickory. In 1964, site W led in total basal area, but by 1981 the addition of many young trees boosted basal area far beyond that for W. On the mined sites, red ash occurred everywhere except at sites B, C and S and had become 22 percent of the total tree population. Other species successful on spoilbanks include silver maple, jack, Virginia and white pines, black cherry and hawthorns. Species richness increased by seven species and site H in 1981 supported more basal area than site A in 1964. New species included one tulip poplar and one beech. However, the first occurrence of black willow on the sheltered banks nearest the stripmine lakes may indicate that these sites were the only moist sites within dispersal range of black willow stands off-site to the north.

Importance values, a composite figure reflecting each species percent contribution to each plot in both numbers and basal area together, are given in Tables 5 and 6. While one tree assumes total importance on sites C and M in 1964, by 1981 no tree stands alone in its defined site. While red ash assumes great importance across most strip mine sites, the two red ash trees present on site C in 1964 are no longer present in 1981.

All tabular data reflect only the woody stems that survive to be one inch dbh or greater, and in both years many stems may have existed just below this point to go unrecorded only to appear later as important elements of the new community.

Sites without trees in 1964 are excluded from the dendrograms (B, D, I, L-O, P, Q and T). According to tree numbers, the unmined sites W and A are separate and distinct from the spoilbanks although tree basal area of site A is still closer to

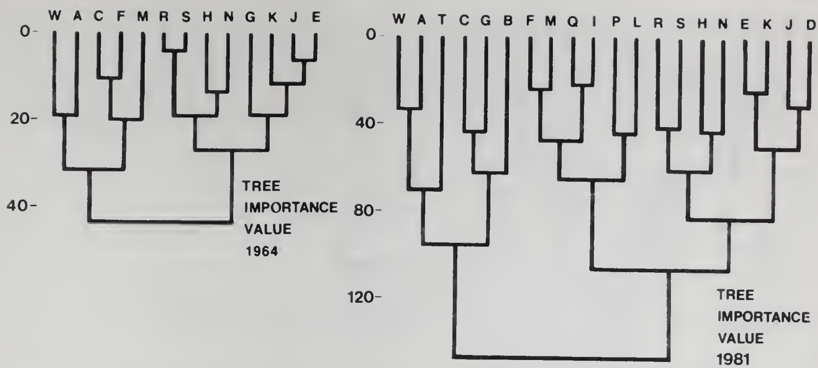

FIGURE 5. Dendrograms clustering sites by tree importance values in 1964 and 1981.

the spoilbanks than the forest (Figure 4). By 1981, site A is most similar to forest site W, the relative amalgamation distance having decreased for their similarity based on both numbers and basal area (Figures 2 and 4). The stripmine sites, all represented by trees in 1981, are more disparate among themselves than A is from W, a reversal over 1964 (Figure 2). Sites B, C, and G, while closer to W and A in number of trees, are still closer to the spoilbanks in basal area produced in 1981.

That tree associations, even small ones, are laboriously slow in changing composition, is illustrated in the joint dendrogram of tree numbers in Figure 6. Sites for 1981 generally cluster very close to their 1964 positions indicating that the sites have not generally moved on to become like other sites. This pairing is probably more noticeable than shown since sites without trees in 1964 and trees less than 2.54 cm. (1 in.) dbh are excluded. Site W has changed less than site A during these 17 years. Sites N, F, H, M, G and J have undergone minor changes. Major shifts have occurred at sites T, S, P, B, C and I.

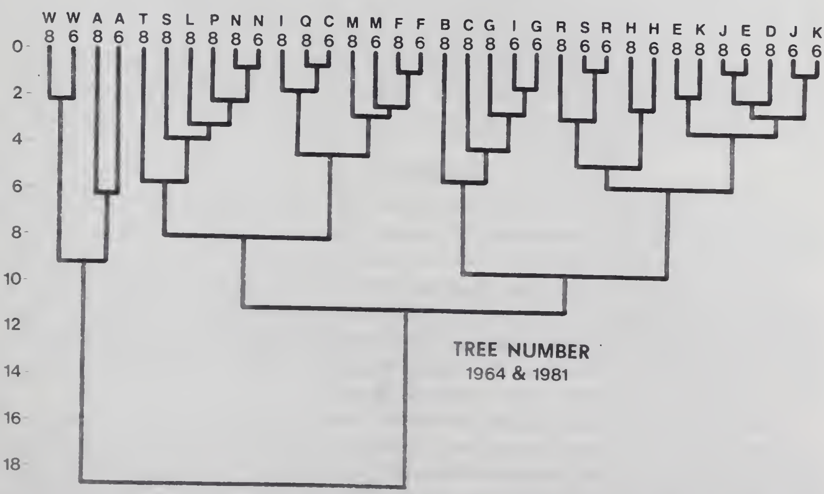

FIGURE 6. Dendrogram clustering 1964 (W6, A6, B6. . .T6) and 1981 (W8, A8, B8. . .T8) sites together on number of trees of 2.54 cm (1 inch) dbh or greater.

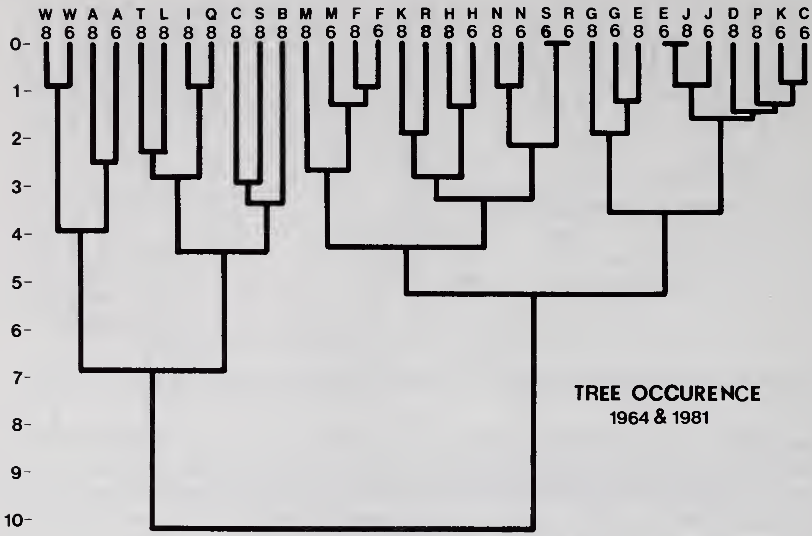

FIGURE 7. Dendrogram clustering 1964 and all 1981 sites together on presence and absence of trees of 2.54 cm (one inch) dbh or greater.

By general appearance, sites B, C, and T in 1981 appear most forest-like. These sites cluster with the forested unmined sites based on the importance values of trees (Figure 5). Sites W and A are very distinct from spoilbanks based only on presence and absence of trees in 1964 or 1981 (Figure 3). However, the anticipation that tree species would cluster by site proximity in the occurrence cluster is not met either study year. With respect to tree occurrence, sites W and A are little changed in amalgamation distance over 17 years, while the spoilbanks show much greater variation and greater amalgamation distances in 1981.

Combined 1964 and 1981 tree occurrence data (Figure 7) yield a dendrogram similar to combined tree number data (Figure 6). Again, many 1981 sites remain generally closer to their 1964 composition than to other sites (W, A, F, H, N and M, G and J).

Conclusions

Natural tree invasion of humid midwestern coal spoils varies widely on 32-year-old sites, from extremely limited growth on acidic banks to a closed canopy on banks within the normal local soil pH.

Among the workers who have appraised planted and naturally dispersed tree survival on coal spoilbanks are: Arnott (1), Indiana planted; Brewer and Triner (4), Illinois natural; Croxton (7), Illinois planted; Davidson (10), central U.S. planted; DenUyl (12), Indiana planted; Limstrom and Deitschman (18), Indiana planted; Stiver (34), Indiana planted; and Tarbox (51), Indiana planted.

The ash *Fraxinus pennsylvanicus* was the most widespread volunteer on the spoilbanks and is the most tolerant early colonizer. It has been considered a good survivor (1, 4, 10, 12, 18) although Miles et al. (21) found ". . .little growth or vigor after 4 years." This same ash is a successful survivor on coal spoils extending to semiarid North Dakota mines (9).

Cottonwood has been found to be a good (7, 12, 17, 34) or fair (1, 18) survivor

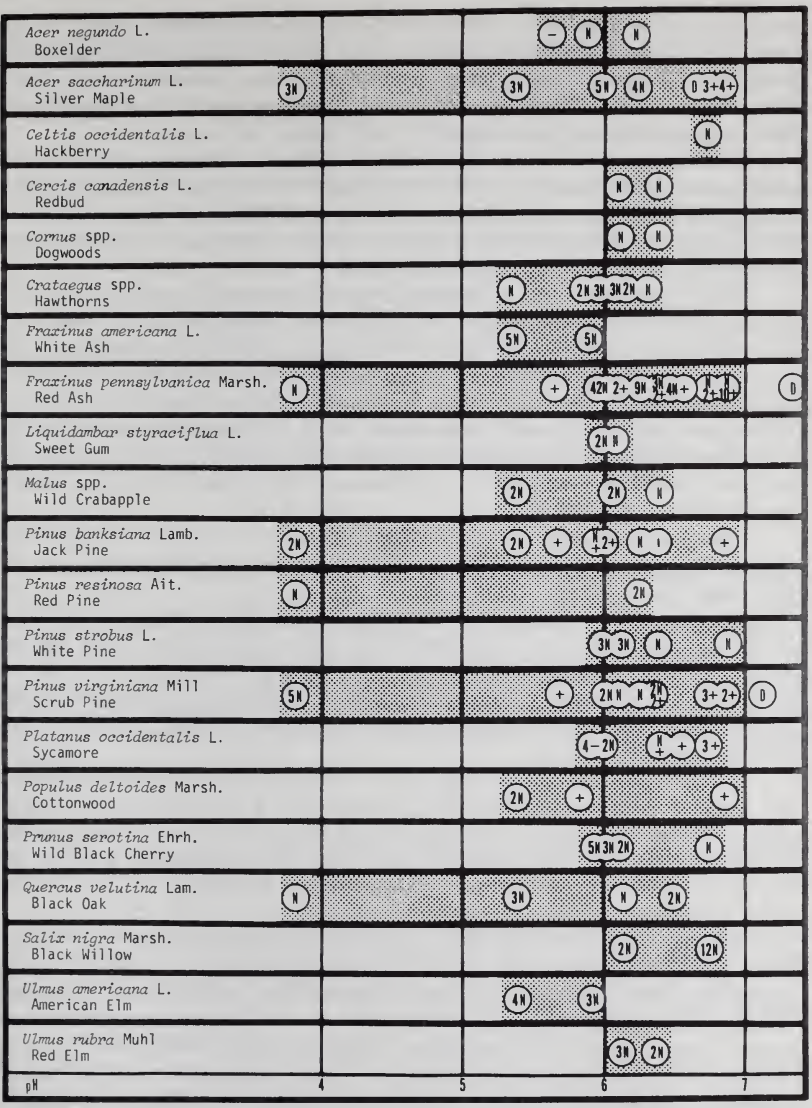

FIGURE 8. Occurrence of tree species on spoilbanks. (N) = new in 1981. (D) = present in 1964 but died or disappeared in 1981. A plus indicates growth between 1964 and 1981 exceeded expected growth in forest stands (33). A minus indicates growth between 1964 and 1981 was less than expected.

on spoilbanks and has generated the hope some spoilbanks could eventually produce pulpwood commercially. Cottonwood was a rare colonizer in this study.

Black locust, considered ". . .the No. 1 tree for its widespread adaptation to all spoil groups and its rapid growth and quick cover. . ." (12) and considered a good survivor (1, 12, 17, 35) but poor by Davidson (10), was conspicuously absent on these study sites in spite of seed supplies nearby. Observations by Sawyer (29) suggest locust is subject to insect attack and is not a good competitor once reforestation is underway. This is also confirmed by Boring and Swank (3) where locust only dominates early forest regeneration and yields rapidly to other dominants.

Sycamore stands out as one tree which consistently fails to equal or exceed growth rates expected in Indiana forests. Miles et al. (21) also detected lack of vigor and growth but attributed its poor performance on spoils to the seedlings not being from a local source. Others found sycamore a good (1, 4, 7, 17) or fair (12, 18) survivor but did not compare its growth with non-mined rates.

While white pine failed to become established when direct seeded on banks by Miles et al. (21), it spread on eight sites in this study. White pine has previously been considered a fair (18) and good (17) spoil survivor. Compared to other pines, white pine has shown the best survival on all spoil texture classes (28). New red pines appeared on only a few sites. Survival has been considered poor (18) and it has the lowest seedling survival rate on spoils among pines tested by Plass (28). Sawyer (30) concluded that slopes were far more favorable than graded level areas, with Virginia, Jack and pitch pine survival being 80% and 25% respectively. Pines in this study survived equally well on all aspects.

Sweet gum was rated a poor survivor in Miles et al. (21), fair in other studies (1, 17, 18) and good in two studies (12, 35). Several trees invaded our study site with better-than-forest growth.

Limstrom (17) concluded stripmine tree studies showed ". . .little or no differences in tree survival among aspects and between upper and lower slopes." This was supported by sites K, H, F and G in this study facing N, W, S and E respectively, showing no unique tree associations. Nor do sites with similar aspects, soil textures or pH, cluster consistently in similarity dendrograms based on tree numbers, occurrence, basal area or importance value.

Overall, competition should also result in tree death or less-than-normal growth. But deaths and decreased growth are inconsequential in this measurement from 15 years to 32 years after mining, and suggest competition as detected by Vogel and Berg (37) occurs much later or on reclaimed sites. Competition with smaller trees less than one inch dbh may occur similar to the suppression of close-planted black walnut on spoils described by Geyer and Noughton (14).

The clustering of sites based on chi-square similarity produces nonrigid dendrograms which can be rotated to orient the sites from the forest site W to the near-barren spoilbank D. While some internodes can still rotate, clusters are forced into intermediate positions that correspond to successional stages for coal stripmine spoils. Four different "counts" used for clustering were based on different assumptions. "Tree occurrence," based on the presence or absence of trees, presumed the number and size of trees is unimportant or chance. . .the important factor being whether the tree species survive on the site. (Sites with 1 and 5 trees of species A are similar, different from a site with none.) "Tree number" minimizes this threshhold effect and weighs the number of trees of each species regardless of their basal area. (Sites with 0 and 1 trees of species A are similar, different from a site with 5 trees.) "Basal area" clusters on productivity visible above 1" dbh and "Importance Value" measures similarity on an average of percentages of density and basal area per species per site. Each count, based on a different premise, yields a different dendrogram. Nevertheless, the old field site A always remains distinct from the stripmine sites and associated with the maturing forest, and the more densely revegetated spoils fall in intermediate positions.

Although only trees greater than one inch dbh were "visible" in this analysis, the assortment of trees appeared to support Bauer's (2) proposal that they were merely a ". . .chance combination of species. . ." able to survive on the spoils. The fact that 1981 stripmine sites clustered nearest or very near to their 1964 position when pooled together indicates that competition from herbaceous vegetation as described by Vogel and Berg (37) was insufficient to change these tree communities in any single direction.

In 1959, DenUyl (12) measured 10 hardwoods planted on Indiana spoils in 1949, six of which naturally invaded the spoils in this study. All six species in DenUyl's study exhibited a normal range of variation in diameter growth over 11 growing seasons, the mode for all six being clearly greater than in-forest growth for these species in Indiana as later measured by Smith and Schifley (33). The accelerated growth on the unshaded spoilbanks for most species was confirmed in this study and represents "release" from the shaded forest environment.

In 1925, McDougall (26) subjectively described the spoilbanks one county west of this study site as originally a typical bottomland forest association which ". . .under favorable conditions. . .is reestablished in about 24 years." In contrast, this study reveals unreclaimed Indiana coal spoils, 32-years old, to be a highly variable and highly fragmented assemblage, likely to be determined by chance dispersal and tolerance to pH and aridity, unlikely to yet be shaped by competition. . .and far too premature to be considered a reestablished forest.

Acknowledgments

The Clinton Chapter of the Isaac Walton League graciously granted permission for the 1964 and 1981 studies. Without their ongoing efforts over the last 34 years, this specific site of naturally revegetating spoil banks would not have existed undisturbed. Munsee designed the original 1964 study and carried out the 1964 fieldwork. Schrock conducted the 1981 fieldwork, the between year comparisons, and wrote this text. We would like to thank our wives who were financially supportive throughout the research period. We are indebted to Dr. Leland Chandler, Purdue University, and Dr. Edward Martinko, University of Kansas, who served as major professors in the respective studies.

Literature Cited

1. Arnott, Jr., D. 1950. Initial Survival of Planted Hardwoods on Strip Mine Spoil Banks of Indiana. M.S. Thesis, Dept. of Forestry, Purdue University, West Lafayette, IN. 61 p.
2. Bauer, H.J. 1973. Ten years' studies of biocenological succession in the excavated mines of the Cologne lignite district. In Hutnik, R.J. and G. Davis (eds.) Ecology and Reclamation of Devastated Land. Gordon and Breach, Inc., NY.
3. Boring, L.R. and W.T. Swank. 1984. The role of black locust (*Robinia pseudoacacia*) in forest succession. J. Ecol. 72:749-766.
4. Brewer, R. and E.D. Triner. 1956. Vegetational features of some strip-mined land in Perry County, Illinois. Ill. Acad. Sci. Trans. 48:73-84.
5. Byrnes, W.R. and J.H. Miller. 1973. Natural revegetation and cast overburden properties of surface-mined coal lands in southern Indiana. In Hutnik, R.J. and G. Davis (eds.) Ecology and Reclamation of Devastated Land. Gordon and Breach, Inc., NY.
6. Chambers, J.C. 1983. Measuring Species Diversity on Revegetated Surface Mines: An Evaluation of Techniques. Intermountain Forest and Range Exp. Stat. Res. Paper INT-322. 15 p.
7. Croxton, W.C. 1928. Revegetation of Illinois coal-stripped lands. Ecology. 9:155-175.
8. Curtis, J.T. and R.P. McIntosh. 1951. An upland forest continuum in the prairie-forest border region of Wisconsin. Ecology. 32:476-496.

9. Darris, D.C., E.T. Jacobson and R.J. Haas. 1982. Performance and adaptation of 20 trees and shrub species for surface mine revegetation in North Dakota. Society for Range Management, 1982 Annual Meeting, Calgary, Alberta, Canada. 8 p.
10. Davidson, W.H. 1979. Results of tree and shrub plantings on low pH stripmine banks. Northeastern For. Exp. Stat. Res. Note NE-285. 5 p.
11. DenUyl, D. 1955. Hardwood Tree Planting Experiments on Strip Mine Spoil Banks of Indiana. Purdue Univ. Agric. Exp. Stat. Bull. 619. Lafayette, IN. 16 p.
12. DenUyl, D. 1962. Survival and growth of hardwood plantations on strip mine spoil banks of Indiana. J. of Forestry. 60:603-606.
13. Fernald, M.L. 1950. Gray's Manual of Botany. 8th ed. revised. American Book Co., NY. 1632 p.
14. Geyer, W.A. and G.G. Naughton. 1979. Black walnut (*Juglans nigra* Linnaeus) response to release and fertilization on strip-mined lands in southeastern Kansas. Trans. Kan. Acad. Sci. 82:178-187.
15. Gleason, H.A. and A. Cronquist. 1963. Manual of Vascular Plants of Northeastern United States and Adjacent Canada. D. VanNostrand Co., NY.
16. Harlow, W.M. 1942. Trees of the Eastern United States and Canada. McGraw-Hill Book Co., NY. 288 p.
17. Limstrom, G.A. 1960. Forestation of Strip-mined Land in the Central States. U.S.D.A. For. Serv. Agric. Handbook 166. 74 p.
18. Limstrom, G.A. and G.H. Deitschman. 1951. Reclaiming Illinois strip coal lands by forest planting. Ill. Agric. Exp. Stat. Bull. 547. 50 p.
19. Lindsey, A.A., W.B. Crankshaw and S.A. Qadir. 1965. Soil relations and distribution map of the vegetation of presettlement Indiana. Bot. Gazette. 126:155-163.
20. McDougall, W.B. 1925. Forests and soils of Vermillion County, Illinois, with special reference to the "Striplands." Ecology. 6:372-379.
21. Miles, V.C., R.W. Ruble and R.L. Bond. 1973. Performance of plants in relation to spoil classification in Pennsylvania. In Hutnik, R.J. and G. Davis (eds.) Ecology and Reclamation of Devastated Land. Gordon & Breach, Inc., NY.
22. Mohlenbrock, R.H. 1973. Forest Trees of Illinois. Dept. of Conserv., Div. of Forestry, IL. 178 p.
23. Munns, E.N., T.G. Hoerner and V.A. Clements. 1949. Converting Factors and Tables of Equivalents Used in Forestry. U.S.D.A. Misc. Publ. No. 225. Supt. of Documents. U.S. Printing Office, Washington, DC.
24. Munsee, J.R. and J.R. Schrock. 1982. Comparison of ant faunae from unreclaimed coal stripmines in Indiana in 1964 and 1981. Proc. Ind. Acad. Sci. 92:257-261.
25. Munsee, J.R. 1966. The Ecology of Ants of Stripmine Spoil Banks. Ph.D. Dissertation. Purdue University, West Lafayette, IN. 243 p.
26. Neumann, U. 1971. Die Sukzession der Bodenfauna (Carabidae: Coleoptera, Diplopoda und Isopoda) in den Forstlich Rekultivierten Gebieten des Rheinischen Braunkohlenreviers. Pedobiologia. 11:193-226.
27. Neumann, U. 1973. Succession of soil fauna in afforested spoil banks of the brown-coal mining district of Cologne. In Hutnik, R.J. and G. Davis (eds.) Ecology and Reclamation of Devastated Land. Gordon and Breach, Inc., NY.
28. Plass, W.T. 1974. Factors Affecting the Establishment of Direct-Seeded Pine on Surface-mine Spoils. U.S.D.A. For. Serv. Res. Paper NE-290. 5 p.
29. Sawyer, L.E. 1946. Indiana strip-mine plantings. J. Forestry. 44:19-21.
30. Sawyer, L.E. 1949. The use of surface mined land. J. Soil and Water Conserv. 4:161-166.
31. Schrock, J.R. 1983. The Succession of Insects on Unreclaimed Coal Strip Mine

Spoil Banks in Indiana. Ph.D. Dissertation. University of Kansas, Lawrence, KS. 207 p.

32. Schrock, J.R. and J.R. Munsee. 1984. A comparison of soils on unreclaimed Indiana coal stripmine surfaces in 1964 and 1981. Proc. Ind. Acad. Sci. 94:579-596.
33. Smith, W.B. and S.R. Shifley. 1984. Diameter Growth, Survival, and Volume Estimates for Trees in Indiana and Illinois. U.S.D.A. North Cent. For. Exp. Stat. Res. Paper NC-257. 10 p.
34. Stiver, E.N. 1949. Revegetation of Strip Coal Spoil Banks of Indiana. Ph.D. Dissertation, Dept. of Forestry, Purdue University, Lafayette, IN. 91 p. (Abridged version, same title, same year, was printed by Coal Production Association, Terre Haute, IN. 16 p.)
35. Tarbox, Jr., G.L. 1954. The Survival and Growth of Young Hardwood Plantations on the Strip-mine Spoil Banks of Indiana. M.S. Thesis, Dept. of Forestry, Purdue University, West Lafayette, IN. 136 p.
36. VanderAart, P.J.M. and N. Smeenk-Enserink. 1975. Correlations between distributions of hunting spiders (Lycosidae, Ctenidae) and environmental characteristics in a dune area. Neth. J. Zool. 25:1-45.
37. Vogel, W.G. and W.A. Berg. 1973. Fertilizer and herbaceous cover influence establishment of direct-seeded black locust on coal-mine spoils. In Hutnik, R.J. and G. Davis (eds.) Ecology and Reclamation of Devastated Land. Gordon and Breach, Inc., NY.