FOREST PRODUCTIVITY AND WOODY SPECIES DIVERSITY ON PRE-SMCRA MINED LAND[1]

by

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Abstract. Citizens and landowners in the midwestern and eastern coal mining region are concerned that current reclamation procedures are not achieving land use, species diversity and productivity levels required by the Surface Mining Control and Reclamation Act of 1977 (SMCRA). The purpose of this study was to investigate the effects of mining and reclamation practices, used prior to the passage of SMCRA, on various forest attributes including forest site productivity and woody species diversity in the canopy, understory, and groundlayers. Forest diversity and productivity of fourteen mined and eight natural sites in the eastern and midwestern coalfield regions were compared. Results show that forest site productivity and woody species diversity varied among site types, canopy cover types, and regions. Species richness of the canopy layer and understory between eastern and midwestern mined sites were very different. The use of white pine (*Pinus strobus*) for reclaiming mined sites in the eastern region resulted in a decrease of hardwoods present in the canopy layers on mined sites. Midwestern mined sites more closely approximated regional non-mined sites in commercial species composition. Reclamation procedures including degree of compaction and stand history played an important role in the development of forest stands on mined land. Pre-SMCRA midwestern mined sites were growing as well as non-mined forests in the region, while mined site growth in the eastern region was usually poorer than on non-mined forests. Forests on pre-SMCRA mined lands are productive, valuable, and diverse. They should provide insight into the impacts of current reclamation practices on reforestation success and potential forest productivity.

Additional Key Words: reforestation, mined land, site productivity, species richness, reclamation

Introduction

Surface mining drastically disturbs land, forests, and waterways. Prior to the enactment of the Surface Mining Control and Reclamation Act (SMCRA) in 1977, high levels of land disturbance by mining prompted some mine operators, landowners, and surrounding communities to reclaim mined areas (DenUyl, 1955). Many states with mining activity enacted regulations to control the mining and reclamation process (Davidson, 1981; Sandusky, 1980). In the midwestern and eastern states most sites were reclaimed to forests through the planting of trees. The diversity and productivity of sites reclaimed with trees decades ago is unknown, and even though many mined sites had the potential to develop into productive forests, many environmental problems remained, including erosion, degraded water quality, toxic spoils, uneven landscapes, acid drainage, highwalls and subsidence.

SMCRA was enacted to address human safety, land productivity, and environmental problems that occurred during mining and reclamation. However, in the process of meeting these objectives, disincentives to reforest mined land were created, and the post-mining landscape is commonly unproductive for forestry land uses (Burger, 1999). Post-law emphasis was placed on water quality and erosion at the expense of site productivity and reforestation (Boyce, 1999). The Code of Federal Regulations, 30, Mineral Resources (1997) interpreting SMCRA requires that states restore disturbed land to conditions that are capable of supporting the uses which they were capable of supporting before any mining (715.13(a)), and that a diverse, effective, and permanent vegetation cover of native species be established (715.20(a)). However, current reclamation in the Appalachian region results in mine soils that are usually thin, alkaline, highly compacted, and covered with competitive grasses which makes it difficult to accomplish the productivity and diversity requirements. For example, Torbert et al. (1999) reported eleven-year results of a

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test planting of three pine species on a pre-SMCRA mined site and a post-SMCRA mined site. Trees planted on the pre-SMCRA mined site were planted on the flat bench that remained after contour coal extraction, while the post-SMCRA mined site was reclaimed to its "approximate original contour." The height and diameter growth of all three pine species (loblolly (*P. taeda*), Virginia (*P. virginiana*), and white (*P. strobus*)) was greater on the pre-SMCRA mined sites than the post-SMCRA mined sites. The heights on the pre-SMCRA mined sites averaged 7, 5.6 and 3.7 meters, while the heights on the post-SMCRA mined site averaged 6.7, 5.3, and 3.1 meters for loblolly, Virginia, and white pine, respectively. The diameter growth on the pre-SMCRA mined site averaged 11.2, 9.7, and 5.3 centimeters while on the post-SMCRA mined site the diameters averaged 8.9, 7.4, and 3.6 centimeters. Projecting these growth rates to a harvest age of 20 years indicates that stumpage value on the post-SMCRA site will be approximately half that on the pre-SMCRA site.

The lack of productivity standards for reclaiming forest land allows for forestland degradation. Current practice in most Appalachian states allows the operator to choose the rock overburden that is placed on the surface as long as it supports herbaceous ground cover and allows a minimum number of trees to survive for the bond period. Research has shown that the type of overburden suitable for the temporary ground cover is not necessarily the best choice for long-term forest uses (Torbert, 1995). Overburden selected for placement on the surface should be chosen for the target plant community and the specified post mining land use (Boyce, 1999). Forestry post-mining land uses should also meet a productivity standard in order to ensure that the land is restored to its original productivity as the spirit of the law requires.

Mature forests on older reclaimed mined sites might be used to provide insight into the conditions that need to be present for reclaiming mined land for forestry. Pre-law mined sites are growing forests in the midwest and the eastern coalfields over a wide environmental gradient that exists across these regions (Burger et al., 1998; Andrews, 1992; Plass, 1982). Through investigation and characterization of twenty- to sixty-year-old sites throughout the two regions, we hope to meet the following two objectives: (1) characterize the woody species diversity within three different strata on mined sites throughout the eastern and midwestern coal regions and qualitatively compare the diversity estimates to those on natural forest sites in the regions; (2) estimate and compare the mined sites' potential productivity to the potential productivity of natural forest sites within the region.

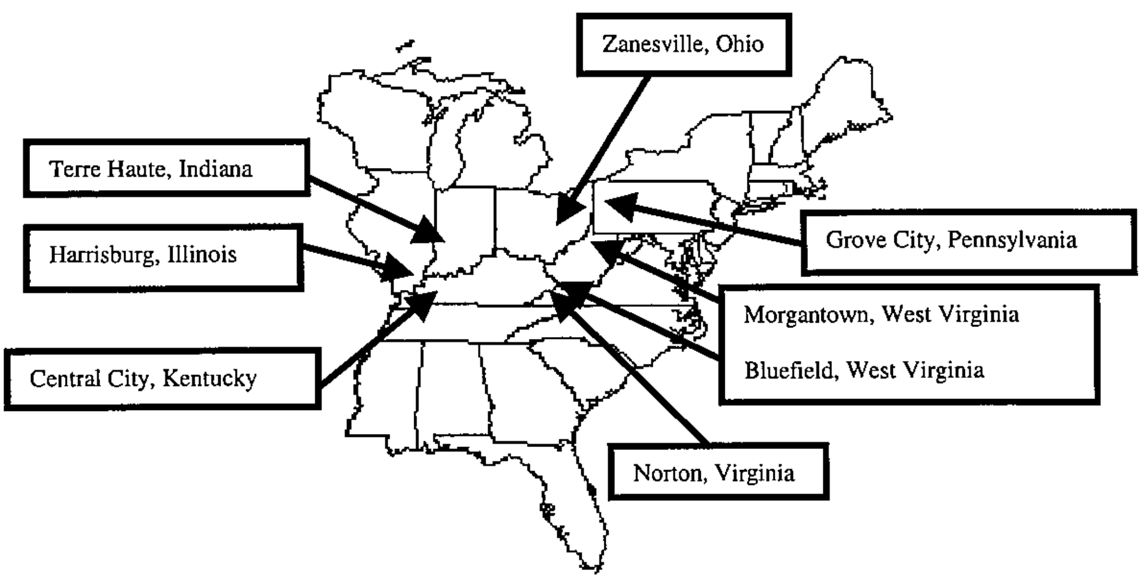

Figure 1. Study site locations.

Methods

Site Selection and Layout

Fourteen forest sites across seven states, each with a size of 0.8 to 3 hectares of contiguous forest cover, were located on reclaimed mined lands in the midwestern and Appalachian coal fields (Figure 1). The fourteen sites ranged from 20 to 55 years old. The canopy layer species ranged from pure hardwood and conifer stands to mixed conifer or hardwood stands (Table 1). These sites also covered a spectrum of spoil types. The measurement sites were chosen to represent a cross-section of stand size, stand age, and stand conditions.

Within each similar geographic region (e.g. southern Illinois) reference native forest sites (e.g. control site) representing minimally manipulated regional forests were also located and measured. Undisturbed control sites represented land conditions similar to what was present on the mined sites before they were disturbed. For this reason the undisturbed site was chosen in close proximity to the chosen mined sites. All sites were mature, well stocked, native forest stands, but all had been harvested at some point in their history.

After the boundaries of each study site were established, a 20x20-meter grid was superimposed on cardinal directions. Grid lines were placed perpendicular to the banks on open-pit mined sites where more than one spoil bank existed to ensure that the sites' micro-topography was taken into account. A 20 meter buffer strip was maintained on all edges of each forest site. All subsequent sampling was based from the intersections of the grid (Figure 2). Field data collection took place between May and August, 1999, with the exception of two sites which were measured in August, 1998.

Woody Species Diversity and Stand Composition

Tree and shrub species composition and diversity was measured on each site by randomly choosing 4 measurement points at 20x20 meter grid intersections. Plots were established at each point. Vegetation was divided into three strata; canopy, understory, and ground layer; defined as woody plants greater than 5 cm dbh, less than 5 cm dbh and taller than 1 m, and less than 1 m, respectively. The tree species in the canopy layer were tallied within a 404 m^2 circular plot. Canopy-layer measurements included density, dbh, and species. The understory layer was tallied within 80 m^2 circular plots using the same plot center as the 404 m^2 canopy layer plot (Figure 2). The woody ground layer was tallied in four -4 m^2 circular plots located in cardinal directions 4.9 m from the main plot center. The use of the 4.9 m radius was to remove the sampling points from the center of the plot where human-induced disturbance occurred as the canopy layer and understory samples were collected.

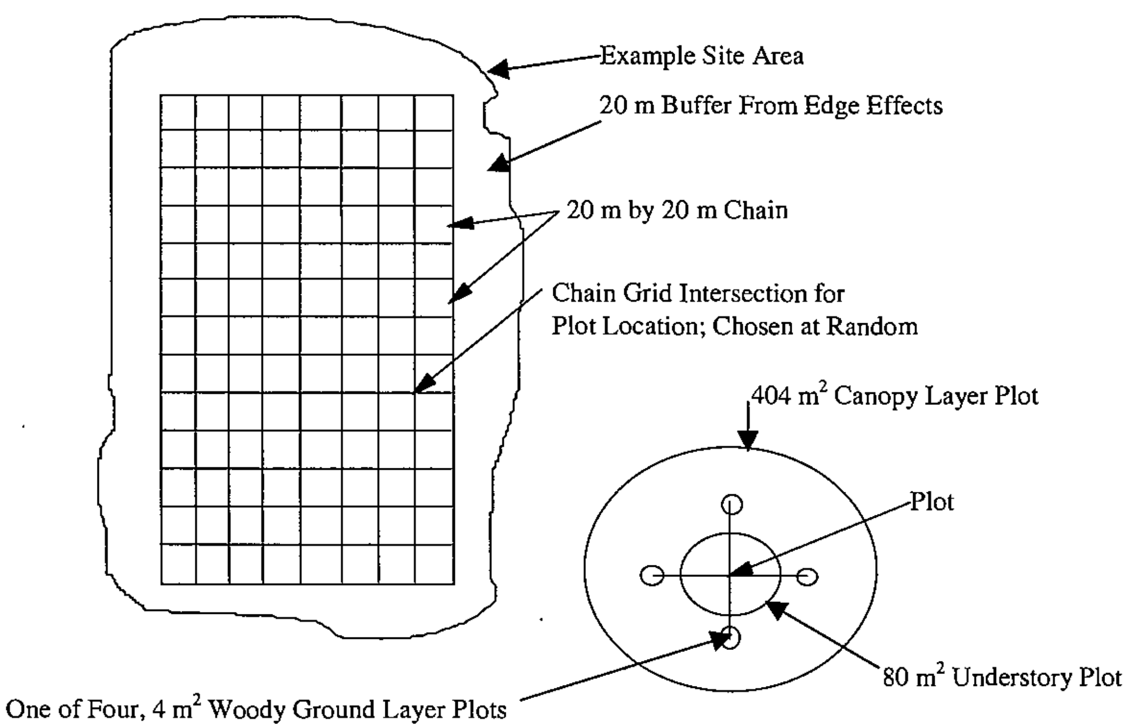

Figure 2: Site layout depicting 20 by 20 m grid, plot, and subplot arrangement.

Table 1. Location, description, and age of study sites.

State (County)	Site Name	Mining History	Regeneration History	Approximate Year Planted
Illinois	Non-mined		2^{nd}–3^{rd} Generation bottomland hardwood site (*Q. coccinea, A. rubrum*).	Multi-aged
(Saline)	IL-1	Open-pit mined, cast overburden	Planted to *Q. alba* and *R. pseudoacacia*. Partially underplanted with *L. tulipifera*. *R. pseudoacacia* is no longer present.	*Q. alba* 1938 *L. tulipifera* 1953
	IL-2	Open-pit mined, cast overburden, leveled with dragline	Planted to *P. deltoides*.	1956
Indiana	Non-mined		2^{nd}–3^{rd} Generation upland *Quercus spp*., *L. tulipifera* site.	Multi-aged
(Vigo)	IN-1	Open-pit mined, cast overburden	Planted to *P. rigida*.	1944
	IN-2	Open-pit mined, cast overburden	Planted to *P. rigida*. *P. rigida* has been unsuccessful allowing for invasion of secondary succession hardwoods and shrubs.	1949
Kentucky	Non-mined		2^{nd}–3^{rd} Generation upland mixed *Quercus spp.* site.	Multi-aged
(Ohio)	KY-1	Open-pit mined, cast overburden, top graded	Planted to *L. tulipifera*, *P. occidentalis*, *Q. rubra*, *P. deltoides*.	1964
(Muhlenberg)	KY-2	Open-pit mined, cast overburden, top graded	Planted to *L. tulipifera*, *P. occidentalis*, *Q. rubra*, *P. deltoides*, *L. styraciflua*, *Fraxinus spp.*.	1964
	KY-3	Open-pit mined, cast overburden	Planted to *P. strobus* with *P. taeda* patch.	1959
	KY-5	Open-pit mined, cast overburden	Planted to *P. taeda*.	1966
Ohio	Non-mined		2^{nd}–3^{rd} Generation upland mixed *Quercus spp.* site.	Multi-aged
(Muskingum)	OH-1	Open-pit mined, cast overburden, lightly top graded	Planted to *Q. rubra*, *P. grandidentata*, *Fraxinus spp*, and *L. tulipifera*.	1949
(Noble)	OH-3	Open-pit mined, cast overburden	Planted to *P. occidentalis*, *Q. rubra*, *Fraxinus spp*, *L. tulipifera*.	1949
Pennsylvania	Non-mined		2^{nd}–3^{rd} Generation upland hardwood site (*L. tulipifera*, *P. serotina*, *Acer spp.*, *Quercus spp.*).	Multi-aged
(Mercer)	PA-1	Open-pit mined, leveled by dragline	Planted to alternating rows of *P. strobus* and *P. sylvestris*.	1959
West Virginia	Non-mined(N)		2^{nd}–3^{rd} Generation upland hardwood site (*L. tulipifera*, *M. acuminata*, *Acer spp.*, *Quercus spp.*).	Multi-aged
(Monongalia)	WV-1	Contour mined, graded	Planted to *P. strobus*.	1961
(Mercer)	Non-mined(S)		2^{nd}–3^{rd} Generation Appalachian mixed *Quercus spp.* site (*Q. alba*, *Q. rubra*, *L. tulipifera*, *Carya spp.*).	Multi-aged
	WV-2	Contour mined, partially leveled	Planted to white pine.	1971
Virginia	Non-mined		2^{nd} Generation Appalachian cove hardwood site (*L. tulipifera*, *Quercus spp.*, *Carya spp.*).	Multi-aged
(Wise)	VA-1	Contour mined, leveled	Planted to *P. strobus*.	1977

Species richness values and evenness curves were calculated for the canopy layer, understory, and ground layer of each site, using methods described in Kimmins (1987). Species richness (number of species per area sampled) for the three different canopy layers were compared on mined and non-mined sites; pine and hardwood canopy types for mined sites; and between eastern and midwestern mined sites. Evenness values were compared between non-mined sites, midwestern mined sites, and eastern mined sites. Species abundance and dominance values were analyzed for species present on greater than 1% of non-mined and mined sites in the midwestern and eastern coal regions. Commercial species on non-mined and mined sites in the midwestern and eastern coal regions were analyzed separately.

Site Potential Productivity

Site index (height of the tree canopy at a specific age) was used to estimate site productivity by picking an intermediately shade-tolerant tree in a dominant or co-dominant position in the canopy that had no evidence of stem damage, and that had been in a free to grow position for most of its life. On each of the four measurement plots, tree height and age were measured on one tree of each of the three main species in the canopy layer. Regional site index curves were used in conjunction with tree height and age to obtain estimates of productivity. To make direct comparisons between mined sites and their non-mined site, site index estimates for each species were converted to a site index for white oak using Doolittle's (1958) conversion for species in the Appalachian region.

Data Analysis

Species abundance differences between region and mining conditions were tested using t-tests. Simple linear regression was used to test the significance between stand age and richness among mined sites. Differences in productivity between mined sites and the representative non-mined sites were calculated by subtracting the white oak site index of the non-mined site from the white oak site index of the mined site. These differences were tested using a t-test. Results from t-tests termed "different" in this paper have a significance level of $p \leq 0.10$.

Results and Discussion

Woody Species Diversity

A complete list of species and their scientific names found on the sites are located in the appendix.

Mined and non-mined sites had the same number of species on average. This was the case for all vegetative levels within the stands (canopy layer, understory, and ground layer) (Figure 3). This is consistent with results reported by Thompson et al. (1996) who found that pre-SMCRA reclaimed mined sites after attaining an age of 14 and 21 years supported species richness levels comparable to that expected on non-mined areas. In our study, 2 to 5 species were planted on many of the hardwood sites, which increased the initial richness present on those sites. Of the top five canopy layer richness values including both disturbed and undisturbed sites, mined areas made up three of the first five. Many of the volunteers present on mined sites were present on non-mined sites. Species such as black cherry, elm and red maple were present at low to moderate levels of abundance (90 stems ha^{-1}), but lower levels of dominance (7 m^2 ha^{-1}), indicating that they were present in the suppressed to small pole positions in the canopy layers. Wade and Thompson (1999) reported that red maple made up a dominant proportion of the saplings on a mined site in eastern Kentucky. Even in the younger pine stands planted on this study's mined sites, many of the volunteers were hardwoods present in a wide range of sizes, indicating the development of successional stages in the youngest reclaimed sites. Thompson et al. (1996) also noted that the presence of black cherry and red maple on mined sites represents enhanced successional development.

Many of these same species were found in the understory and ground layer of both the non-mined and mined sites. Red maple, black cherry, green ash, and sycamore are species whose seed is easily dispersed to the mined sites to become established under the planted trees in the canopy layer. Black cherry and red maple have been listed as important invasion species on mined sites in both the eastern and midwestern regions (Wade and Thompson, 1999; Andrews et al., 1998; Skousen et al., 1994; Schuster, 1983).

The presence of these species in the lower canopy level on the mined sites, suggests that the mining and reclamation process does not change successional trends. As is common with pine species

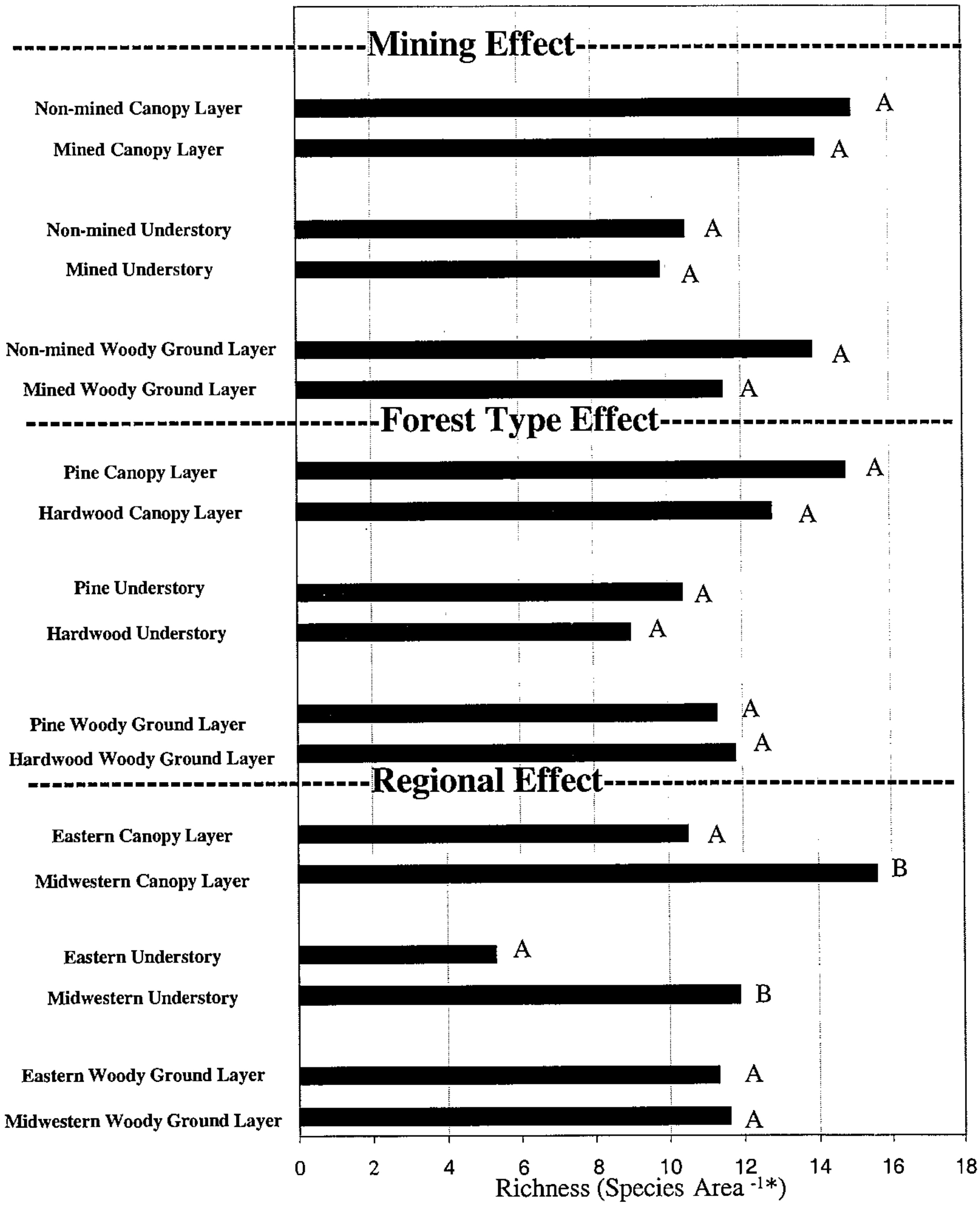

Figure 3: Woody species richness comparisons Note: Different letters represent values statistically different from each other at ≤ 0.10. * canopy layer richness = species $0.16ha^{-1}$; understory richness = species $0.04ha^{-1}$; woody ground layer = species $0.0064ha^{-1}$

planted in the mixed mesophytic and Appalachian oak hickory/forest types, the species composition in the lower levels of the canopy layer represents similar secondary succession invasion species found in nearby native forests. Further analysis of the understory and ground layer data will provide more information on the successional trends of the stands after harvest.

Species richness on mined sites planted to pine was the same as that on mined sites planted to hardwoods for all canopy layers (Figure 3). Wade and Thompson (1999) reported that woody species richness was greater on sites planted to mixed hardwoods rather than Virginia pine. This is likely true when pine sites (e.g. white pine) are compared to mixed hardwood plantings, but they also concluded that Virginia pine sites contained the best conditions for seedling establishment, due to its lighter shading effect, but not necessarily seedling persistence. Zeleznik and Skousen (1996) also found ample hardwood tree invasion on white pine plantations. High pine richness values in the vegetative layers of our planted pine sites were found predominantly on mined sites in Indiana and Kentucky (IN-1, IN-2, KY-3, KY-4) (Table 2). These sites contained older plantings of pine (40 to 50 years old), open canopy species (pitch pine) with early invading wind disseminated hardwoods interspersed (e.g. mined sites in Indiana), and species planted out of their range (loblolly pine in Kentucky) whose canopies had thinned. On these sites, more invading hardwood species were present in the canopy layer, thus increasing their species richness levels.

Lower richness in the canopy and understory layers on sites in the eastern coal region (Figure 3) was most likely due to the sites being reclaimed to pine more recently than sites in the Midwest (Table 2). This difference was not apparent in the woody ground layer comparisons of pine and hardwood sites (Figure 3), suggesting that succession on most mined sites is dominated by invasion from nearby natural stands, which contain shade tolerant, readily disseminated tree species such as red maple, black cherry, and sourwood (Wade and Thompson, 1999; Thompson et. al., 1996).

Species richness increased with stand age in the canopy layer. Stand age explained 23 % of the variation in canopy layer richness for the mined study sites. For midwestern and eastern pine sites, stand age explained 76 % of the variation in richness ($p \leq 0.10$) (Figure 4) though other underlying factors such as species specific canopy densities were previously discussed. Richness and age were found un-

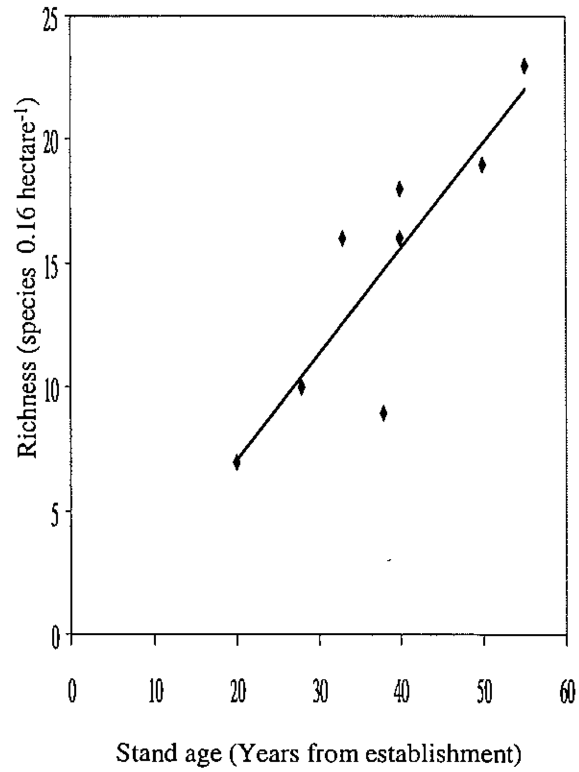

Figure 4. Trend in canopy layer woody species richness and age for pine sites in the midwestern and eastern coal fields.

correlated for hardwood canopy layers. The strong correlation between stand age and richness in pine sites suggests that as pine canopies age, light levels increase, allowing for further species invasion. Light levels are higher at earlier ages for hardwood plantings allowing species invasions earlier. Holl and Carins (1994) reported that tree and shrub species richness greatly increased with age, stating that a larger part of the floral community was found on mined sites older than 25-30 years. Richness was not affected by stand age in the understory and woody ground layers on our mined study sites.

Evenness

Species evenness (number of individuals of a species compared to other species present) was compared between natural sites and mined sites in the eastern and midwestern coal regions (Figure 5). Eastern mined sites were less even than non-mined sites or midwestern mined sites, throughout all three vegetative layers. That is, one species tended to dominate in terms of numbers per hectare. In the East, almost 60 % of the canopy layer was made up of a single planted species, white pine, which is why the relative density values are skewed to the left in

Table 2: Richness values for non-mined and mined sites in the central and eastern coalfields.

Note: Sites are sorted by non-mined, mining region and by increasing richness.

Overstory Richness		Understory Richness		Woody Ground Layer Richness	
Site (age in yrs.)	Species $0.16ha^{-1}$	Site (age in yrs.)	Species $0.03ha^{-1}$	Site (age in yrs.)	Species $0.0065ha^{-1}$
Non-mined		**Non-mined**		**Non-mined**	
IN-3 (Uneven)	20	PA-2 (Uneven)	16	IN-3 (Uneven)	19
WV-4 (Uneven)	20	IN-3 (Uneven)	15	WV-4 (Uneven)	17
VA-2 (Uneven)	18	KY-4 (Uneven)	12	OH-2 (Uneven)	17
OH-2 (Uneven)	15	WV-2 (Uneven)	11	VA-2 (Uneven)	17
KY-4 (Uneven)	14	WV-4 (Uneven)	9	KY-4 (Uneven)	14
WV-2 (Uneven)	12	VA-2 (Uneven)	9	WV-2 (Uneven)	12
PA-2 (Uneven)	12	OH-2 (Uneven)	9	PA-2 (Uneven)	12
IL-3 (Uneven)	9	IL-3 (Uneven)	3	IL-3 (Uneven)	6
Midwestern Mined		**Midwestern Mined**		**Midwestern Mined**	
IN-1(55)	23	IN-1(55)	23	IN-1(55)	15
KY-1* (35)	20	KY-5 (33)	17	IL-1(54)	13
IN-2 (50)	19	IN-2 (50)	15	KY-1* (35)	13
KY-3 (40)	18	OH-3 (50)	15	KY-2 (35)	13
KY-5 (33)	16	KY-2 (35)	12	OH-3 (50)	13
IL-2 (43)	15	KY-1* (35)	11	IN-2 (50)	11
OH-1(50)	15	OH-1(50)	8	OH-1(50)	11
OH-3 (50)	13	IL-1(54)	7	KY-5 (33)	10
KY-2 (35)	11	KY-3 (40)	7	IL-2 (43)	9
IL-1(54)	10	IL-2 (43)	3	KY-3 (40)	9
Eastern Mined		**Eastern Mined**		**Eastern Mined**	
PA-1(40)	16	PA-1(40)	10	PA-1(40)	18
WV-3 (28)	10	VA-1* (20)	5	VA-1* (20)	9
WV-1 (38)	9	WV-3 (28)	4	WV-1 (38)	9
VA-1* (20)	7	WV-1 (38)	2	WV-3 (28)	9

*** KY-1 contained five sample plots; VA-1 contained three sample plots, all others contained four sample points.**

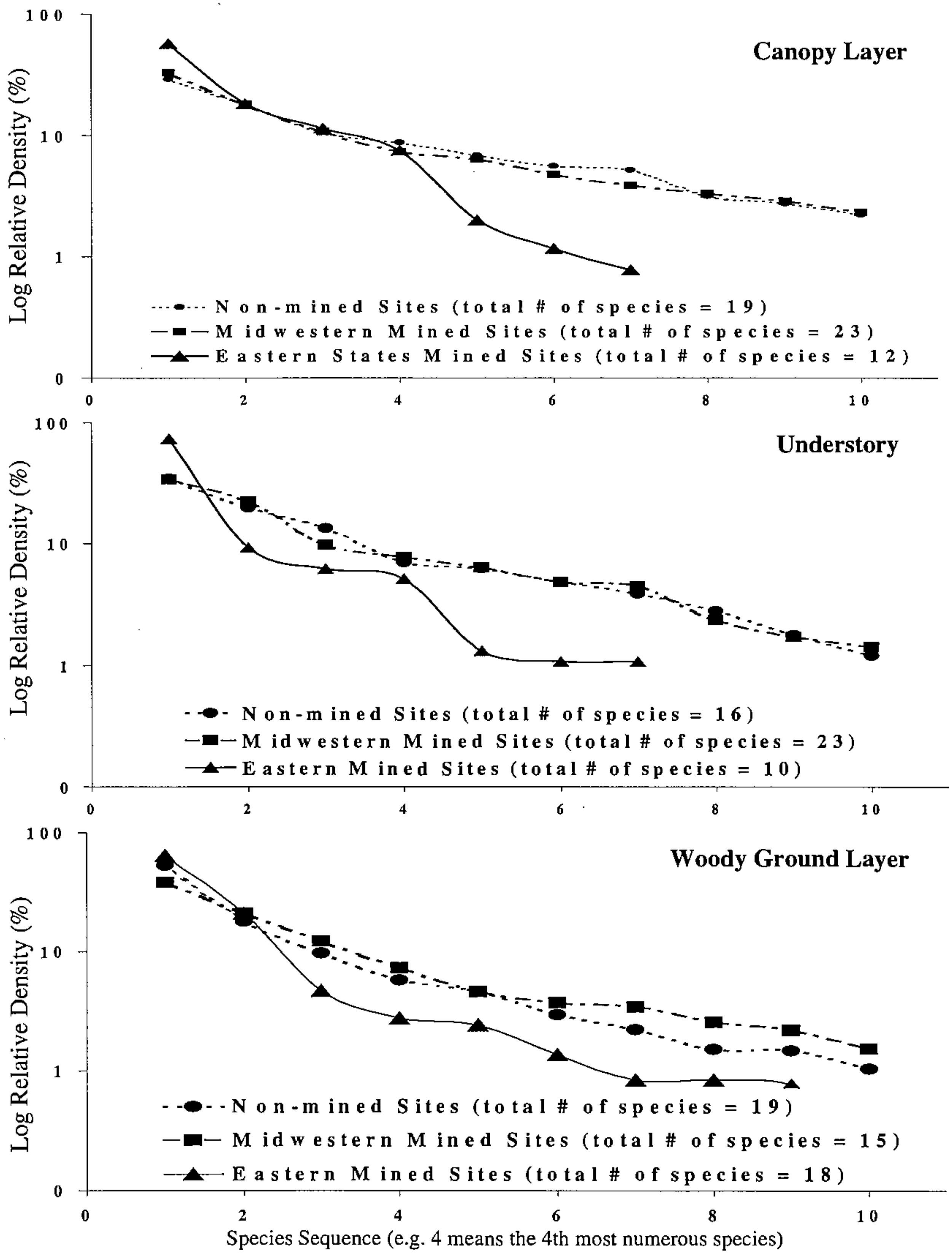

Figure 5. Comparison of species evenness for non-mined and mined study sites in the midwestern and eastern coal regions by canopy layer.

Figure 5. In the canopy layer, the midwestern and non-mined sites had lower relative densities but a greater number of species, suggesting that these stands were more even. The canopy layers of midwestern mined sites were mainly planted to mixed hardwoods and open-canopied pines. The higher light levels present on these sites allowed greater numbers of volunteers into the canopy. In the eastern region, mined sites were commonly planted to white pine, which limited the amount of light through the main canopy and prohibited volunteers from invading the canopy. Schuster (1983) reported that woody tree invasion was low under stands of white pine planted on spoils in Pennsylvania. The relative density for the second most numerous species in the canopy layer was the same among all regions (18%). The eastern mined sites' canopy layers continued to maintain their lower evenness values. By the 5th species in the sequence, the relative density approaches zero. This was not the case with the non-mined and midwestern sites, whose species relative densities leveled out around 5%. The eastern sites also had the lowest total number of species on site (12); the midwestern mined sites had the most species present (23), and the non-mined sites fell in between (19).

The trends in understory evenness were similar to those in the canopy layer, but a different species represented the most numerous species. Understory evenness in the East dropped from relative densities of 74% to 9% by the second species in the sequence (Figure 5). The midwestern sites were similar to the non-mined sites, maintaining higher levels of relative density for longer portions of the sequence. Again, the eastern sites contained the lowest number of species, reiterating the impact of a vigorous, planted white pine canopy layer (Figure 5).

The same general trends in the canopy and understory layers are found in the ground layer except for the non-mined sites which are less even and had a relative density controlled by red maple at 55% (Figure 5). All sites converged to approximately 20% relative density by the second species. The hardwood mined sites had the lowest relative density for the first most abundant species. In the ground layer, the non-mined sites had the most species present (19), followed closely by the eastern sites (18 species) and finally by the midwestern sites (15 species). Lower evenness levels in the East are strongly influenced by the use of white pine in eastern reclamation strategies. White pine controls understory light levels much more uniformly than hardwoods of varying species composition. More generally, the data reflects the effect of one or two dominant species on the distribution of species in the sequence. With one species monopolizing a large percentage of the available light, the ability of other species to become established and thrive on the site is greatly diminished. The woody ground layers of the non-mined and mined sites in the East were dominated by red maple, reflecting its ability to thrive at lower light levels. The most numerous species in the understory varied for both eastern site types but commonly consisted of the species black cherry and sourwood. Autumn olive was also numerous on eastern mined sites reflecting its planting history in the region and bird dispersal of seed. The understory and woody ground layer of non-mined and mined sites in the midwestern region were also variable, reflecting the competitive environment under mixed hardwood species.

Species Abundance and Dominance in the Canopy Layer

The abundance and dominance of species present in the canopy layer of mined and non-mined sites were compared across the eastern and midwestern coal regions (Figure 6). In Figure 6, the bars represent species abundance (stems ha^{-1}) and the dashed lines represent dominance in basal area (m^2 ha^{-1}). The species are ordered from highest to lowest dominance. Each species listed makes up greater than 1 % of the average population across the sites. A species with a large abundance but a small dominance is a tree that occupies a suppressed or sapling position. These species, along with species in the understory and woody ground layer, are most likely to replace the present canopy stand if it were harvested. Trees both abundant and dominant are the trees that were best positioned in the upper canopy.

The canopy layer of non-mined sites in the eastern region contained an average of 16 species each, which made up more than 1% of the population on the sites (Figure 6). Red maple is the most dominant in the canopy, but red oak, tulip poplar, black cherry, and black birch are important components of the stands. Red maple is the most common in all canopy levels except for the canopy layer position. The most common tree in the main canopy is red oak. Tulip poplar was also present in larger sizes but was not as abundant in the mature forests of the eastern region. Other species such as black cherry, green ash, pignut hickory, cucumber tree and basswood were larger trees but are more scattered than tulip poplar. Elliott et al. (1997) found that red oak, black oak, tulip poplar, and hickory were the most common species in southern Appalachian cove and mixed oak sites. Gilliam et al. (1995) listed sugar maple, tulip poplar, black cherry

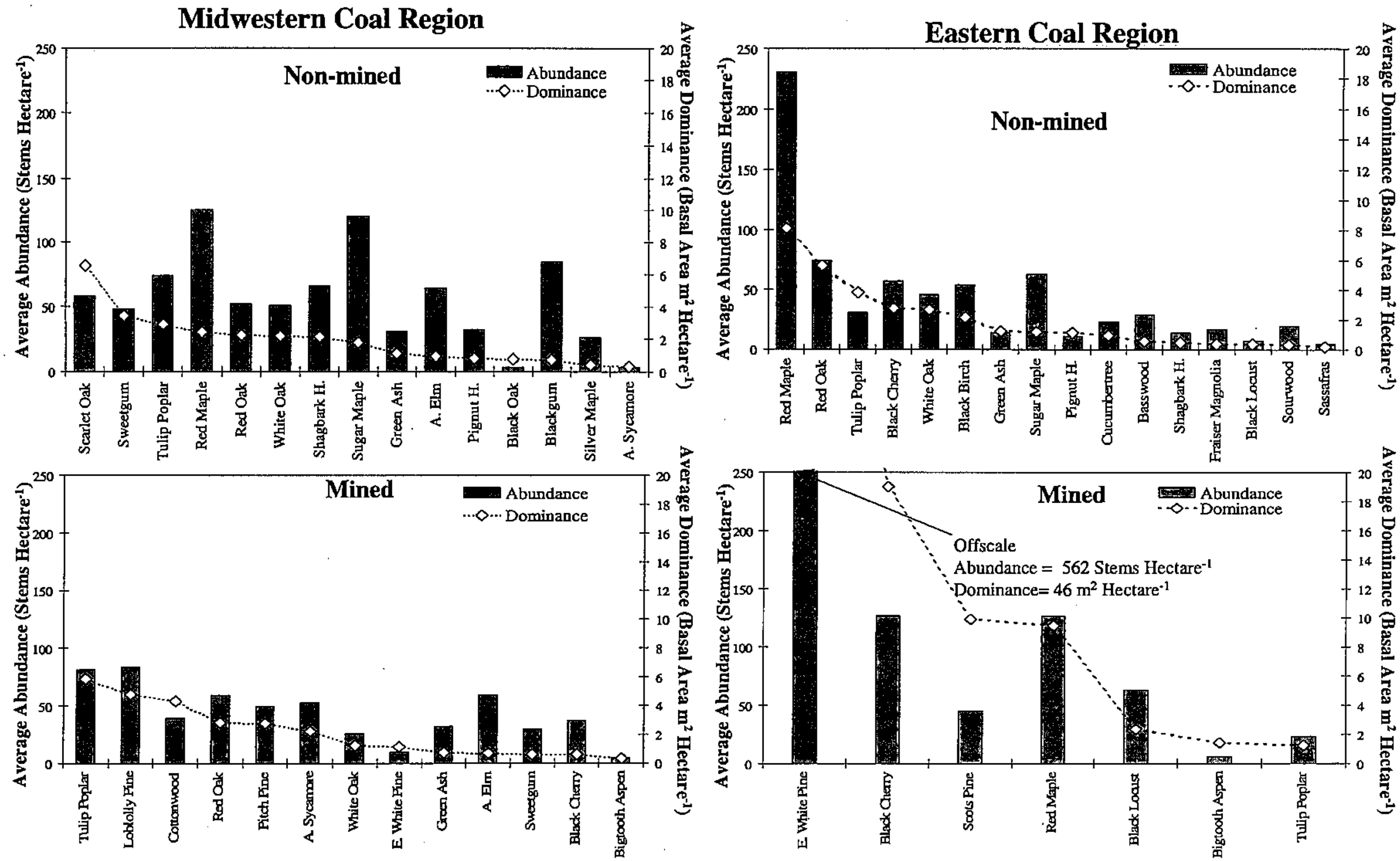

Figure 6. Canopy layer species abundance and dominance on non-mined and mined study sites in the midwestern and eastern coal regions. Note: Each species listed has an abundance greater than 1%.

and red oak as the four most important species on mature central Appalachian sites. Gilliam et al. (1995) also reported finding an average of 800 stems ha^{-1} and a basal area of $43m^2$ ha^{-1} on mature central Appalachian sites. The non-mined sites in the eastern region of this study contained an average of 826 stems ha^{-1} and 34 m^2 ha^{-1}.

White pine was commonly used for reforestation of mined sites in the eastern region. On the study sites white pine abundance levels were 562 stems ha^{-1}. Andrews et al. (1998) reported that white pine abundance levels for sites in Virginia, West Virginia averaged 687 stems ha^{-1}. This average was measured on mined sites 5-9 years after stand establishment. On the eastern sites of our study, seven species made up greater than 1 % of the abundance on the mined sites (Figure 6). Similarly, Zeleznik and Skousen (1996) found that an average of six species invaded mined sites planted to white pine in Southeastern Ohio. The only other species that was planted on the study sites in the eastern region was Scots pine, which was not very abundant (40 stems ha^{-1}) but was co-dominant in the main canopy. The rest of the species present were species that volunteered into the stand.

The non-mined sites of the Midwest region also contained a large array of species (15) (Figure 6). Red and sugar maples were the most abundant species but not the most dominant. Scarlet oak is the most dominant species in the canopy layer, followed by sweetgum and tulip poplar. The large presence of scarlet oak reflects its low desirability as a timber species. Tulip poplar, red oak, and white oak make up similar proportions of the stand, while red maple, sugar maple, American elm and blackgum are found in large numbers in subordinate positions. The mined sites in the midwestern region have distinctly more species than the eastern mined sites (13 versus 7). Eleven of the thirteen species present on midwestern mined sites are present due to planting. The only volunteer species making up greater than 1 % of the total population on the site were American elm and black cherry. Zeleznik and Skousen (1996) also found elm invading in high numbers on various white ash, white pine and tulip poplar sites in Ohio. The composition of mined stands in the midwestern region were similar to non-mined sites, with 7 species in common. The only species on mined sites not found on the non-mined sites were planted conifers and planted shade intolerants such as aspen and cottonwood, species that are uncommon within the mixed mesophytic and oak-hickory forest regions. The forests on mined sites in the midwestern region are more representative of their undisturbed counterparts than mined sites in the eastern region. Through the use of multiple planted hardwood species on mined sites in the midwestern region, the mature canopy layer of these sites contains species numbers similar to the canopy layer composition of native forest communities.

Species planted on mined sites were most dominant in the canopy layer on each site (Table 3). On mined site KY-2 that was planted to 5 hardwood species, those species made up 97.8 % of the canopy layer basal area. Planted species account for almost half of the site richness (Table 2). Other sites planted to multiple hardwoods species also have high percentages of the main canopy in those species. Conversely, sites planted to pines have pines dominant in the canopy layer. Young white pine sites such as VA-1 have 92.8 % of the canopy in the planted species. Older pine sites still have pine dominant in the canopy layer (Table 3). The planted species on single species sites are less important in the overall richness of the canopy layer. Site IN-1, which was planted to pitch pine, contained 22 other species in the canopy layer, while WV-3 contained 15 species other than the planted white pine (Table 2). Though the planted species on such sites contribute little to richness, they still play a very large role in dominance over the site. On highly compacted sites (WV-1) the planted species was not able to maintain its dominance. On WV-1 or WV-3, whose bench sites showed signs of surface compaction, planted white pine made up 76.2 and 58.8 %, respectively, of the canopy layer. Black locust intermixed across the two sites was mostly deteriorated, having a negative effect on planted species dominance. The dominance of the planted species on site IN-2, whose pitch pine was not able to maintain its canopy, was 46.5 %. This site also contained many species that had invaded the openings and were competing for site resources.

In most cases, planted species make up the majority of the basal area on the site. This has strong implications for future forest management of mined sites. Evidence from this study indicates that planting of commercially valuable species increases the assurance that the sites will develop into stands of commercial importance. Those species planted have a head start on species attempting to invade the site, allowing them to establish quickly and reach dominant positions. The use of a single species, such as pine, limits species richness and reduces stand value in this hardwood-dominated market.

Deciduous and coniferous trees are commonly referred to as hardwood and softwoods, respectively. Deciduous species are often put into

Table 3: Species dominance on mined study sites in the midwestern and eastern coal regions. Note: Bold cells represent planted species.

Site	AE	AS	AP	BB	BC	BE	BG	BL	BW	CO	CW	GA	HB	LP	PE	PP
IL-1					1.0											
IL-2	3.7	6.3			5.0	1.9		2.2			**67.0**		6.5			
IN-1	5.1	14.2			2.4		1.3				4.0					**61.2**
IN-2	3.5	8.0			7.0	3.7			1.5		15.1	5.3			2.3	**46.5**
KY-1		**16.0**									**40.0**					
KY-2		**7.2**									**15.4**					
KY-3		11.4						2.8			3.0		1.0	**41.9**		
KY-5		1.9												**92.2**		
OH-1			**10.3**		1.2					1.6		**9.9**				
OH-3	7.3	**10.9**										**8.8**				
PA-1			4.2													
WV-1				2.3	9.4			**16.1**								
WV-2					1.7			**9.1**								
VA-1					3.4											

Site	RB	RM	RO	SC	SF	SG	SH	SO	SM	SW	ST	TP	VP	WA	WO	WP
IL-1												**62.4**			**35.8**	
IL-2		2.5			1.0				1.5	1.0						
IN-1	1.0	1.5			2.2		1.1						1.1			
IN-2			2.9	1.0												
KY-1			**18.6**			2.8			4.1			**14.8**		1.0		
KY-2			**38.3**			**15.5**		1.8				**21.4**				
KY-3																**34.8**
KY-5						2.4										
OH-1			**42.7**									**17.6**				
OH-3		1.2										**69.3**				
PA-1		2.9									**26.3**	1.2				**61.5**
WV-1		9.8										1.4				**60.1**
WV-2																**87.4**
VA-1		3.7										2.0				**92.8**

Total relative dominance of planted species (% basal area (m² ha⁻¹))

Site	
IL-1	98.2
IL-2	67.0
IN-1	61.2
IN-2	46.5
KY-1	85.8
KY-2	97.8
KY-3	76.7
KY-5	92.2
OH-1	80.5
OH-3	69.3
PA-1	87.8
WV-1	76.2
WV-3	58.8
VA-1	92.8

Total basal area of planted species ($m^2 ha^{-1}$)

Site	
IL-1	31.6
IL-2	24.0
IN-1	19.1
IN-2	8.6
KY-1	21.3
KY-2	25.0
KY-3	25.1
KY-5	34.1
OH-1	23.9
OH-3	30.0
PA-1	29.4
WV-1	23.9
WV-2	42.7
VA-1	16.2

Total basal area for the site ($m^2 ha^{-1}$)

Site	
IL-1	32.2
IL-2	35.7
IN-1	31.2
IN-2	18.6
KY-1	24.8
KY-2	25.5
KY-3	32.7
KY-5	37.0
OH-1	29.7
OH-3	33.7
PA-1	33.5
WV-1	31.3
WV-2	48.8
VA-1	17.5

Species Code

AE	=	A. Elm	RB	=	Redbud
AS	=	A. Sycamore	RM	=	Red Maple
AP	=	Bigtooth Aspen	RO	=	Red Oak
BB	=	Black Birch	SC	=	Scarlet Oak
BC	=	Black Cherry	SF	=	Sassafras
BE	=	Boxelder	SG	=	Sweetgum
BG	=	Blackgum	SH	=	Shingle Oak
BL	=	Black Locust	SO	=	Shurmard Oak
BW	=	Black Walnut	SM	=	Silver Maple
CO	=	Chestnut Oak	SW	=	Sourwood
CW	=	Cottonwood	ST	=	Scots Pine
GA	=	Green Ash	TP	=	Tulip Poplar
HB	=	Hackberry	VP	=	Virginia Pine
LP	=	Loblolly Pine	WA	=	White Ash
PE	=	C. Persimmon	WO	=	White Oak
PP	=	Pitch Pine	WP	=	White Pine

two groups, hard and soft hardwoods based on wood density and wood product use. Non-mined sites in the midwestern region contained five hard-hardwood species while the mined sites in the midwestern region contained four (Figure 7). In the Midwest, red oak was present on non-mined and mined stands at similar levels of abundance and dominance, while white oak had only half the abundance and dominance on the mined sites. Sugar maple was very abundant in non-mined stands but it was not present on mined sites in the midwestern region, suggesting that it is not competitive at this stage of secondary succession. The non-mined sites in the midwestern region contained four soft-hardwood species while mined sites contained five soft-hardwoods. Tulip poplar, which was present on both site types, was present in similar abundance but was higher in dominance on the mined sites because it was a planted species. Green ash was similar in abundance and dominance on both site types. Red maple was more prevalent on the non-mined sites but it maintained the same subordinate position. in each community. In the non-mined sites, its abundance was high, but it wasn't dominant. On the mined sites in the region, the abundance of red maple was low and its dominance was almost negligible. The mined sites also contained a significant proportion of planted softwoods (pine species) that were not present in the non-mined canopies. Pine species will not readily regenerate under their own canopy; therefore, after their removal. a secondary successional hardwood stand will emerge. This is a typical fate of pine stands planted in midwestern hardwood forests.

The eastern mined areas contained mostly softwoods that were dominant in the canopy layer. The ability of the mined sites in the eastern region to support hard-hardwoods and soft-hardwoods seemed significantly deterred by the presence of dense planted pine canopies (Figure 7). As mentioned, the only species present in the canopy layers with white pine are those species that can withstand low light levels. The eastern mined sites contained only one hard-hardwood species and two soft-hardwood species. This paled in comparison to the six hard-hardwood species and four soft-hardwood species present on non-mined sites in the midwestern region. Those species that were able to utilize the gaps in the pine canopies were able to do so successfully because of the lack of competition in the lower levels of the canopy. The non-mined sites in the eastern region contained greater amounts of hard-hardwoods compared to mined areas. Though the mined sites in the eastern region contained higher abundance and dominance of a single species, the mined sites in the midwestern region were comparable to the natural sites, and will ultimately provide higher-value wood products at rotation age. The principle product of the mined sites in the eastern region will be lower-value softwood and soft-hardwood products.

Site Productivity

Overall, site productivity appeared to be the same on non-mined and mined sites in the Midwest (Table 4 and Figure 8). All mined sites in the midwestern region consisted of cast overburden receiving little or no grading. Surface mining may increase rooting depth, reduce the effects of natural root limiting layers, improve drainage and improve fertility, allowing sites to have equal or better productivity levels compared to non-mined sites, especially those sites that have lost topsoil due to poor farming practices (Plass, 1982). Conversely, intensive grading greatly reduces tree growth, by increasing soil compaction during dry periods and by creating poor drainage that leads to hypoxic conditions during wet periods (Ashby, 1987; Limstrom, 1960; Deitschman, 1950).

The productivity levels of the non-mined versus mined site in Illinois were almost equal (Table 3). Of the two hardwood sites located in Kentucky, KY-2 had a site index level greater than the non-mined site, but KY-1 was less productive than the non-mined site (Figure 8). The third site in Kentucky (KY-3) was planted to white pine with a small proportion of loblolly pine. The white pine grew better than the loblolly pine. This site was 5% higher in productivity than the non-mined site. The fifth mined site in Kentucky (KY-5) was planted to loblolly pine about 35 years ago. The loblolly pine had shown good initial growth but may be plateauing given that it is out of its natural range (Figure 8). This site was slightly lower in productivity than the non-mined site. Both mined sites in Ohio were growing better than the natural sites in the area. At least part of the non-mined site in Ohio showed evidence of being an old farm site and of having a root restricting layer in the sub-soil horizons. These soil characteristics, along with the deeper rooting, and un-compacted rooting volume present on the cast overburden of the mined sites, may have contributed to the mined sites' higher productivity levels. The OH-3 site was 16 % more productive than the comparable undisturbed site. It also had lower variation in productivity than the non-mined site.

In the East, productivity was significantly less on 2 out of 4 mined sites (Figure 8). There was some indication that the 32% decline in productivity

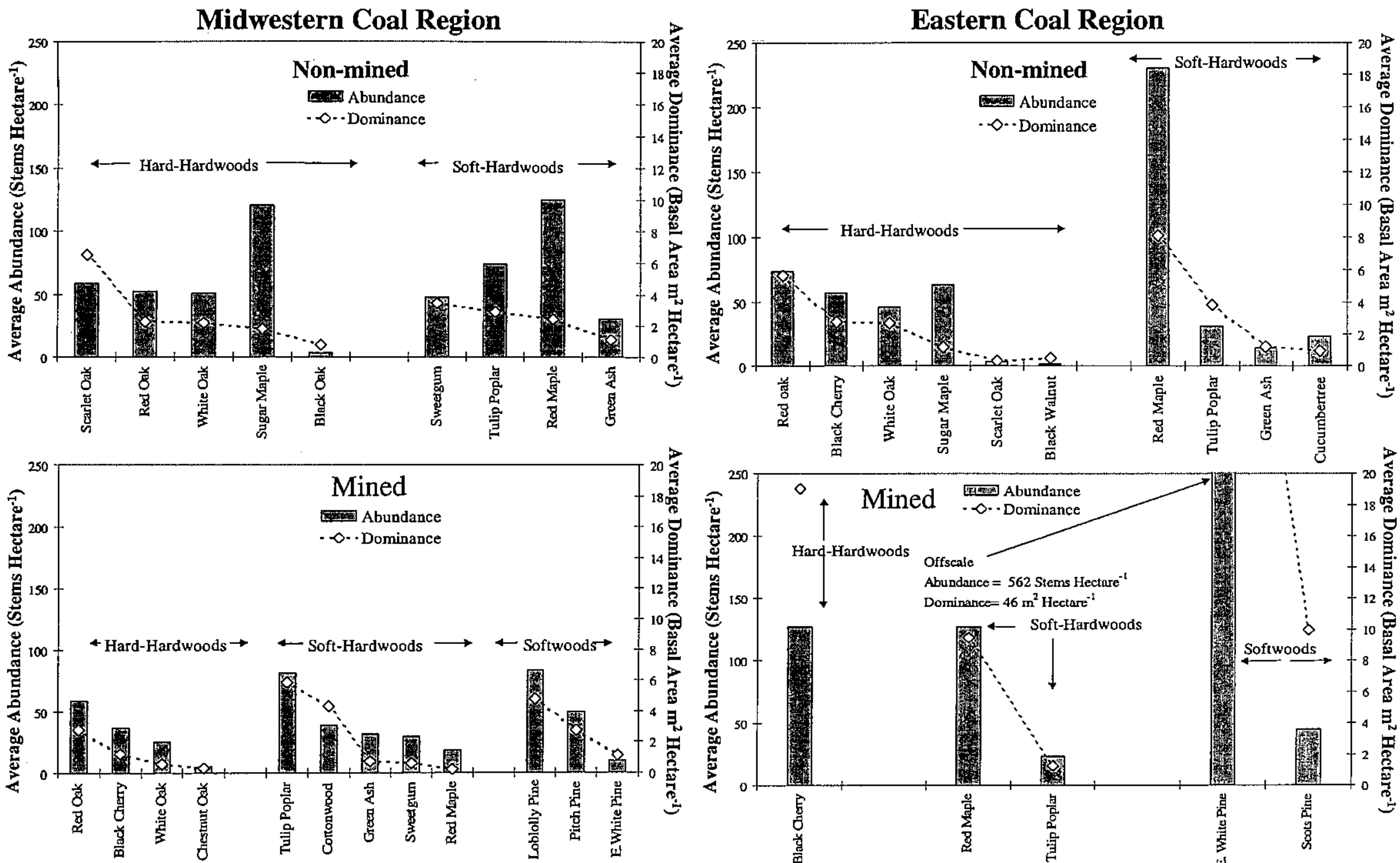

Figure 7. Canopy layer commercial species abundance and dominance on non-mined and mined study sites in the midwestern and eastern coal regions.

Table 4. Non-mined and Mined Site Productivity Comparisons.

State	Site	History	Canopy Type	SI White Oak (meters)	Standard Deviation (meters)	P-value for contrast vs Natural Site
Illinois	1	Mined	White Oak/ T. Poplar	28.0	1.3	0.91
	2	*Non-mined*	*Scarlet Oak/R. Maple*	27.7	4.2	-----
Kentucky	1	Mined	Mixed Hwd	22.7	0.7	0.16
	2	Mined	Mixed Hwd	25.4	1.9	0.13
	3	Mined	W. Pine/Lob. Pine	25.0	4.6	0.52
	4	*Non-mined*	*Oak/T.Poplar*	23.8	1.7	----
	5	Mined	Loblolly Pine	22.7	1.0	0.35
Ohio	1	Mined	Mixed Hwd	25.1	2.4	0.32
	2	*Non-mined*	*Oak/T.Poplar*	23.1	4.0	----
	3	Mined	Mixed Hwd	26.8	1.2	0.16
West Virginia	1	Mined	White Pine	16.8	1.5	0.01
(North)	2	*Non-mined*	*Oak/T.Poplar*	24.7	4.1	----
West Virginia	3	Mined	White Pine	28.7	3.4	0.20
(South)	4	*Non-mined*	*Oak/T. Poplar*	25.9	1.1	----
Pennsylvania	1	Mined	W. Pine/Scots Pine	20.3	0.7	0.02
	2	Non-mined	Oak/T.Poplar/Cherry	24.8	2.0	----
Virginia	1	Mined	White Pine	25.2	1.6	0.22
	2	*Non-mined*	*Oak/ T. Poplar*	26.9	1.6	----

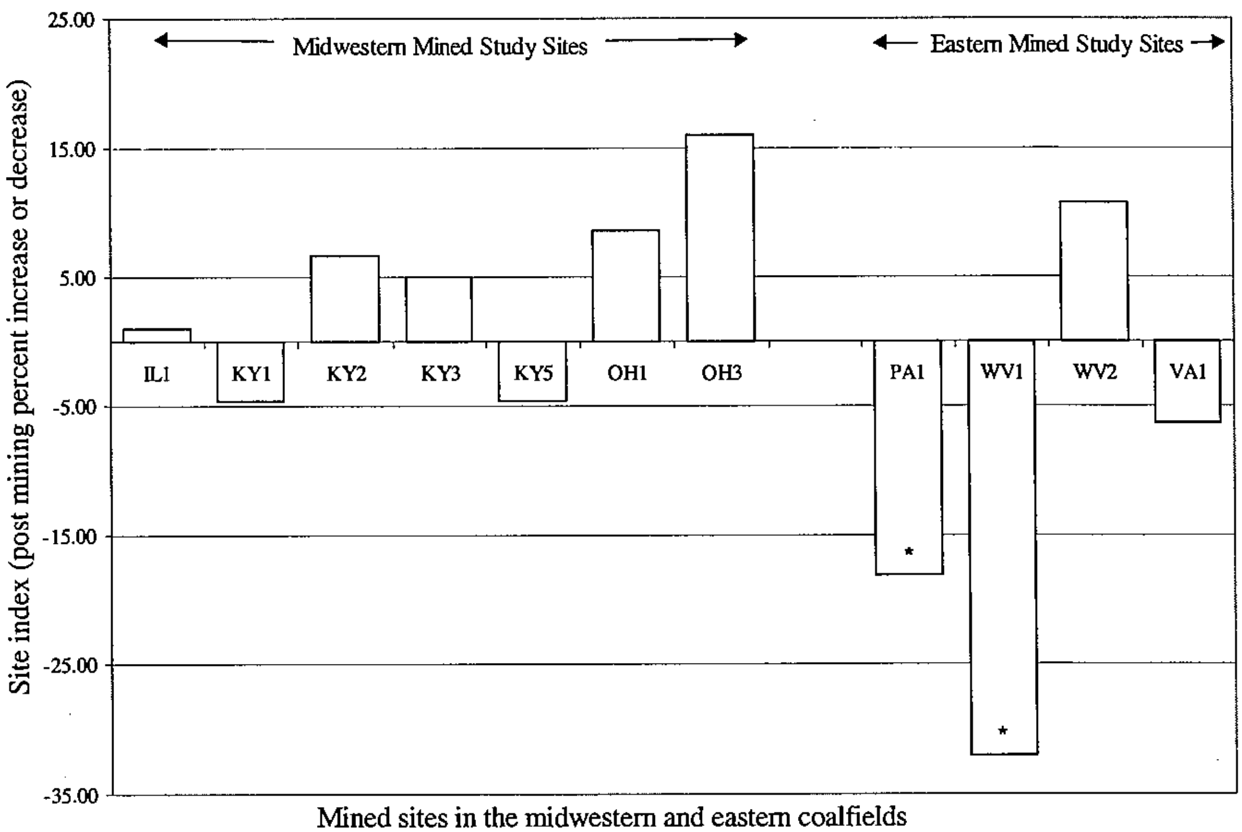

Figure 8. Site index comparisons between non-mined sites (set to zero) and nearby mined sites. Note: * shows significance differences in site index at p≤ 0.10.

on WV-1 was due to compaction. Average soil depth was 83 cm. Trees on this site also showed a tendency toward surface rooting. Similar problems with compaction were found throughout the eastern region (Daniels and Amos, 1981, Torbert et al., 1994). The mined site in Virginia (VA-1) was approximately 8% less productive than the non-mined site. The non-mined site used for comparison with VA-1 was a cove site while the mined site was established on the contour of a back slope. The inherent differences in productivity between these two types of landforms may explain the differences in productivity between the two sites. Productivity levels on WV-2 were similar to the non-mined site in the area (Figure 8). Wade et al. (1985) found productivity levels comparable to natural sites in Southeastern Kentucky. The authors attributed good mine soil productivity to greater soil depth and increased water availability.

Conclusions

Mined sites, especially sites planted to multiple hardwood species, are capable of developing into forest communities that possess vegetative diversity and productivity similar to local native forests. The similarity in diversities is related to the planting of multiple late-successional species during reclamation and the invasion of woody species into all levels of the developing forest community. Sites planted to multiple species contain high proportions of those species in the canopy layer, both richness and dominance. Single planted species sites are still dominated by that planted species but they make up a lesser part of the sites' canopy layer richness. Much of the vegetative composition found on mined sites are combinations of the planted species that dominate the upper levels of the canopy and the natural species that are capable of invading into the understory. In situations where the planted canopy is unable to maintain its dominance, invading species quickly fill the gaps. In many cases, the planted species present in the canopy of mined sites have commercial value. For the most part, invading, secondary successional species such as red maple, black cherry, sourwood and sassafras will not generate into stands with the same value as planted stands.

Nine of the eleven mined sites tested were as productive as their non-mined counterparts. SMCRA requires that reclaimed mined sites be comparable in capability to that existing prior to mining. The preliminary evidence provided by this research suggests that the trees planted on reclaimed mined sites in the Midwest prior to the passage of SMCRA are growing as productively as before mining, but in the East mining has degraded site productivity. Further investigation of soil characteristics should provide cause and effect evidence for productivity levels existing on each site, and will be reported at a later date. The results also reinforce concerns about reclaimed mined land conditions created by new regulations after SMCRA was passed. The sites with lower productivity levels were those that were most compacted, a condition commonly associated with post-SMCRA reclamation.

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<u>Appendix</u>. Woody species found on study sites.

		*= 1=Canopy, 2=Understory, 3=Ground			
Species Common Name	**Species Scientific Name**	**Eastern Mined***	**Midwest mined***	**East non-mined***	**Midwest non-mined***
Ailanthus	Ailanthus altissima Mill.		1, 3		
Alternate-Leaf Dogwood	Cornus alternifolia L.	3	1	2	
American Beech	Fagus grandifolia Ehrh.		3		
American Elm	Ulmus americana L.		3		
American Basswood	Tilia americana L.	3	1, 3	1, 2, 3	1, 2, 3
American Beech	Fagus grandifolia Ehrh.			3	1, 2, 3
American Chestnut	Castanea dentata Marsh.		1, 3	1, 3	
American Elm	Ulmus americana L.	1	1, 2		1, 2, 3
American Holly	Ilex opaca Ait.		3		2, 3
Apple	Malus sylvestris L.			1	
Autumn Olive	Elaeagnus umbellata Thumb.	1, 2, 3	1, 2, 3		
Bigtooth Aspen	Populus grandidentata Michx.	1	1		
Black Birch	Betula lenta L.	1, 2, 3	3	1, 2, 3	
Black Cherry	Prunus serotina Ehrh.	1, 2, 3	1, 2, 3	1, 2, 3	1, 2, 3
Black Haw	Viburnum prunifolium L.		3		
Black Locust	Robinia pseudoacacia L.	1, 3	1, 3	1	
Black Oak	Quercus velutina Lam.	3	1		1
Black Walnut	Juglans nigra L.		1, 3	1	1
Blackgum	Nyssa sylvatica Marsh. var. sylvatica	1, 2, 3	1, 2, 3	1, 2, 3	1, 2, 3
Blueberry	Vaccinium vacillans Torr.			2	
Boxelder	Acer negundo L.		1, 2, 3		
Brainerd Hawthorn	Crataegus brainerdii Sarg.	3	1	2	2
Cherrybark Oak	Quercus falcata var. pagodifolia Ell.		1, 2, 3		
Chestnut Oak	Quercus prinus L.		1, 2, 3	1, 2	
Common Persimmon	Diospyros virginiana L.		1, 2, 3		
Common Privet	Ligustrum spp.	3	2, 3		3
Cottonwood	Populus deltoides Bartr. ex Marsh. var. deltoides		1		
Cucumbertree	Magnolia acuminata L.			1, 3	
Devils Walking Stick	Aralia spinosa L.				3
Downy Serviceberry	Amelanchier arborea Michx. f.		3	1, 2, 3	
E. Redcedar	Juniperus virginiana L.			3	
E. White Pine	Pinus strobus L.	1, 2, 3	1, 2, 3		
Eastern Hemlock	Tsuga canadensis L.			3	
Eastern Hophornbeam	Ostrya virginiana K. Koch	2, 3	2, 3	1	1, 2, 3
Eastern Redcedar	Juniperus virginiana L.		1, 2, 3		1, 2, 3
Flowering Dogwood	Cornus florida L.	3	1, 2, 3	2	1, 2, 3
Fraiser Magnolia	Magnolia fraseri Walt.			1, 2, 3	
Green Ash	Fraxinus pennsylvanica Marsh.	1, 2, 3	1, 2, 3	1, 2, 3	1, 2, 3
Hackberry	Celtis occidentalis L.		1, 2, 3	2	
Hawthorn	Crataegus spp.				3
Honey Locust	Gleditsia triacanthos L.				1
Hornbeam	Carpinus caroliniana Walt.		1, 3	1, 2, 3	1
Loblolly Pine	Pinus taeda L.		1, 3		

Species Common Name	Species Scientific Name	Eastern Mined	Midwest mined	East non-mined	Midwest non-mined
Maple Leaf Viburnum	Viburnum acerifolia L.			2, 3	
Mockernut Hickory	Carya tomentosa Poir.	1			
Multiflora Rose	Rosa multiflora Thumb.	3	2, 3	2	2
N. Red Oak	Quercus rubra L.	1	1, 2, 3	1, 2, 3	1, 2, 3
Nannyberry	Viburnum lentago L.	2			2
Northern Arrowwood	Viburnum dentatum Fern.		2, 3		
Pawpaw	Asimina triloba L.				2, 3
Pignut Hickory	Carya glabra K. Koch	3	1, 2, 3	1	1, 2, 3
Pitch Pine	Pinus rigida Mill.		1, 2, 3		
Post Oak	Quercus stellata Wangenh.		1		
Red Bud	Cercis canadensis L.		1, 2, 3	2	1, 2, 3
Red Maple	Acer rubrum L.	1, 2, 3	1, 2, 3	1, 2, 3	1, 2, 3
Red Mulberry	Morus rubra L.		1, 2, 3		1
Rhododendron	Rhododendron maximum L.			1, 2, 3	
River Birch	Betula nigra L.	1, 3	1, 3	2, 3	
Sassafras	Sassafras albidum Nutt.	1, 3	1, 2, 3	1, 2, 3	1, 2, 3
Scarlet Oak	Quercus coccinea Muenchh.		1	1, 2	1
Scots Pine	Pinus sylvestris L.	1, 3			
Shagbark Hickory	Carya ovata K.Koch	3	2, 3	1, 2, 3	1, 2, 3
Shingle Oak	Quercus imbricaria Michx.		1, 2, 3		1, 2
Shining Sumac	Rhus copallina L.		1, 3		
Short Leaf Pine	Pinus echinata Mill.		2		
Shumard oak	Quercus shumardii Buckl.		1		
Silver Maple	Acer saccharinum L.	3	1, 2	1	1, 2, 3
Sourwood	Oxydendrum arboreum L.	1, 2, 3	1, 2, 3	1, 2, 3	2, 3
Southern Red Oak	Quercus falcata Michx.var. falcata		1, 2		
Spicebush	Lindera benzoin L.		2, 3	2, 3	2, 3
Striped Maple	Acer pensylvanicum L.	3			
Sugar Maple	Acer saccharum Marsh.	1, 2	1, 2	1, 2, 3	1, 2
Sweet Cherry	Prunus avium L.	1, 3	1, 2		2
Sweetgum	Liquidambar styraciflua L.		1, 2, 3		1
Sycamore	Platanus occidentalis L.		1, 3		1
Trumpet Creeper	Campsis radicans L.		2		2
Tulip poplar	Liriodendron tulipifera L.	1, 2	1, 2, 3	1	1, 2, 3
Unidentified species 1	Unidentified species 1	1, 2			
Unidentified Species 3	Unidentified Species 3	2, 3			
Unidentified Species 4	Unidentified Species 4	3			
Unidentified species 5	Unidentified species 5				2
Virginia Pine	Pinus virginiana Mill.		1		
White Ash	Fraxinus americana L.		1, 2, 3		
White Oak	Quercus alba L.	3	1, 2, 3	1, 2	1, 2, 3
Witch-hazel	Hamamelis virginiana L.	3		1, 2, 3	
Yellow Buckeye	Aesculus octandra Britton.			1, 2, 3	