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Forestry and Natural Resources

Status of Reforested Mine Sites in Southwestern Indiana

Reclaimed Under the Indiana Mining Regulatory Program

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Executive Summary

The Need

Current Indiana coal mine reclamation regulations require the maintenance of at least 450 living trees and shrubs per acre, as determined in the last year of a five year responsibility period, in order to obtain final bond release. However, the minimum stocking requirement for bond release does not necessarily equate to long-term reforestation success. No attempt has ever been made to track the long-term progress of reforested mine sites following bond release.

Tim Taylor

In 2002 and 2003 a joint research team from Southern Illinois University Department of Forestry and Purdue University Department of Forestry and Natural Resources conducted a survey of surface mines reforested from 1988 to 1995. The purpose of the survey was to determine how well reforested mine sites were performing in terms of values and services normally ascribed to native forests and what their future potential might be. The survey results are presented within the context of 1) long-term forest health, 2) viability of reforested mine sites as future contributors to local economies, and 3) the viability of reforested mine sites as producers of environmental assets.

Long-Term Forest Health

*Black locust (*Robinia pseudoacacia*) was the most abundant species on 67 percent of the surveyed sites and accounted for 47 percent of all tallied trees and shrubs across all sites. Green ash (*Fraxinus pennsylvanica*) dominated 18 percent of the sites and made up 14 percent of all tallied trees and shrubs. Both black locust and green ash are still widely planted in reclamation. Many black locust stands are currently experiencing decline and dieback caused, in part, by the locust borer. Where black locust and green ash comprise a large proportion of the stand, long-term forest growth and health are at risk. Greater seedling availability and Indiana Department of Natural*

Resources, Division of Reclamation's (INDOR) recommendation to reduce the amount of black locust in tree plantings has reduced the proportion of this species in more recent reclamation plantings.

Viability of Reforested Mines as Future Contributors to Local Economies

Tree growth rates reflected the variation between the reclaimed sites. Forty percent of stands approached unmined planted tree height growth rates, while only 27 percent approached stem diameter growth rates of the stands on unmined sites.

Most reclaimed mine sites had measured site quality indices below the poorer quality sites in the region's native forests. Higher rates of tree mortality, lower stocking rates, slow growth, and low-quality timber are expected for many of these sites. Some of the more recently reclaimed sites (1994/95) had site indices approaching or meeting those of local native forest, suggesting that the potential exists for improving site productivity in mine reclamation.

Overall stocking in the establishment phase of stand development appeared adequate for future commercial timber production on many of the study sites, with the exception of several under-stocked stands. However, the dominance of black locust stocking in many stands limits their future viability for timber production.

Viability of Reforested Mine Sites as Producers of Environmental Assets

Tall fescue and sericia lespedeza provide rapid and reliable erosion control but inhibit tree establishment and growth. These planted ground covers along with naturally occurring goldenrod were the most common ground covers in surveyed tree plantings. Thus long-term benefits of forest cover to watersheds and wildlife are delayed. Tree compatible groundcover alternatives should be used to speed the transition from a tree planting that meets bond release requirements to a healthy, viable forest.

Most of the sites surveyed would not be good candidates for market-based carbon sequestration programs. Poor site quality of most sites make current and future tree growth and carbon capture rates too low to be profitable in market-based carbon sequestration programs. The preponderance of black locust on many sites reduces their long-term carbon storage potential as durable wood products.

Conclusions

With few exceptions, the reclaimed mine sites in this study show very low levels of productivity for forest products and carbon sequestration relative to native forests of this region, even though stocking levels appeared to be adequate. This suggests that the current bond performance measurement of 450 trees/acre bears little relevance to long-term forest productivity. Soil stabilization and erosion control were achieved in the short term through the use of aggressive ground covers. Forest wildlife habitat development will likely be delayed. The results of this survey should serve as a baseline to determine the extent to which recent and future changes in reclamation methods improve reforestation success.

Status of Reforested Mine Sites in Southwestern Indiana

Reclaimed Under the Indiana Mining Regulatory Program

Introduction

A Brief History of Mine Reclamation in Indiana

Surface coal mining in the first half of the 20th century in Indiana often resulted in acute environmental problems like acid mine drainage and public safety hazards such as open pits with unstable side walls. Reclamation in the early 20th century was limited to some coal companies voluntarily planting trees on spoil banks (Anon. 1993).

Indiana was the second state in the nation to enact a mine reclamation law. A 1941 state law required coal companies to plant trees on spoil banks. Mine reclamation then was synonymous with reforestation. Many productive stands of hardwood timber have been documented growing on these old spoil bank plantings (Ashby 1998, Rodrigue 2002).

In 1967 Indiana became the first state to require grading and contouring of mine spoils. This law also provided for reclaiming surface mines to farm land, ordered the burial of acid forming rock, and required coal companies to post a performance bond until reclamation and revegetation were complete.

In 1977, Congress passed the Surface Mining Control and Reclamation Act (SMCRA). SMCRA established national standards for reclaiming surface mines. The federal Office of Surface Mining (OSM) was established to oversee the implementation of SMCRA. Included in those standards were requirements to restore reclaimed land to its original use or a "higher and better" use, stockpile and replace topsoil, return the landscape to approximate original contour, grade slopes, control erosion through rapid re-vegetation, and prevent acid drainage, among others (Figure 2).

The new contour, grading, soil erosion, and water quality requirements of SMCRA impacted the reforestation of reclaimed mines. In those early years, the decade of the 1980's, mine operators generally had difficulty maintaining forest tree plantings. Reclamation methods in the early years of SMCRA resulted in heavily compacted soils. Aggressive grasses and other ground covers were planted to meet the stringent erosion control requirements of SMCRA. Tree species not suited to the new reclaimed mine conditions were often planted. Survival and growth of planted trees was generally poor. Many

Louis Ladislas

Figure 1. Spoil banks as they were commonly left following surface coal mining in Indiana between 1920's and 1967. State law required planting trees on spoil banks after 1941.

Tim Taylor

Figure 2. Following the passage of SMCRA in 1977, surface mines had to be reclaimed to its original use or to a "higher and better" use. The land needed to be returned to its approximate original contour.

mine operators opted to reclaim to "higher and better" uses, such as agriculture, hay land and pasture, and wildlife habitat. Establishing and maintaining grasses was much easier under the new conditions resulting from SMCRA's implementation.

In 1982, the Indiana Department of Natural Resources Division of Reclamation (INDOR) assumed regulatory authority over the reclamation of surface mines from OSM. Reclamation techniques have evolved since SMCRA's implementation. Reclamation specialists working for mine operators have experimented over the years to improve results while controlling their costs.

Research Needs

For reforested reclaimed mines to be released from bonding, the Indiana mining regulatory program requires the maintenance of at least 450 living trees and shrubs per acre. However, the minimum stocking requirement for bond release does not necessarily equate to long-term reforestation success. Such success is a longer-term prospect that ultimately results in a healthy, vigorous, naturally functioning forest that is highly likely to produce wood products and the environmental amenities commonly produced by native forest. Environmental amenities include watershed protection, flood control, wildlife habitat, recreation opportunities, and removing greenhouse gases, like carbon dioxide, from the atmosphere (carbon sequestration).

No attempt has ever been made to track the long-term progress of reforested mine sites following bond release. Knowing the fate of these reforested mine sites is important for the following reasons:

1. To contribute to the knowledge base of reclamation practices so improvements can be made in the future.
2. To provide knowledge of how reforested mine sites contribute to the overall state-wide forest inventory and health analysis.
3. Assist landowners and foresters in making decisions regarding the feasibility of implementing various forestry practices on reforested mine sites.
4. To understand how these sites contribute to the long-term economic prosperity of the local community.
5. To better understand the feasibility of utilizing these sites in carbon sequestration programs.
6. To understand the environmental services and amenities these sites provide or are likely to provide in the future (i.e., flood control, watershed protection, wildlife habitat, outdoor recreation opportunities).

Mine Reforestation Survey

In 2002 and 2003 a joint research team from Southern Illinois University Department of Forestry and Purdue University Department of Forestry and Natural Resources conducted a survey of surface mines reforested from 1988 to 1995. The purpose of the survey was to determine how well reforested mine sites were performing in terms of values and services normally ascribed to native forest and what their future potential might be. Specifically the survey did the following:

Figure 3. The coal mining region of southwest Indiana.

- Quantified post-bond release tree stocking;
- Determined post-bond release tree growth and growth potential;
- Determined post-bond release vegetation composition of the sites;
- Estimated carbon sequestration potential of tree stands on reclaimed mine sites.

A total of 22 different reclaimed tracts on 16 mines totaling 798 acres were included in the survey. The sites were located throughout the coal mining region of southwestern Indiana (Figure 3), from Terre Haute in the north to Evansville in the south. Site selection criteria sought to include the range of reclamation methods as well as land ownership (i.e., state, private individuals, and coal company).

Sites reclaimed prior to 1988 were excluded from the survey because SMCRA implementation was still in a transitional phase. Mine reclamation methods have evolved since 1977 with many changes occurring in the first 10 years of implementation. Sites reclaimed after 1995 were also excluded because they were too young to provide an indication of future growth potential. The survey was not designed to quantify the number of sites originally reforested that still have trees on them. In fact, anecdotal evidence suggests that many reforested mine sites were subsequently converted by landowners to other uses following bond release. None of these converted sites were included in the survey. For a detailed description of methods used in the survey see Fillmore, 2003.

Survey Results

The survey results, discussed in the context of practical outcomes for landowners and local economies and environmental benefits accrued to society, better underscore the relevance of this information. Therefore we present the survey results within the context of 1) long-term forest health, 2) viability of reforested mine sites as future contributors to local economies, and 3) the viability of reforested mine sites as producers of environmental assets.

Long-Term Forest Health

When we think of forest health, we often think of damaging insect and disease outbreaks. Many insect and disease outbreaks are merely secondary manifestations of environmental stresses on trees such as drought stress or flooded, saturated soil. Trees not adapted to the soils and inherent environmental stresses of a site more easily succumb to insect predation, disease, and to competition from other vegetation.

Long-term forest health is best achieved when tree species well-adapted to a site and its growing conditions are planted. Foresters in Indiana generally favor planting a variety of tree species that are well-adapted to the site being planted. Monocultures, or plantings where a single species dominates, are at greater risk of catastrophic loss to insect and disease outbreak and long-term chronic health problems.

Mine sites reclaimed and reforested from 1988 to 1995 and included in this survey were dominated by three woody species. Black locust (*Robinia pseudoacacia*) was the most abundant species on 15 of 22 (67 percent) sites (Figure 4). It accounted for at least 25 percent of tallied stems on over three quarters of the sites, at least 50 percent of the stem tally on nearly one half of the sites, and around 75 percent or more of tallied stems on five of the sites. It accounted for 47 percent of all tallied trees and shrubs across all sites (Figure 5).

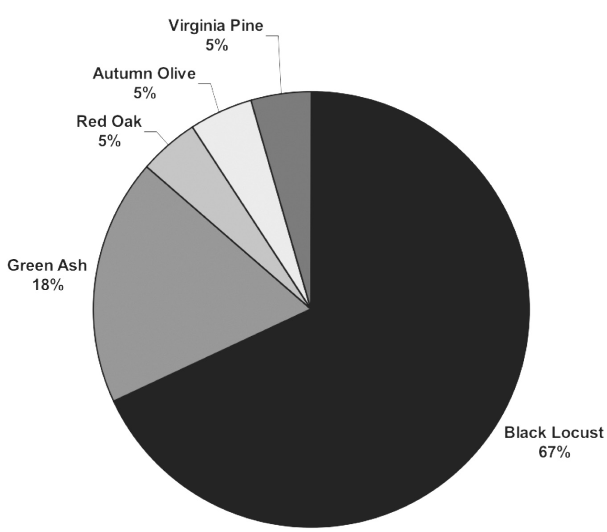

Figure 4. Percentage of sites dominated by tree and shrub species commonly planted on Indiana mines reclaimed from 1988 to 1995.

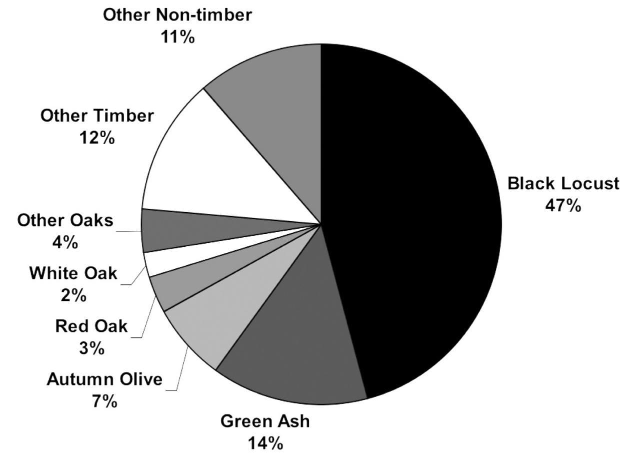

Figure 5. Abundance of trees and shrubs commonly planted on Indiana mines reclaimed from 1988 to 1995 as a percentage of the total number inventoried in the survey.

Green ash (*Fraxinus pennsylvanica*) dominated 4 of 22 sites (18 percent) and made up 14 percent of all tallied trees and shrubs. Autumn olive (*Eleagnus umbellatum*), a non-native shrub, was the third most abundant species planted. Forty-five other tree and shrub species comprised the remaining species. Together, three species, black locust, green ash, and autumn olive accounted for two-thirds of all stems tallied across all sites.

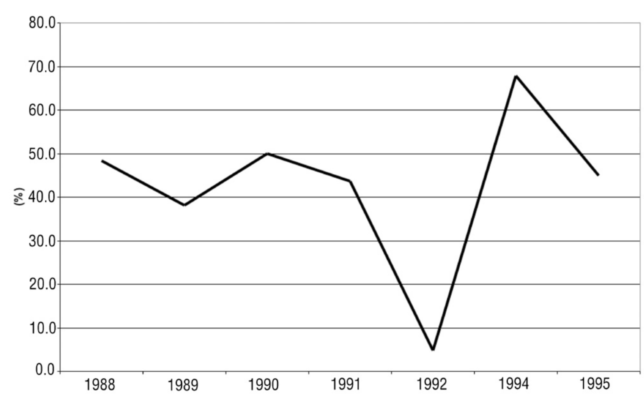

Figure 6. Percentage of total stems that were black locust on surveyed Indiana mines reclaimed from 1988 to 1995.

Individual sites exhibited different levels of species diversity. Two of the most recently planted sites (1995) contained 22 and 36 different species respectively. On the other extreme, two sites planted in 1991 were each dominated by black locust and contained only four species each. Throughout the surveyed period, with the exception of 1992, black locust dominated stand stocking (Figure 6). Only two sites reclaimed in 1992 and one in 1994 were surveyed. In 1999, INDOR issued a recommendation that no more than 25 percent of the stand stocking requirement should be satisfied using black locust.

Although insect pest and disease data were not collected in this survey, observations of tree health conditions were noted. Black locust crowns, particularly on older plantings, were beginning to die back (Figure 7). Black locust borer (*Megacyllene robinia*) severely damages black locust trees throughout southern Indiana. Trees growing under the harsh conditions of many reclaimed mine sites are particularly vulnerable.

Green ash may also prove vulnerable to insect and disease. Ash yellows (a mycoplasma like organism or MLO) causes decline and slow death of ash trees. Recent introductions of the Asian native emerald ash borer to Michigan and Ohio portend further trouble for ash trees should it spread to southern Indiana.

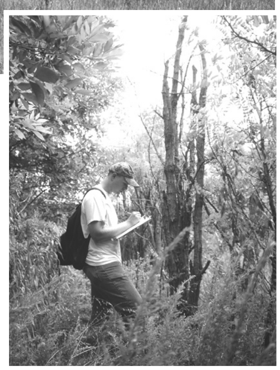

Figure 7. Many black locust stands on reclaimed mine land in Indiana are currently experiencing symptoms of decline. Black locust borer severely damages its host.

Summary

Both black locust and green ash were and still are widely planted in reclamation because of their ability to survive through the seedling establishment phase under reclaimed mine conditions and thus ensure timely bond release. Original planting composition could not be determined from records. Therefore, it is not certain whether the lack of diversity in species on older sites is due to not many species being planted or poorly adapted species disappearing from the stand. Nonetheless, where black locust and green ash comprise a large proportion of the stand, long-term forest growth and health are at risk. Greater seedling availability and INDOR's recommendation to reduce the amount of black locust in tree plantings has reduced the proportion of this species in more recent reclamation plantings.

Viability of Reforested Mines as Future Contributors to Local Economies

Wood manufacturing is the fifth largest industry in Indiana, valued at approximately $3.5 billion and employing over 54,000 workers. The wood industries are concentrated in the southern half of the state and are vitally important to many local economies. Thus there are strong local markets for timber in the coal producing region of the state. A primary contribution reforested mine sites would potentially make to local economies in the future would be the sale and supply of timber to local mills. In fact, mines reforested in the mid-20th century have recently had timber harvested from them.

Foresters attempt to forecast the productive potential of forests for producing timber by observing 1) tree growth rates, 2) site quality, and 3) stand stocking.

Tree Growth Rates

Tree growth is measured directly as height and as diameter of the bole at 4.5 feet above the ground, or "breast height" (Dbh). Growth measurements of stands of different ages can be compared by dividing height or Dbh by the age of the trees to obtain a mean annual growth increment (MAI).

MAI for tree heights (excluding shrubs) ranged from 0.37 feet/year to 1.91 feet/year, with a mean of 0.91 feet/year across all sites (Table 1). Average stand heights ranged from 4.8 feet in a 13-year-old stand to 17.5 feet in a 10-year-old stand. Dbh MAI ranged from 0.03 inch/year to 0.49 inch/year with a mean of 0.11 inch/year across all sites. Average Dbh ranged from 0.45 inch in the same 13-year-old stand to 3.43 inches in a seven-year-old stand. Two 10-year-old white oak stands planted on unmined old field sites in southern Indiana had MAI for height of 0.95 feet/year and 2.29 feet/year, respectively (O'Connor and Beineke 2004). Stand MAI for Dbh for the same two stands was 0.19 inch/year and 0.50 inch/year, respectively. Approximately 40 percent of surveyed mine site stands had MAI for height and 27 percent had MAI for Dbh within their respective ranges of the aforementioned white oak stands growing on unmined sites. The remaining stands fell below the ranges observed on the unmined sites.

Site Quality

Site quality refers to the influence of soils and other site factors on long-term tree growth rates. Perhaps one of the best measures of site quality is the quantity of wood a site can produce over a given amount of time. This measure of site productivity is not possible for

Table 1. Summary of Tree Growth Measurements on Indiana Mines Reclaimed from 1988 to 1995.

Measurement	Maximum	Minimum	Mean	Median
Individual Heights (ft.)	35.0	0.5	10.0	17.8
Mean Stand Height (ft.)	17.5	4.8	10.6	11.2
MAI Height (ft./yr.)	1.91	0.37	0.91	1.14
Individual Dbh (in.)	8.40	0.10	1.26	4.25
Mean Stand Dbh (in.)	3.43	0.45	1.26	1.94
MAI Dbh (in./yr.)	0.49	0.03	0.11	0.26

Table 2. Summary of Site Quality and Stand Stocking Data of Indiana Mines Reclaimed from 1988 to 1995.

Site/Stand Characteristics	Maximum	Minimum	Mean	Median
Site Index (ft. black oak, base age 50 years)	65	<20	40	30
Percent Stocking	93	13	69.5	72.7
Density (trees/acre)	3,859	575	1,551	2,217
Basal Area (ft^2/acre)	78.3	1.4	25.6	39.9

young stands growing on sites that do not have a timber harvest record.

Site index (SI) is the most common measurement of site quality used in forestry. The SI of a site is commonly measured as the height of the dominant, best growing trees when they are age 50. Equations have been developed allowing foresters to determine SI when trees are much younger and much older than 50 years old by simply aging the tree and measuring its height.

Tree height growth is sensitive to site quality and less sensitive to inter-tree competition than stem diameter growth. Thus SI becomes an easily-measured surrogate for all the site factors that influence tree growth. SI is commonly used in developing stand yield prediction equations and models.

Using black oak, one of the most commonly occurring species in southern Indiana, as the standard, SI on surveyed sites ranged from less than 20 feet to 65 feet and averaged 40 feet at the base age of 50 (Table 2) (Carmean 1971). The median and the mode were both 30 feet. Within site variability occurred with one site averaging SI = 40 feet but having small pockets of SI = 80 feet. Black oak site indices for unmined upland sites in southern Indiana range from 40 feet to 80+ feet, with the average SI = 65 to 70 feet (Hannah 1968). Low site indices (40 to 65 feet) are usually associated with dry sites, shallow soil depth, slow-growing trees, lower rates of stocking, and lower quality timber. Higher site indices (70 to 80 feet) are associated with deep soils, good soil moisture, faster tree growth, higher stocking rates, and better timber quality. At the current stage of stand development, most sites fell well below the lowest site quality of local native forests.

Stand Stocking

Stocking of trees refers to the number of trees competing for a limited amount of space and resources (soil moisture, nutrients, and sunlight) in a stand. Forest stands can be understocked, fully stocked, or overstocked. Understocking occurs when the trees growing in a stand do not fully utilize the site's space and resources. Future profit potential is lost due to unutilized space and resources. Additionally, trees growing with too much space do not experience the competitive pressure they need to grow tall, straight, limb-free trunks that are most highly-valued in timber markets. Understocked stands result in trees with poor timber form and quality (Figure 8).

Overstocked stands are overcrowded. There are not enough site resources to meet the growing demands of all

Figure 8. In understocked stands, trees lack sufficient inter-tree competition needed to grow tall, straight, limb-free trunks that are most highly-valued in timber markets.

Figure 9. Understocked stands (left) may have well stocked pockets interspersed with understocked or un-stocked areas. The photo on the right represents good hardwood stocking.

trees present. The growth of large numbers of trees may be stunted, tree health may decline, and mortality occurs. Self-thinning will naturally occur in overstocked stands. Foresters usually prescribe timely thinning for well-stocked and overstocked stands to increase the growth potential and vigor of remaining trees.

Stocking guidelines have been established for the Central Hardwood Region forests (Roach and Gingrich 1968). These guidelines are based on the average diameter of tree stems in a stand and the total number of trees per acre. Foresters often measure stocking as a percentage of full stocking.

Surveyed stands ranged in stocking from 13 percent of full stocking to 93 percent of full stocking (Table 2). Four of the stands were considered understocked. None of the stands were overstocked while 18 out of the 22 stands were considered fully stocked (Figure 9).

All stands still met or far exceeded the 450 stems per acre bond release requirement. Tree and shrub densities ranged from 575 stems/acre in an understocked stand reforested in 1992 to 3,859 stems /acre on a 93 percent fully stocked stand reforested in 1990 (three fourths of the stems were black locust, however). The mean number of trees per acre was 1,551.

Basal area is a measure of stocking based on the collective tree trunk cross-sectional areas of a stand measured at breast height and expressed as ft^2/acre. It provides a more accurate measure of tree use of space and resources than "trees/acre". Basal areas in surveyed stands ranged from 1.4 ft^2/acre on the same understocked stand in the preceding paragraph to 78 ft^2/acre on a mine reforested in 1995.

Stocking of commercially marketable species is also necessary to produce a viable stand of timber. Black locust comprised 46 percent of the basal area across all sites while green ash comprised 15 percent (Figure 10). All oak species combined across all sites totaled 14 percent of the basal area with red oak comprising 5.9 percent of the total basal area. Other commercially valuable timber species made up another 15 percent of the basal area.

Black locust is generally not considered a commercial timber species in conventional timber markets. Its markets are currently limited to firewood, fence posts, railroad ties, and pallet stock. Quality green ash and oak command higher prices in local timber markets.

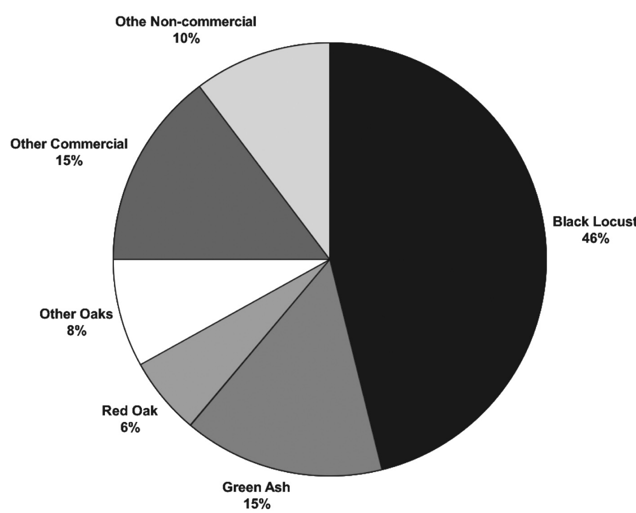

Figure 10. Percentage of basal area by species on surveyed mines in Indiana reclaimed from 1988 to 1995.

Summary

Tree growth rates as measured by MAI of height and Dbh reflected the variation between the reclaimed sites. Forty percent of stands approached unmined planted tree height growth rates, while only 27 percent approached Dbh growth rates of the stands on unmined sites.

Most reclaimed mine sites had site indices well below the poorer quality sites in the region's native forests. Higher rates of tree mortality, lower stocking rates, slow growth, and low-quality timber are expected for many of these sites. Some of the more recently reclaimed sites (1994/95) had site indices approaching or meeting those of local native forest suggesting that recent innovations in reclamation are improving the potential for reforestation success. One site had a SI = 65 feet while pockets with even higher site indices occurred on other sites. This suggests that the potential exists for improving site productivity on a wider scale in mine reclamation.

Overall stocking in the establishment phase of stand development appeared adequate for future commercial timber production on many of the study sites, with the exception of several understocked stands. However, the dominance of black locust stocking in many stands limits their future viability for timber production.

Viability of Reforested Mine Sites as Producers of Environmental Assets

Although forests provide a multitude of environmental benefits, we chose to focus on only three as particularly relevant: watershed protection, wildlife habitat, and carbon sequestration.

Watershed Protection and Wildlife Habitat

Forests protect watersheds and thus enhance water quality by preventing soil erosion and filtering polluted runoff. Forests also provide habitat for the majority of wildlife in Indiana. SMCRA regulations require the establishment of groundcovers to control soil erosion on newly reforested mines. Mine reclamation personnel select groundcover species primarily for their ease of initial establishment and their long-term success of maintaining a dense covering which meets the requirements for bond release. Cost, availability of seed, and value as wildlife food and cover are also important considerations.

Kentucky-31 fescue or tall fescue (*Festuca arundinaceae*) was the most common groundcover surveyed. It was present on 15 of the 22 sites. Where present, it ranged from 19 percent of the groundcover on a site reclaimed in 1990 to 75 percent of the groundcover on a site reclaimed in 1995. Goldenrod (*Solidago canadensis*) was the second most common groundcover.

Figure 11. Dense ground covers like tall fescue or the sericia lespedeza pictured here control soil erosion but inhibit planted tree growth and prevent establishment of native vegetation. Their value as wildlife habitat is also limited.

Although not intentionally planted during the mine reclamation, it seemed to quickly invade and establish on many reclaimed mine sites. It was found on 18 of the 22 sites and where present ranged from 15 percent to 45 percent of the groundcover. Sericia lespedeza (Lespedeza cuneata) was found on 10 of 22 sites ranging from 15 percent to 41 percent of the groundcover where present (Appendix B).

Tall fescue and sericia lespedeza were the groundcovers of choice for mine reclamation until recently. They were relatively easy to establish and provided rapid and reliable cover and erosion control. Tall fescue and sericia lespedeza strongly compete with tree seedlings for water and nutrients (Figure 11). Recent research demonstrates that tall fescue releases allelopathic chemicals that further inhibit the growth of neighboring vegetation. These species also have limited value as wildlife food.

As recently as 1995, tall fescue and sericia lespedeza were being established in tree plantings on reclaimed mines. On older sites the original groundcovers still persisted after 14 years. Tree crown closure was insufficient to shade them out. In the declining black locust stands, dense groundcovers will inhibit the establishment of native trees and shrubs that may seed in naturally.

Burger and Torbert (1999) recommend a mixture of grasses and leguminous forbs sown at a rate that provides adequate erosion control throughout the tree establishment phase without severely competing with the trees

Table 3. Species and Fertilizer Recommendations for a Tree-Compatible Ground Cover for Recommended Mine Soils in the Appalachians (Burger and Torbert 2002).

Species	Application Rate
	(lbs/acre)
Grasses:	
Winter Rye (*Secale cereale*) or Wheat (*Triticum aestivum*) (fall seeding)	15
Foxtail Millet (*Setaria italica*) (summer seeding)	5
Redtop (*Agrostis gigantean*)	2
Perennial Ryegrass (*Lolium perenne*)	2
Orchardgrass (*Dactylis glomerata*)	5
Weeping Lovegrass (*Eragrostis curvula*)	2
Legumes:	
Kobe Lespedeza (*Lespedeza striata var. Kobe*)	5
Birdsfoot Trefoil (*Lotus corniculatus*)	5 – 10
Ladino or White Clover (*Trifolium repens*)	3
Fertilizer (elemental rate):	
Nitrogen	50 – 75
Phosphorus	80 – 100

(Table 3). They provide improved wildlife habitat as well. Although tailored specifically for Appalachian reclamation, most of the recommended species are adapted to and readily available in this region. Further investigation is needed to determine their suitability for mine reforestation in this region and to determine optimum seeding rates.

Carbon Sequestration

Recent public and scientific interest has focused on the role forests play in capturing and storing carbon dioxide, the chief greenhouse gas implicated in global warming. Within the electric utility and coal production industries interest has arisen over the use of reclaimed mine land and abandoned mine land for the sequestration of atmospheric carbon through reforestation (Kane and Klein 2002).

Before use on mine land for carbon sequestration becomes reality, basic questions of feasibility and profitability must be answered. Such questions might include:

1. How much carbon can realistically be captured and stored in forest growth on reclaimed mine land?
2. How much will it cost to store carbon on this land?
3. How profitable is timber management on these sites?
4. How profitable is it to market carbon being stored on these sites (Konrad et al. 2002)?

This survey addresses the first question by estimating the current rate of carbon sequestration.

Carbon sequestration by forests is a function of stand stocking and tree growth rates. These measures are in turn functions of site quality and management practices. Site quality, tree growth rates, and stocking were addressed previously. Additionally, species and timber quality determine the likelihood of stored carbon remaining in long-term storage as durable wood products (furniture, buildings, etc.).

Mean annual carbon capture ranged from 0.004 ton/acre/year in a 10-year-old stand growing on a site with SI = <20 feet to 0.55 ton/acre/year in a seven-year-old stand growing on a site with SI = 45 feet (Appendix A). The average carbon capture rate across all sites was 0.13 ton/acre/year (Table 4). Younger stands, less than 11 years old, produced higher carbon capture rates than older stands. This reflects the higher site quality and tree growth rates of more recently reclaimed sites.

Summary

Tall fescue and sericia lespedeza provide rapid and reliable erosion control but inhibit tree establishment and growth. These planted groundcovers along with naturally occurring goldenrod were the most common groundcovers in surveyed tree plantings. Thus long-term benefits of forest cover to watersheds and wildlife are delayed. Tree compatible groundcover alternatives should be used to speed the transition from a tree

Table 4. Summary of Carbon Sequestration Estimate Data from Indiana Mines Reclaimed from 1988 to 1995.

Stand Characteristics	Maximum	Minimum	Mean	Median
Total Carbon (tons C/acre)	3.89	0.04	1.36	2.00
Carbon Increment (tons C/acre/year)	0.55	0.004	0.13	0.28

planting that meets bond release requirements to a healthy, viable forest.

Most of the sites surveyed would not be good candidates for market-based carbon sequestration programs. Poor site quality of most sites make current and future tree growth and carbon capture rates too low to be profitable in market-based carbon sequestration programs. The preponderance of black locust on many sites reduces their long-term carbon storage potential. Black locust wood is not currently used in furniture manufacture, construction, or other durable products other than fence posts, pallets, and railroad ties. Black locust's health problems as cited earlier preclude its use for long-term, on-site carbon sequestration.

Conclusions and Recommendations

Significant forest health problems currently exist in some forest stands surveyed in this study. Potential forest health threats exist for many other sites dominated by a single species. With few exceptions the reclaimed mine sites in this study show very low levels of productivity for forest products and carbon sequestration relative to native forests of this region, even though stocking levels appeared to be adequate. This suggests that the current bond performance measurement of 450 trees/acre bears little relevance to long-term forest productivity. Soil stabilization and erosion control were achieved in the short term through the use of aggressive groundcovers. Forest wildlife habitat development will likely be delayed.

Determining cause-and-effect relationships between specific reclamation practices and tree performance was not possible within the scope of this survey. However, we know that the interpretation and implementation of SMCRA has evolved and continues to do so. The improved productivity of some of the younger sites in this study reflects improvements in reclamation practices. Anecdotal evidence suggests that sites reclaimed more recently than those of this study show improved levels of productivity than on older reclaimed sites.

Improvements in reforestation may be attributed to the following:

1. Improved soils handling including the mixing of A and B horizons and a shift away from the use of scrapers for topsoil replacement to that of end dumping and grading with dozers (Ashby 1998).
2. Decreased use of black locust. Since 1999, Indiana Division of Reclamation has recommended that black locust comprise no more than 25 percent of the planting stock.
3. Decreased reliance on Kentucky-31 tall fescue and sericia lespedeza as groundcovers with a shift to more tree-compatible groundcovers (Burger and Torbert 1992).
4. Improvement in tree planting methods and weed control. Heavy duty tree planting machinery has replaced hand planting and contractors experienced in mine land tree planting have improved initial seedling survival and establishment resulting in improved long-term tree growth.
5. Increased availability of quality tree planting stock.

Further gains in forest productivity and long-term reforestation success can be achieved with the following recommendations:

1. Better educate landowners on their post-mining options. Ensure coordination and good communication among landowners, coal operators, and regulators during preparation of the mining permit and through the mining and reclamation phases.
2. Provide at least four feet of uncompacted soil (Burger and Torbert 1999).
3. Reduce grading and tracking of the soil surface to a level that reduces compaction but yet facilitates the use of tree planting machines. This will reduce equipment costs while providing a better rooting medium for trees. Ripping or subsoiling may be necessary for already compacted soils (Burger and Torbert 1999).

4. Provide incentives to landowners to maintain and manage their lands reclaimed to a forestry land use. Market-based carbon sequestration programs may provide financial incentives if reforested mines can demonstrate adequate rates of carbon capture and storage. Demonstration of post-mining forest productivity meeting or exceeding that of pre-mined forests may qualify reforested, reclaimed mines for enrollment in Indiana's Classified Forest program. The Classified Forest program provides property tax abatement to forest landowners meeting specified forestry standards. However, the best incentive is to leave the landowner a healthy, thriving forest that holds the promise of a productive legacy.

How much recent changes in reclamation practices may improve long-term forest productivity is currently unknown. Stands reclaimed with newer technology are still too young. The results of this survey should serve as a baseline to determine the extent to which recent and future changes in reclamation methods improve reforestation success while meeting the other mandates of the Indiana mining regulatory program.

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Appendix A. Summary of Site-Specific Data from the 2002 Survey of Mines Reclaimed in Indiana from 1988 to 1995.

Site No.	Year Reclaimed	Tract Size	Overburden Removal Method	Topsoil Replacement Method	Most[1] Abundant Tree	No.[2] Species	Mean[3] Height	MAI Height	Mean Dbh	MAI Dbh	Site[4] Index	Trees Acre	Stocking[5] Rate	Basal Area	Fixed Carbon	Carbon Capture Rate
		acres					-- ft.--	ft./yr.	- in. -	in./yr.	ft.		-- % --	ft.^{2}/acre	tons/acre	tons/acre/yr.
12	1988	11	Truck/Shovel	Scraper	Black Locust	6	15.0	1.07	1.45	0.10	32	1,746	91	30.8	1.64	0.11
17	1988	60	Dragline/Truck/Shovel	Scraper	Green Ash	6	10.4	0.74	0.97	0.07	30	1,310	81	15.7	0.88	0.06
18	1988	50	Dragline/Truck/Shovel	Scraper	Black Locust	8	9.4	0.67	0.61	0.04	30	1,884	72	6.0	0.21	0.01
11	1989	70	Truck/Shovel	Scraper/End Dump	Black Locust	5	11.4	0.85	1.14	0.09	30	1,333	78	18.7	0.96	0.07
15	1989	15	Dragline	Scraper	Virginia Pine	13	9.0	0.69	0.79	0.06	30	1,770	72	11.7	0.46	0.03
16	1989	59	Dragline	Scraper/End Dump	Black Locust	5	4.8	0.37	0.45	0.03	35	758	13	12.6	0.71	0.05
2	1990	40	Dragline/Truck/Shovel	Scraper/End Dump	Green Ash	8	9.0	0.75	1.33	0.11	30	1,471	73	9.9	0.28	0.02
3	1990	60	Truck/Shovel	End Dump/Dozer	Black Locust	5	11.3	0.94	1.30	0.11	30	1,103	53	11.4	0.55	0.04
13	1990	8	Truck/Shovel	Scraper	Black Locust	8	9.3	0.78	0.55	0.05	30	3,859	93	10.1	0.37	0.03
14	1990	9	Truck/Shovel	Scraper	Green Ash	8	14.2	1.18	1.54	0.13	32	1,379	81	31.2	1.74	0.10
1	1991	23	Truck/Shovel	Scraper	Black Locust	8	7.5	0.68	1.18	0.11	32	2,021	84	16.5	0.85	0.07
5	1991	26	Dragline	Scraper/End Dump	Black Locust	4	15.1	1.37	2.29	0.21	30	1,080	69	36.0	3.21	0.29
6	1991	6	Dragline	Scraper/End Dump	Green Ash	5	7.6	0.69	2.44	0.22	30	2,689	81	53.0	1.77	0.16
7	1991	59	Dragline	Scraper/End Dump	Black Locust	10	8.8	0.80	1.36	0.12	30	919	62	7.7	0.32	0.02
8	1991	48	Dragline	Scraper/End Dump	Black Locust	9	8.4	0.76	1.32	0.12	30	805	56	8.5	0.36	0.03
9	1991	28	Dragline	Scraper/End Dump	Black Locust	4	16.3	1.48	2.46	0.22	30	1,287	81	59.5	3.50	0.31
4	1992	6	Truck/Shovel	Scraper	Red Oak	6	5.4	0.54	0.76	0.08	<20	575	31	1.4	0.04	0.004
10	1992	26	Dragline	Scraper	Autumn Olive	6	17.5	1.75	2.31	0.23	30	1,379	62	54.3	3.89	0.38
20	1994	23	Dragline	Scraper	Black Locust	6	7.3	0.91	0.88	0.11	40	1,802	65	21.9	1.01	0.12
19	1995	30	Dragline	Scraper	Black Locust	22	10.6	1.51	3.43	0.49	45	1,470	67	78.3	3.90	0.55
21	1995	38	Dragline/Truck/Shovel	Scraper	Black Locust	6	13.4	1.91	1.66	0.24	45	1,657	84	42.3	2.09	0.29
22	1995	104	Dragline/Truck/Shovel	Scraper	Black Locust	19	10.4	1.49	1.10	0.16	65	1,823	80	26.2	1.21	0.17

[1] As a percentage of the total stem count

[2] Comprising at least 1% of the total stem count

[3] Height data excludes shrubs

[4] Black oak, base age 50 years (Carmean 1971)

[5] Roach and Gingrich 1975

Appendix B. Summary of Site-Specific Ground Cover Data from the 2002 Survey of Mines Reclaimed in Indiana from 1988 to 1995.

Site No.	Year Reclaimed	Total Site Ground Cover	Ground Cover Species	*Scientific Name*	Plots Where Observed	Mean[1] Plot Ground Cover	Mean[2] Site Ground Cover
		Percent			Percent	Percent	Percent
12	1988	62	Goldenrod	*Solidago canadensis*	69	38	26
			Korean Lespedeza	*Lespedeza stipulaceae*	41	16	6
			Tall Fescue	*Festuca arundinaceae*	31	32	10
17	1988	55	Goldenrod	*Solidago canadensis*	75	45	34
			Rush	*Juncus tenuis*	41	28	11
			Siricea Lespedeza	*Lespedeza cuneata*	22	18	4
18	1988	72	Fall Panicum	*Panicum dichotomiflorum*	97	36	35
			Goldenrod	*Solidago canadensis*	88	37	32
11	1989	50	Tall Fescue	*Festuca arundinaceae*	69	23	16
			Goldenrod	*Solidago canadensis*	69	34	24
			Orchard Grass	*Dactylis glomerata*	34	25	9
15	1989	22	Goldenrod	*Solidago canadensis*	72	17	12
			Broomsedge	*Andropogon virginicus*	34	14	5
16	1989	74	Tall Fescue	*Festuca arundinaceae*	84	22	7
			Siricea Lespedeza	*Lespedeza cuneata*	31	23	18
			Common Ragweed	*Ambrosia artemisiifolia*	72	54	39
2	1990	68	Tall Fescue	*Festuca arundinaceae*	90	43	39
			Goldenrod	*Solidago canadensis*	85	27	23
			Ox-Eye Daisy	*Leucanthemum vulgare*	3	14	3
3	1990	62	Goldenrod	*Solidago canadensis*	78	15	26
			Rush	*Juncus tenuis*	56	30	17
			Blackberry	*Rubus allegheniensis*	41	15	6
			Tall Fescue	*Festuca arundinaceae*	34	19	7
			Siricea Lespedeza	*Lespedeza cuneata*	18	15	2
13	1990	78	Tall Fescue	*Festuca arundinaceae*	100	71	72
			Orchard Grass	*Dactylis glomerata*	22	16	4
14	1990		Goldenrod	*Solidago canadensis*	97	37	36
			Tall Fescue	*Festuca arundinaceae*	94	20	19
			Korean Lespedeza	*Lespedeza stipulaceae*	16	18	3
1	1991	66	Tall Fescue	*Festuca arundinaceae*	78	47	38
			Goldenrod	*Solidago canadensis*	31	28	11
			Broomsedge	*Andropogon virginicus*	28	18	5
5	1991	49	Siricea Lespedeza	*Lespedeza cuneata*	81	26	21
			Brome	*Bromus tectorum*	28	28	8
			Goldenrod	*Solidago canadensis*	22	34	8
6	1991	40	Siricea Lespedeza	*Lespedeza cuneata*	50	36	18
			Goldenrod	*Solidago canadensis*	22	26	6
			Trumpet Creeper	*Campsis radicans*	22	14	3
			Tall Fescue	*Festuca arundinaceae*	9	55	5

Appendix B. continued.

Site No.	Year Reclaimed	Total Site Ground Cover	Ground Cover Species	*Scientific Name*	Plots Where Observed	Mean[1] Plot Ground Cover	Mean[2] Site Ground Cover
		Percent			Percent	Percent	Percent
7	1991	62	Tall Fescue	*Festuca arundinaceae*	78	48	37
			Broomsedge	*Andropogon virginicus*	38	23	9
			Siricea Lespedeza	*Lespedeza cuneata*	25	19	5
			Blackberry	*Rubus allegheniensis*	19	32	6
8	1991	76	Tall Fescue	*Festuca arundinaceae*	97	68	66
			Goldenrod	*Solidago canadensis*	19	27	5
9	1991	74	Tall Fescue	*Festuca arundinaceae*	75	68	51
			Goldenrod	*Solidago canadensis*	25	29	7
			Sedge	*Cyperus spp.*	9	73	7
4	1992	57	Orchard Grass	*Dactylis glomerata*	38	21	8
			Tall Fescue	*Festuca arundinaceae*	34	66	25
			Red Clover	*Trifolium pratense*	31	13	4
			Goldenrod	*Solidago canadensis*	28	34	10
			Brome	*Bromus tectorum*	19	35	7
10	1992	75	Tall Fescue	*Festuca arundinaceae*	97	56	55
			Goldenrod	*Solidago canadensis*	38	21	8
			Orchard Grass	*Dactylis glomerata*	25	48	12
20	1994	65	Tall Fescue	*Festuca arundinaceae*	71	50	36
			Goldenrod	*Solidago canadensis*	38	29	11
			Barnyardgrass	*Echinochloa crus-galli*	16	57	9
			Blackberry	*Rubus allegheniensis*	13	13	2
19	1995	53	Tall Fescue	*Festuca arundinaceae*	60	40	24
			Siricea Lespedeza	*Lespedeza cuneata*	46	29	13
			Goldenrod	*Solidago canadensis*	41	25	10
			Blackberry	*Rubus allegheniensis*	25	14	2
21	1995	85	Tall Fescue	*Festuca arundinaceae*	97	75	70
			Siricea Lespedeza	*Lespedeza cuneata*	11	41	4
			Blackberry	*Rubus allegheniensis*	11	23	3
			Jap. Honeysuckle	*Lonicera japonica*	6	52	3
22	1995	71	Tall Fescue	*Festuca arundinaceae*	62	46	28
			Goldenrod	*Solidago canadensis*	50	32	16
			Blackberry	*Rubus allegheniensis*	29	33	10
			Wild Oats	*Avena fatua*	19	55	11
			Siricea Lespedeza	*Lespedeza cuneata*	8	24	2

[1]Mean percentage of ground covered in plots where species is observed.
[2]Mean percentage of ground covered by the species across all plots on the site.

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