Stand Characteristics and Productivity Potential of Indiana Surface Mines Reclaimed Under SMCRA

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ABSTRACT: *The Surface Mining Control and Reclamation Act of 1977 (SMCRA) addresses a wide range of environmental concerns. However, its impacts on forest stand development and productive potential have only recently been investigated. We surveyed the vegetation and forest productivity on 22 surface mine sites throughout the coal-bearing region of Indiana that were reclaimed to forest cover under the provisions of SMCRA 7–14 years prior to sampling. Black locust (*Robinia pseudoacacia*) and green ash (*Fraxinus pennsylvanica*) were the most widely occurring tree species. Tall fescue and goldenrod were the most widely occurring nonarborescent species. Median site index (base age 50 for black oak) was 30 ft. Although satisfying forest cover stocking requirements for bond release, these reclaimed surface mines almost always displayed a level of productivity far below those of native forests typical of this region. Reclamation techniques differing from those used on these study sites are needed to restore forest productivity to surface-mined lands while still complying with SMCRA. North. J. Appl. For. 23(2):94–99.*

Key Words: Black locust, forest productivity, green ash, herbaceous competition, strip mine reclamation.

Prior to implementation of the Surface Mining Control and Reclamation Act of 1977 (SMCRA), some operators successfully established forest cover to the extent that mines often equal or exceed nonmined reference sites in terms of forest productivity and economic values (Rodrigue et al. 2002). SMCRA focused reclamation efforts toward a broader set of environmental values and has succeeded in improving water quality and soil stability, as well as eliminating the incidence of extreme soil pH conditions (Davidson et al. 1984). Specific management practices implemented to address SMCRA regulations have included intensive grading, compaction of replaced topsoil, and the establishment of aggressive ground cover species. Conditions likely to impede stand development and forest productivity have resulted (Chaney et al. 1995, Ashby 1996a, Torbert et al. 2000).

In Indiana, surface mine reclamation has historically provided a significant opportunity to produce growing stock for a forest products industry focused on utilization of fine hardwoods. More recently, the potential for these lands to sequester carbon has been considered a source of landowner income (Schneider and McCarl 2003). Both of these objectives necessitate the establishment of stands of desirable species composition, stem quality, and productivity. State regulations require mine operators to maintain 450 trees per acre for 5 consecutive years to achieve bond release under a forestry postmine land use. However, no provisions existed to ensure desirable forest composition or productivity beyond this establishment period, and the long-term prospects for these forests are not known.

The objectives of this study were to evaluate early stand development and assess productivity potential of Indiana surface mines reclaimed to forest cover under the provisions of SMCRA.

Methods

Study Area and Site Selection

Study sites were distributed throughout the Indiana coal basin in the west-central and southwestern portions of the state. All study sites were located within the Wabash Lowland physiographic province where topography is flat to gently rolling. A total of 22 sites on 16 mines, constituting

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798 ac, were inventoried with sites ranging in size from 6 to 70 ac.

Sites were selected to represent the range of overburden removal and topsoil replacement techniques, ownership status, and geographic distribution associated with forest cover reclamations planted from 1988 to 1995 (7–14 years prior to the study) (Table 1). Overburden was removed via dragline ($n = 13$), truck/shovel ($n = 6$), or it was removed using both techniques ($n = 3$). Topsoil was removed with scrapers on two sites. Following subsoil replacement, topsoil replacement was accomplished via scraper/end dump ($n = 5$), or scraper alone ($n = 16$). End dump-bulldozer was used on one site. Ownership of the mine sites at the time of the survey included state, company, and private individuals. While the entire Indiana coal-producing region is represented, study sites were predominantly within the southern two-thirds of the study area, reflecting the concentration of mining activity there during the late 1980s to early 1990s.

Sampling Methods and Analysis

Prior to inventorying, sites were evaluated for tree cover heterogeneity using on-the-ground observation and aerial photographs. Transects were established across sites to ensure complete coverage of a site and to capture variance in topography and/or species composition. Points were randomly located along transects, and 1/735th ac plots were established 33 ft from points in each of the cardinal eight directions. A total of 1,280 plots were established across all study sites with a minimum of 32 plots at each study site. Sampling intensity increased as a function of site size and heterogeneity.

All trees within each plot were identified to species. Height was measured to the nearest 0.5 ft. Additionally, diameter at breast height (dbh) was determined for all trees >4.5 ft in height. Attempts to distinguish planted and volunteer trees were abandoned due to the frequent deviation of operators from written reclamation plans. Stocking of tree species followed standards for even-aged upland hardwood stands (Ginrich 1967, Roach and Gingrich 1968). Within each plot, all nonarborescent plant species were identified. Percent cover was recorded for all species constituting >10% of cover based on ocular estimates.

All site index estimates were based on black oak (*Quercus velutina*) at a base age of 50 years (Carmean 1971). Correlations between herbaceous cover and tree height average annual increment (AAI) were analyzed using paired *t*-tests. The effect of black locust (*Robinia pseudoacacia*) presence on green ash (*Fraxinus pennsylvanica*) height growth was evaluated using a paired *t*-test. Because of its frequent occurrence, green ash was selected as the only species for the analysis of black locust efficacy as a nurse species. All analyses were conducted using the JMP (SAS Institute, Cary, NC) statistical package. Following the precedent set by the USDI Office of Surface Mining and others for survey-based research on surface mines, $\alpha < 0.1$ was considered significant unless otherwise noted (Bryan and Price 1992). Carbon sequestration estimates for bolewood used a conoid volume equation (Avery and Burkhart 2002). Wood volume to carbon-sequestered conversions assumed a carbon to dry wood yield ratio of 0.46 (Marland 1988). Attempts to relate site productivity with overburden removal or reclamation techniques did not yield statistically significant results and are not discussed further.

Results

Forest Vegetation

Black locust was the most frequently occurring arborescent species across all sites, comprising 46% of all stems tallied and was the most frequently occurring tree species on

Table 1. Sites included in Indiana Mine Reclamation study. Species codes are derived from first two letters of genus and species for tree species (Table 2) and herbaceous species (Table 3).

Mine	Operator	County	Overburden removal/ replacement	Dominant tree species	Dominant herbaceous species
Elberfeld	Solar Sources	Warrick	T/S	ROPS, PLOC	FEAR, SOCA, ANVI
AMC#3	Phoenix	Daviess	DT/ES	FRPE, DIVI, QUAL	FEAR, SOCA, ASSP
West Fork	United Minerals	Daviess	T/EB	ROPS, PODE	FEAR, SOCA, JUSP, RUSP
Viking	Black Beauty	Daviess	T/S	QURU	DAGL, SOCA, TRSP, BRTE
Westfield #1	Kindill	Pike	D/ES	ROPS	LECU, BRTE, SOCA
Westfield #2	Kindill	Pike	D/ES	FRPE, ROPS, SANI	LECU, SOCA, CARA
Westfield #3	Kindill	Pike	D/ES	ROPS, QURU	FEAR, ANVI, LECU
Westfield #4	Kindill	Pike	D/ES	ROPS	FEAR, SOCA
Westfield #6	Kindill	Pike	D/ES	ROPS, ELUM	FEAR, SOCA
Chinook	Mdwest	Clay	D/S	QURU, ELUM, FRPE, JUNI	FEAR, SOCA, DAGL
Alfordsville	BFC	Daviess	T/ES	ROPS, PLOC	FEAR, SOCA, DAGL
Corning	Black Beauty	Daviess	T/S	ROPS, FRPE, ELUM	SOCA, LEST, FEAR
Glendale North	BFC	Daviess	T/S	ROPS, FRPE	FEAR, DAGL
Glendale West	BFC	Daviess	T/S	FRPE, ROPS	SOCA, FEAR, LEST
Saline #1	Brazil	Clay	D/S	PIVI, QURU, LITU	SOCA, ANVI
Hawthorn	Peabody	Sullivan	D/ES	ROPS, FRPE	LECU, AMAR, FEAR
Indian	Phoenix	Daviess	DT/S	FRPE, SANI, QUAL	SOCA, JUSP, LECU
American	Phoenix	Daviess	DT/S	ROPS	PADI, SOCA
Lynnville	Peabody	Warrick	D/S	ROPS, FRPE	FEAR, LECU, SOCA, RUSP
Ayrshire	AMAX	Pike	D/S	ROPS, ELUM, FRPE	FEAR, SOCA, ECCR, RUSP
Squaw Creek Lackehart	Peabody	Warrick	DT/S	ROPS	FEAR, LECU, RUSP
Squaw Creek Northwest	Peabody	Warrick	DT/S	ROPS, FRPE	FEAR, SOCA, AVFA, RUSP

Key: B, bulldozer; D, dragline; E, end dump; S, scraper; T, truck and shovel.

Table 2. Overstory species observed on reclaimed mine sites in Indiana comprising at least 1% of all individuals measured.

			Number of sites ($n = 22$)	
Common name	Scientific name	Percent of all sampled trees	Most common species on a site	>10% of trees on a site
Black locust	*Robinia pseudoacacia*	45.7	15	17
Green ash	*Fraxinus pennsylvanica*	14.2	4	11
Autumn olive	*Elaeagnus umbellata*	7.1	1	5
Northern red oak	*Quercus rubra*	3.4	1	4
Sycamore	*Platanus occidentalis*	2.1	0	2
White oak	*Quercus alba*	2.1	0	2
Bristly locust	*Robinia viscose*	1.7	0	0
Winged sumac	*Rhus coppalina*	1.7	0	0
Black walnut	*Juglans nigra*	1.6	0	1
Red maple	*Acer rubrum*	1.6	0	0
Virginia pine	*Pinus virginiana*	1.6	1	1
Persimmon	*Diospyros virginiana*	1.5	0	1
Black cherry	*Prunus serotina*	1.4	0	0
Sawtooth oak	*Quercus accutissima*	1.4	0	0
Smooth sumac	*Rhus glabra*	1.3	0	0
Eastern redbud	*Cercis canadensis*	1.1	0	0
Sweetgum	*Liquidambar styraciflua*	1.1	0	0
Black willow	*Salix nigra*	0.8	0	2
Yellow-poplar	*Liriodendron tulipifera*	0.7	0	1
Hawthorn	*Crataegus* sp.	0.7	0	0
Eastern red cedar	*Juniperus virginiana*	0.5	0	0
Cottonwood	*Populus deltoides*	0.5	0	1
Swamp chestnut oak	*Quercus michauxii*	0.5	0	0
Bur oak	*Quercus macrocarpa*	0.5	0	0

68% of study sites (Table 2). Green ash was the second most frequently occurring species, comprising 14% of all tallied trees and was the most frequently occurring species on 18% of sites. The remaining 45 species comprised 34% of all stems tallied. A total of 12 tree species constituted at least 10% of individuals on at least one site.

The greatest stem diameter (8.4 in. dbh) measured in this study was a black locust. The greatest height measured (35 ft) was attained by one individual of each of the following species: black locust, green ash, sawtooth oak (*Quercus acutissima*), and Northern red oak (*Quercus rubra*). Black locust and green ash together comprised over 60% of the basal area across all 22 study sites. Northern red oak, white oak (*Quercus alba*), and black walnut (*Juglans nigra*) comprised the third, fourth, and fifth highest amounts of basal area across the study sites (9.5, 4.1, and 3.6%, respectively).

Herbaceous Stratum and Competitive Interactions

Forty-nine nonarborescent woody and herbaceous species were observed across the study sites, the most common being tall fescue (*Festuca arundinacea*), which was observed on 63.5% of all plots and was the most frequently occurring nonarborescent species on 54% of the sites (Table 3). Goldenrod (*Solidago canadensis*) was tallied in 43% of all plots and was the most commonly occurring nonarborescent species on 23% of sites. Seventeen nonarborescent species constituted at least 10% of cover on at least one site.

Dominant herbaceous species significantly affected tree height AAI (Figure 1). Sites where tall fescue was the dominant herbaceous species showed the largest height AAI. The lowest AAI was observed where a grass species other than tall fescue was the dominant nonarborescent species. Presence or absence of black locust was not associated with any differences in green ash total height ($P = 0.3304$).

Productivity, Stocking, and Carbon Sequestration

Site index ranged from 65 to less than 20 ft, with a median value of 30 (Table 4). The second highest site index value recorded was 45 ft. Basal area across sites ranged from 1.4 to 78.3 ft^2 with a mean of 25.6 ft^2. Stocking averaged 69.5%. All but four sites (82%) supported stands above B-level stocking. No sites were overstocked. However, stocking on eight sites exceeded 90%.

The largest aboveground woody carbon capture value observed on an individual site was 3.89 tons ac^{-1}. This site also displayed the highest carbon average annual increment (0.55 tons ac^{-1} yr^{-1}). The lowest observed carbon capture value was 0.04 tons ac^{-1}, and resulted in an AAI rate of 0.004 tons ac^{-1} yr^{-1}. The mean carbon capture volume and carbon average annual increment across all 22 study sites was 1.36 tons ac^{-1} and 0.13 tons ac^{-1} yr^{-1}, respectively. Carbon capture average annual increment was negatively correlated with stand age (Figure 2).

Discussion

Forest Vegetation

The extensive planting of black locust on surface-mined sites predates the enactment of SMCRA, largely due to its high survival rate under harsh site conditions (Ashby et al. 1985). This practice continued under SMCRA because it enabled operators to quickly and reliably achieve bond release stocking requirements. However, the long-term value of this species is limited. Black locust is subject to early decline due to widespread occurrence of the locust borer (*Megacyllene robinia*). Although not specifically

Table 3. Non-arborescent species observed on reclaimed mine sites in Indiana in at least 1% of all plots.

Common name	Scientific name	Percent of all plots	Number of sites (n = 22)	
			Most common species on a site	>10% cover on a site
Tall fescue	*Festuca arundinaceae*	63.5	12	15
Canadian goldenrod	*Solidago canadensis*	42.7	5	17
Blackberry	*Rubus* spp.	17.7	0	5
Sericia lespedeza	*Lespedeza cuneata*	15.5	3	8
Wild oats	*Avena fatua*	7.6	0	1
Broomsedge	*Andropogon virginicus*	6.5	0	3
Orchardgrass	*Dactylis glomerata*	5.2	1	4
Brome	*Bromus tectorum*	3.8	0	2
Thistle	*Cirsium arvense*	3.3	0	0
Daisy	*Aster* spp.	3.3	0	1
Fall panicum	*Panicum dichotomiflorum*	3.2	1	1
Rush	*Juncus* spp.	2.9	0	2
Barnyard grass	*Echinochloa crus-galli*	2.1	0	1
Horse nettle	*Solanus carolinense*	2.1	0	0
Japanese honeysuckle	*Lonicera japonica*	2.1	0	1
Korean lespedeza	*Lespedeza stipulacea*	2	0	2
Common ragweed	*Ambrosia artemisiifolia*	1.8	0	1
Clover	*Trifolium* spp.	1.7	0	1
Horseweed	*Conyza canadensis*	1.6	0	0
Trumpet creeper	*Campsis radicans*	1.6	0	1
Common pokeweed	*Phytolacca americana*	1.5	0	0
Yellow nutsedge	*Cyperus esculentus*	1.4	0	0
Milkweed	*Asclepias syriaca*	1.3	0	0
Pigweed	*Amaranthus blitoides*	1.2	0	0
Timothy	*Phleum pratense*	1	0	0

measured, black locust dieback appeared to be responsible for the negative correlation between age and net productivity observed in this study.

Green ash has shown considerable utility in achieving early stand stocking objectives due to its survivability on compacted soils characteristic of early post-SMCRA sites (Ashby 1991, 1998). However, green ash is subject to declining growth and deformity from ash yellows, resulting from infestation by a mycoplasm-like organism (Sinclair and Griffiths 1994). Although no evidence of green ash decline was observed in this study, drought-prone sites, such as those found here, have been associated with ash yellows outbreaks.

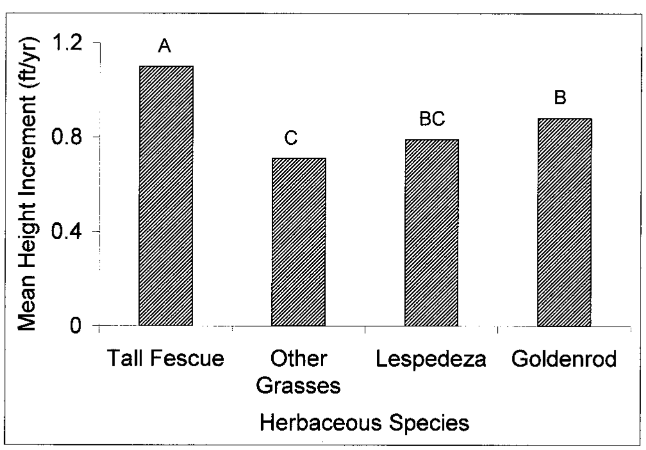

Figure 1. Tree height average annual increment as affected by occurrence of herbaceous species on reclaimed surface mines in Indiana. Means followed by the same letter are not significantly different ($P < 0.05$).

Oak species (*Quercus* spp.) and black walnut have the potential to produce high-value timber on reclaimed mine sites under appropriate site and stand conditions (Ashby 1996b). On pre-SMCRA sites, hardwood sawtimber values often exceeded those associated with natural hardwood stands (Rodrigue et al. 2002). In the present study, these species were present in adequate numbers for crop tree management (Smith and Lamson 1983). However, heavy browsing and open stand conditions resulted in the development of poor stem form and, in most cases, these stands appeared unlikely to ever produce a commercially viable sawlog harvest. Nevertheless, these sites supported mast-producing trees, cover, and woody browse resources with value for wildlife species including deer, turkey, and upland game birds.

Volunteer tree species remained a minor component of these stands. This contrasts with patterns observed on abandoned agricultural lands in nearby southern Illinois (Bazzaz 1968, Kruse and Groninger 2003). Despite their relatively small numbers, volunteer trees were among the largest individuals present on some study sites. The scarcity of volunteer trees may have been a function of large distances from potential seed sources and the competitiveness of herbaceous vegetation. However, volunteer trees, especially cottonwood (*Populus deltoides*), were observed in the unsampled drainage areas adjacent to the study sites. These trees may become seed sources in the near future once these individuals become reproductive, as will the planted trees on the study sites.

Herbaceous Stratum and Competitive Interactions

The herbaceous stratum was dominated by a combination of species planted to provide rapid postreclamation soil

Table 4. Tree stocking and productivity characteristics of post-law Indiana surface mined sites.

Variable	Maximum	Minimum	Mean	Median
Site index (black oak, BA = 50 yr)	65	<20	–	30
Density (trees ac^{-1})	3,859	575	1,551	1,379, 1,470
Basal area (ft^2 ac^{-1})	78.3	1.4	25.6	16.47, 18.71
% stocking	93	13	69.5	72.73
Total carbon (tons C ac^{-1})	3.89	0.043	1.36	0.88, 0.96
Carbon increment (tons C ac^{-1} yr^{-1})	0.55	0.004	0.13	0.07

stabilization (tall fescue and *Lespedeza* spp.) and aggressive invasive herbaceous species typically associated with former agricultural fields (Bazzaz 1968, Kruse and Groninger 2003). The relatively favorable growth of planted trees in the presence of tall fescue appeared to contradict previous reports of the inhibitory effects of this species (Plass 1968, Anderson et al. 1989). However, the present results were less surprising when viewed in the light of overall poor height growth and suggested that tall fescue may merely be less inhibitory than the other commonly occurring herbaceous species. Inhibitory effects of these communities are well-documented and have likely influenced the poor tree growth observed on these sites (Burton and Bazzaz 1995). Although most planted trees appear to have grown beyond the influence of the herbaceous stratum, continued invasion of volunteer trees will likely still be inhibited (Bramble et al. 1990). The relative paucity of volunteer trees to act as trainers will further contribute to the poor form of the planted oaks and walnut.

Investigations of the utility of black locust as a nurse crop for interplanted tree species have produced mixed results (Boyce and Merz 1959, Huntley 1990, Panterra and Pope 1993). The absence of a response reported here should be viewed in the light of overall poor growing conditions as well as the observational nature of this study. In the future, growth benefits may result if surviving trees are able to use resources held by the presently dominant but declining black locust.

Productivity, Stocking, and Carbon Sequestration

Although these sites met stocking guidelines for both Central Hardwoods forests and reclamation bond release, productivity was almost always less than the lowest value provided in published guidelines and models for wood products-based management (Roach and Gingrich 1975, Wiant and Castaneda, 1978, Harris and Zahner 1984). Site index and carbon sequestration values placed these stands on a trajectory far lower than those found on selected pre-SMCRA reclaimed surface mines and comparable reference stands in Indiana and elsewhere throughout the eastern United States (Rodrigue et al. 2002). Accordingly, aboveground carbon capture rates were very low and the potential is very limited for sequestration in high-value, durable forest products.

While it is possible that the continued influx of volunteer species will contribute to increased stocking rates and carbon sequestration, the ongoing decline of black locust will likely more than offset these gains for the next several years. Furthermore, the failure of early tree cover allows persistent and unproductive herbaceous communities to become increasingly entrenched, thereby impeding the long-term carbon sequestration potential of these sites (Groninger et al. 2004). Remedial silvicultural treatments, including intensive vegetation management and further tree planting, would be needed to ameliorate this condition.

The disparity between adequate stocking and low productivity of these sites suggests that conditions satisfying bond release criteria did not necessarily translate into desirable long-term forest stand development and potential for high-quality wood production. One stand did have a site index of 65, and similarly productive pockets of forest vegetation were observed on other sites. These appear to have resulted from undocumented experimental reclamation practices implemented by operators. This suggests that considerable opportunities for improved productivity may exist on surface mines reclaimed under SMCRA.

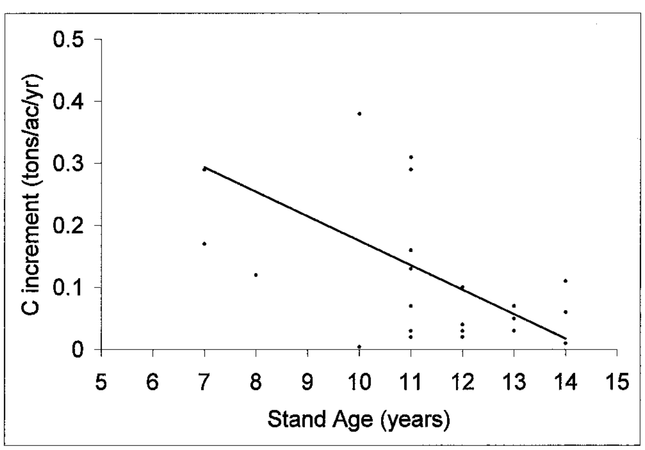

Figure 2. Relationship between stand age and average annual increment of carbon in tree stemwood on reclaimed surface mines in Indiana (n = 22, R^2 = 0.36, Prob >F = 0.0024).

Conclusions

The post-SMCRA-reclaimed sites measured in this study showed very low levels of productivity for forest products or carbon sequestration relative to native forest stands of this region. The present study should serve as a baseline to determine the extent to which more recent and future reclamation efforts result in higher on-site productivity while maintaining the other important environmental attributes mandated by SMCRA.

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