WOODY VEGETATION AND SUCCESSION ON THE FONDE SURFACE MINE DEMONSTRATION AREA, BELL COUNTY, KENTUCKY [1]

by

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Abstract: The long term impact of surface mining on vegetation and plant succession has always been of concern to environmentalists and residents of Appalachia. The Fonde Surface Mine Demonstration Area is a 7.3-ha, NE-NW-aspect contour coal mine at an elevation of 562 m. It was reclaimed in 1965 to show state-of-the-art surface mine reclamation techniques consistent with then-current law and regulations after coal mining in 1959 and 1963. The mine spoils were lightly graded to control erosion and create a bench with water control and two sediment ponds. Soil pH ranged from 2.8 to 5.9. About 80 percent of the mine was planted with 18 tree and shrub species including plantations of mixed pine, mixed hardwoods, black locust, and shrubs for wildlife. In a complete floristic inventory conducted 25 years later, we found the woody flora consisted of 34 families, 53 genera, and 70 species including 7 exotics. This inventory of the Fonde mine shows that a diverse forest vegetation can be reestablished after extreme disturbances in Appalachia. Black locust, yellow poplar, and Virginia pine reproduction varied significantly among plantation types. Canopy tree species significantly affected ground layer cover, total species richness, number of tree seedling species, and total number of tree seedlings present. Mine soil type affected ground layer percent cover and total species richness. Pre-SMCRA (Surface Mining Control and Reclamation Act of 1977) reclaimed and inventoried mines can be used to evaluate biodiversity on post-SMCRA mines.

Additional Key Words: plant invasion, succession, reforestation, reclamation, species richness.

Introduction

The long term impact of surface mining on local floras, vegetation, and ecological succession has always been of concern to botanists, environmentalists, and residents of coal mining regions. Complete inventory studies of mine floras, however, did not really begin until after passage of the Surface Mine Control and Reclamation Act of 1977 (SMCRA, also known as Public Law 95-87). The effects of pre-SMCRA mining and reclamation methods on floras are of interest because:

- Biological inventories of pre- and post- SMCRA reclaimed lands can be used to evaluate effects of SMCRA on the biological recovery of mined lands.
- Biological inventories of disturbed areas have inherent value as records of human impacts upon the environment.
- Intensive study of development of reclaimed sites has great value for fine-tuning reclamation regulations in order to increase reclamation success and local biodiversity.

The objectives of this paper are:

- to describe the success of reclamation plantings on this pre-SMCRA reclaimed surface mine,
- to present a list of woody species that have become established after 25 years, and
- to describe the influence of mine soil quality and plantings on succession and development of the postmine vegetation.

Vegetation refers to the plant community organization and succession based upon our vegetational sampling studies on the Fonde Surface Mine Demonstration Area. Flora, on the other hand, refers to all plant species growing within the confines of the mine boundaries as well as the sampling sites. The total Fonde flora data have been the result of an intensive survey for

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two growing seasons, and the full annotated list of species will be presented in a future paper.

Five vegetation studies and floras of pre SMCRA surface coal mines have been completed in eastern Kentucky (Rafaill and Thompson unpublished; Thompson et al. 1984, 1986, 1996; Thompson and Wade 1991). These studies report development of floras and vegetation on pre-SMCRA mines because there has been insufficient time for the reasonable development of mine floras through ecological succession since SMCRA requirements became effective.

The Study Area

The Fonde Surface Mine Reclamation Demonstration Area is located on a mountain slope approximately 0.5 kilometer south of the town of Fonde in southwestern Bell County, Kentucky, and about 0.1 km from Claiborne County, Tennessee, at longitude 83°52'15"W and latitude 36°35'20"N. The 7.3 ha Fonde NE-NW trending contour mine ranges in elevation from 583 m at the highwall top, 562 m on the bench, to 560 m on the outslope bottom. Rugged mountain terrain in the study area belongs to the Cumberland Mountains of the Appalachian Plateaus Physiographic Province (Fenneman 1938). Bedrock consists of sandstones, siltstones, shales and coals of the Mingo Formation from Lower and Middle Pennsylvanian Series in the Pennsylvanian System (Rice and Maughan 1978). The forest soils of the site prior to coal mining were classified as part of the Fairpoint and Bethesda soils on 2-20 percent slopes and Cloverlick-Guyandotte-Highsplint complex on 35-75 percent, very stony slopes (Childress 1992). Vegetation of the Cumberland Mountains was classified as Mixed Mesophytic Forest Region by Braun (1950) and was mapped as the Mixed Mesophytic Forest (*Acer-Aesculus-Fagus-Liriodendron-Quercus-Tilia*) Vegetation of Küchler (1964).

At the Fonde site, the Mingo coal seam was mined in 1959 and again in 1963. The site was reclaimed in 1965 to show state-of-the-art mine reclamation techniques consistent with the Kentucky mining law and regulations of that time. The mine spoils were minimally graded to contain incoming precipitation and water drainage from about 7.0 ha of upslope secondary deciduous forest. Water was directed back toward the highwall and then to two settling ponds with controlled outlets and capacity to contain a 150-year storm. When possible, acid-forming coal wastes and shales were buried to lessen acid production. No lime or fertilizer were applied except for a few small experimental plots near the dam. The original pH of the mine spoils ranged 2.8-5.9 and the mean pH value was 4.0.

The designers of the original study recognized three general spoil qualities and established plantations with some consideration of spoil quality on the bench and outslope (Figure 1). Mixed hardwoods plantations of yellow poplar (*Liriodendron tulipifera*), northern red oak (*Quercus rubra*), white oak (*Q. alba*), red maple (*Acer rubrum*), sugar maple (*A. saccharum*), American sycamore (*Platanus occidentalis*), and green ash (*Fraxinus pensylvanica*) were planted in three areas on what were considered to be the best quality spoils. Mixed pine plantations of Virginia pine (*Pinus virginiana*), pitch pine (*P. rigida*), and loblolly pine (*P. taeda*) were established in three areas of mostly poorer quality spoils, and black locust (*Robinia pseudoaçacia*) was planted in three areas with the worst spoils including coal waste where little chance was given for success. European black alder (*Alnus glutinosa*), Virginia pine, bicolor lespedeza (*Lespedeza bicolor*), Korean lespedeza (*L. stipulacea*), and sericea lespedeza (*L. cuneata*) were planted in one large area near the center of the mine for

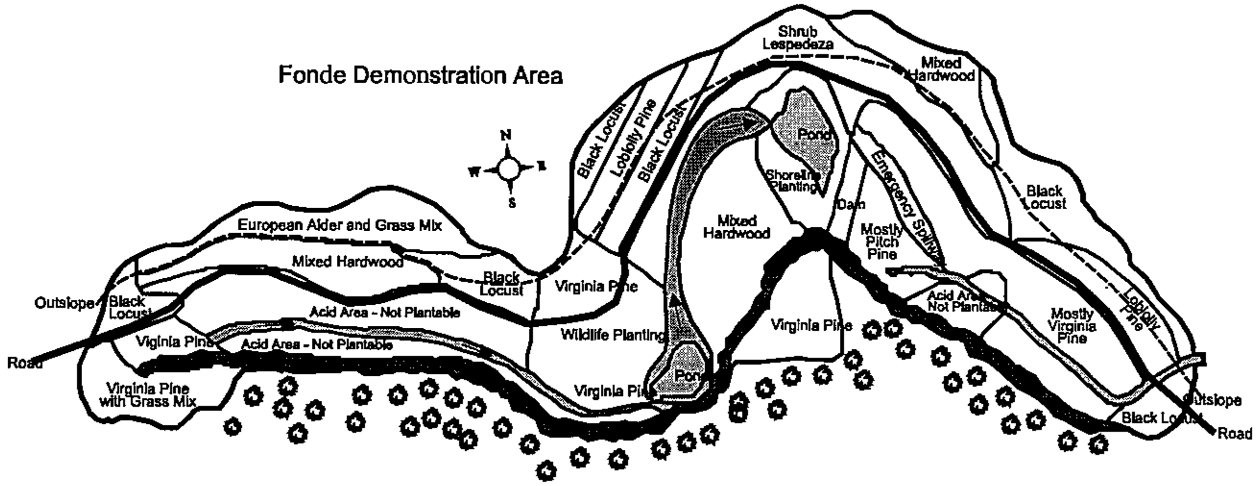

Figure 1. Original design and plantings at the Fonde Surface Mine Demonstration Area.

wildlife use. Additionally, European black alder with a grass mix and shrub lespedeza were also planted in the north center of the mine near the siltation pond. European black alder and the leguminous species were selected for soil enrichment because of their nitrogen-fixing capabilities. Two Virginia pine plantations were planted above the highwall; one with and one without a grass mix. Finally, shoreline plantings were made around the lower siltation pond. Extremely acid areas were not planted. Eighteen woody species of 31 reclamation taxa were planted at Fonde (Table 1).

A later study determined that based upon chemistry and parent material, Fonde mine spoils could be grouped into five parent material types (Table 2), and the development of these soils was described by Wade and Halverson (1988). These five soil types are not evenly correlated with plantation types and all plantations contained two or more of the soils described. Two papers have described development and productivity of the planted forest on the Fonde mine (Wade et al. 1986; Wade and Vogel 1988).

Table 1. Woody reclamation species planted at the Fonde Surface Mine Demonstration Area on bench (B), outslope (O) and highwall (H) habitats.

Species	B	O	H
Pinus virginiana	+	+	+
Pinus rigida	+	+	-
Pinus taeda	+	+	-
Liriodendron tulipifera	+	+	-
Quercus alba	+	+	-
Quercus rubra	+	+	-
Acer saccharum	+	+	-
Acer rubrum	+	+	-
Platanus occidentalis	+	+	-
Robinia pseudoacacia	+	+	-
Fraxinus pensylvanica	+	+	-
**Alnus glutinosa*	+	+	-
**Rosa multiflora*	+	+	-
**Lespedeza bicolor*	+	+	-
Populus deltoides	+	-	-
Populus grandidentata	+	-	-
Magnolia acuminata	+	-	-
**Ligustrum sinense*	+	-	-
Total: 18 present 1990:	18	14	1

+ Surviving planted species
- Not planted
* Exotic species

Methods

The Inventory

Woody plants were collected throughout the 1989 and 1990 growing seasons from early spring through late autumn. Voucher specimens were prepared according to standard herbarium procedures and deposited in the Berea College Herbarium (BEREA). Plant nomenclature was later standardized using Gleason and Cronquist (1991). Relative abundance for each species was determined by field reconnaissance and observations within each habitat on the mine. The abundance categories are the same as used by Thompson et al. (1996):

Rare (R) = 1-5 individuals or isolated colonies
Infrequent (I) = 6-25 individuals or colonies
Occasional (O) = 26-100 individuals or colonies
Frequent (F) = 100s of individuals or colonies, and
Abundant (A) = 1000s of individuals or colonies.

Canopy and subcanopy trees greater than 10 cm were counted and measured at breast height (dbh) in twelve 5 x 30-m transects, 4 in each type of the plantations: mixed hardwoods, mixed pine, and black locust. To determine the influence of tree plantings and substrate on woody species invasion, we inventoried 36 1 x 30-m transects, 12 in each of the three plantation types.

To determine the effects of tree plantings and mine soil on tree seedlings and herbaceous vegetation, we randomly located ten 1-m^2 plots within each of the three replicate plantings of mixed hardwoods, mixed pine, and black locust. We also located 10 plots in the unplanted area near the dam in the center of the mine. At each plot we recorded the overhanging canopy tree species, mine soil type, number of plant species, and percent cover of each species found within each plot.

Statistical Analysis

Independent variables for statistical analyses are plantation type, overstory tree species, and mine soil type based on parent material. The dependent variables are number of tree saplings per 1x30 m transect, number of tree species per transect, 1-m^2 plot total cover and species richness, and number of tree species and total number of tree seedling per 1-m^2 plot. These were checked for normality and equal variance, and total cover was square-root transformed.

Tree plantation replications were not set together in uniform blocks of one planting type each. Therefore we pooled tree, sapling, shrub, and vine transect data by

Table 2. Soil materials and chemistry at the Fonde surface mine in 1988. A horizon values are set over those of the C-B horizon.

Mine Soil Parent Materials	pH	N %	P ppm	K ppm	Ca ppm	Mg ppm	Mn ppm	exch. acid.
1. mixed old soils, sandstone	4.00	0.67	19.5	52.7	205	100	131	6.72
& coal waste	4.10	0.45	2.2	25.4	14	19	24	7.52
2. yellow clay	5.87	0.25	9.4	75.2	398	302	148	0.22
	4.97	0.07	3.3	46.4	81	140	61	2.43
3. orange shale & clay,	4.12	0.19	5.9	49.3	113	17	138	9.94
scattered fine coal	4.02	0.15	2.2	35.6	19	9	18	10.39
4. sandstone, gray shale &	4.51	0.26	12.5	42.6	209	93	118	3.75
clay	4.58	0.22	7.1	38.6	98	80	53	4.13
5. coal frags., gray & black	4.53	0.44	15.1	48.7	317	118	139	4.37
shale, yellow clay	4.45	0.28	7.3	33.4	65	70	33	4.90

pH in 1:1 H_2O
N by Kjeldahl
P, K, Ca, Mg, Mn by 0.1 N HCl extract

plantation type for one-way analysis of variance (ANOVA) of total numbers of trees and individual species per transect.

The 1-m^2 plots in the three plantation types occurred under the canopies of 14 different tree species, however, only plots under Virginia pine, red maple, yellow poplar and in the open area were sufficiently numerous ($n \geq 5$) to allow ANOVA of canopy effects on ground flora total cover and richness. Effects of overstory species on percent cover, total species richness and log number of tree seedlings were analyzed using ANOVA followed by Tukey's means test. Number of tree species in 1-m^2 plots was analyzed using Kruskal-Wallis ANOVA on ranks followed by Dunn's method of all possible comparisons.

Sufficient m^2 plots ($n \geq 5$) were available on soil 4 (Table 2) to allow one-way ANOVA test of overstory tree species effects on herbaceous cover and species richness. Because of differences in soil distributions under different tree species, the effects of soils on cover and richness were tested separately by one-way ANOVA under yellow poplar, pine, and red maple. We also used a two-way ANOVA using data from m^2 plots on mine soils 2 and 4 under yellow poplar and Virginia pine to test for soil-tree canopy interaction effects on cover and species richness.

Results

Site Description

During the 24-year post-mining period, the highwall wasted gradually from a 90° angle to an approximately 45° angle of repose. Two areas "too acid to plant" at the west and east ends of the mine remained largely barren although a few Virginia pine, red maple, black gum (*Nyssa sylvatica*) and sourwood (*Oxydendrum arboreum*) had become established upon them. Most mine soils had developed an A horizon with a discernable C-B horizon. There was little evidence of soil compaction due to grading. Soils on the mine were predominantly loam and silt loams with clay loam and sandy clay loam textures in a few areas. Overall, the mine soils were texturally and chemically similar to the unmined soils but there was more variation among the mine soils (Wade and Halverson, 1988). The old haul road passed though the mine from east to west and was still disturbed occasionally by 4-wheel drive traffic.

The Woody Flora

After 25 years, the woody flora of the Fonde Surface Mine Demonstration Area consisted of 70 species in 53 genera from 34 families (Table 3). The annotated species list includes 49 trees, 13 shrubs, and 8 vines of which 7 are exotic woody species. Of the 18 planted woody species, all remained on the mine (Table 1).

Table 3. Annotated list of woody species at the Fonde Surface Mine Demonstration Area.

PINOPHYTA (Conifers)
Cupressaceae (Cypress Family)
Juniperus virginiana L. Eastern Red Cedar. Tree. 1 a, b, c, e; 2 a, b, c, e=I.
Pinaceae (Pine Family)
o*Pinus rigida* P. Mill. Pitch Pine. Tree. 1 b, c; 2 b, c=F.
o*P. taeda* L. Loblolly Pine. Tree. 1 b, c, g; 2 b, c=F.
o*P. virginiana* P. Mill. Virginia Pine. Tree. 1 a, b, c, d, e, f, g; 2 a, b, c, d; 3 a, b=A.
Tsuga canadensis (L.) Carr. Eastern Hemlock. Tree. 1 a, b; 2 b, f. Rare.

MAGNOLIOPHYTA (Flowering Plants)
Aceraceae (Maple Family)
o*Acer rubrum* L. Red Maple. Tree. 1 a, b, c, d, e f; 2 a, c, d, f; 3 a, b=A.
o*A. saccharum* Marsh. Sugar Maple. Tree. 1 a, b, c, d, e; 2 a, b; 3 a=O.
Anacardiaceae (Sumac Family)
Rhus copallinum L. Dwarf Sumac. Tree. 1 b, c, e, f; 2 c=I.
R. glabra L. Smooth Sumac. Tree. 1 b, c, g, f; 2 c; 3 a=O.
Toxicodendron radicans (L.) Kuntze. Poison Ivy. Woody vine. 1 a, b, c, d, g; 2 a, b, g; 3 a=F.
Betulaceae (Birch Family)
+**Alnus glutinosa* (L.) Gaertn. European Black Alder. Tree. 1 a, c, d, e; 2 d, f; 3 a=F.
Betula lenta L. Sweet Birch. Tree. 1 a, b, c, d; 2 a, c; 3 a=O.
B. nigra L. River Birch. Tree. 1 c, d; 3 a=I.
Carpinus caroliniana Walt. Hornbeam. Tree. 1 a, c; 2 a, c, g; 3 a=I.
Bignoniaceae (Crossvine Family)
**Paulownia tomentosa* (Thunb.) Steud. Chinese Paulownia. Tree. 2 a; 3 a=R.
Caprifoliaceae (Honeysuckle Family)
**Lonicera japonica* Thunb. Japanese Honeysuckle. Woody vine. 1 a, b, c, d, g; 2 b=O.
Sambucus canadensis L. Common Elderberry. Shrub. 1 a, b, c, d, f; 2 a, e; 3 a=O.
Viburnum acerifolium L. Maple-leaf Viburnum. Shrub. 1 b; 2 g; 3 a=I.
V. prunifolium L. Black Haw. Tree. 1 a=R.
Celastraceae (Staff Tree Family)
Euonymus americanus L. Strawberry-bush. Shrub. 2 a, c, g; 3 a=R.
Clusiaceae (Mangosteen Family)
Hypericum stragalum Adams & Robs. St. Andrew's-cross. Suffrutescent Shrub. 1 b, c=R.
Cornaceae (Dogwood Family)
Cornus florida L. Flowering Dogwood. Tree. 1 a, b, c, d, f, g; 2 a, b, c; 3 a=F.
Nyssa sylvatica Marsh. Blackgum. Tree. 1 a, b, c, f; 2 a, b, c; 3 a=F.
Ebenaceae (Persimmon Family)
Diospyros virginiana L. Persimmon. Tree. 1 b, d, f=R.
Ericaceae (Heath Family)
Kalmia latifolia L. Mountain Laurel. Shrub. 1 a, b, c; 2 b; 3 a, b=O.
Oxydendrum arboreum (L.) DC. Sourwood. Tree. 1 a, b, c, d, e, f; 2 a, b, c; 3 a=A.
Vaccinium pallidum Ait. Hillside Blueberry. Shrub. 1 b, c ; 2 b; 3 a, b=I.
Fabaceae (Pea Family)
Cercis canadensis L. Eastern Redbud. Tree. 1 a, b, c, d; 2 a, b, c; 3 a=O.
+**Lespedeza bicolor* Turcz. Bicolor Lespedeza. Shrub. 1 a, b, e, f; 2 a, d, e; 3 a=F.
o*Robinia pseudoacacia* L. Black Locust. Tree. 1 a, b, c, d, e; 2 a, b, c; 3 a=F.
Fagaceae (Beech Family)
Fagus grandifolia Ehrh. American Beech. Tree. 1 a, b, c, d, e; 2 a, c; 3 a=F.
o*Quercus alba* L. White Oak. Tree. 1 a, b, c, f; 2 a, b, c=I.
Q. coccinea Muench. Scarlet Oak. Tree. 1 a; 2 a=R.

Q. prinus L. Chestnut Oak. Tree. 1 a, b, c, f; 2 a, b; 3 a=I.
o*Q. rubra* L. Northern Red Oak. Tree. 1 a, b, c, d; 2 a, b=O.
Q. velutina Lam. Black Oak. Tree. 1 a, b, c, d, e; 2 a, b, c; 3 a=O.

Hamameliaceae (Witch Hazel Family)
Liquidambar styraciflua L. Sweet Gum. Tree. 1 a, b, c, d; 2 a; 3 a=O.

Hippocastanaceae (Buckeye Family)
Aesculus flava Soland. Yellow Buckeye. Tree. 1 a; 2 a=R.

Hydrangeaceae (Hydrangea Family)
Hydrangea arborescens L. Wild Hydrangea. Shrub. 1 a, c, d, g; 2 a, d; 3 a=O.

Juglandaceae (Walnut Family)
Carya cordiformis (Wang.) K. Koch. Bitternut Hickory. Tree. 1 a, c; 2 a, c=I.
C. glabra (P. Mill.) Sweet. Smooth Pignut Hickory. Tree. 1 a, b, c, d, g; 2 a, b, c=O.
C. ovalis (Wang.) Sarg. Sweet Pignut Hickory. Tree. 1 a, b; 2 a=R.
C. ovata (P. Mill.) K. Koch. Shagbark Hickory. Tree. 1 a, b, c; 2 a=I.
Juglans nigra L. Black Walnut. Tree. 1 a, c; 2 a, c, f=R.

Lauraceae (Laurel Family)
Sassafras albidum (Nutt.) Nees. White Sassafras. Tree. 1 a, b, c, f; 2 a, c; 3 a=O.

Magnoliaceae (Magnolia Family)
o*Liriodendron tulipifera* L. Yellow Poplar. Tree. 1 a, b, c, d, e; 2 a, b, c; 3 a=F.
o*Magnolia acuminata* (L.) L. Cucumber-tree. Tree. 1 a=R.

Menispermaceae (Moonseed Family)
Menispermum canadense L. Canada Moonseed. Woody vine. 1 a; 2 a, f=I.

Oleaceae (Olive Family)
Fraxinus americana L. White Ash. Tree. 1 a, b, c, g; 2 a, c; 3 a=O.
o*F. pensylvanica* Marsh. Green Ash. Tree. 1 a, c; 2 a=I.
+**Ligustrum sinense* Lour. Chinese Privet. Shrub. 2 f=R.

Platanaceae (Sycamore Family)
o*Platanus occidentalis* L. American Sycamore. Tree. 1 a, b, c, d, f; 2 a, b, c=O.

Pyrolaceae (Wintergreen Family)
Chimaphila maculata (L.) Pursh. Spotted Wintergreen. Suffrutescent shrub. 1 a, b, f, g; 2 b=I.

Ranunculaceae (Buttercup Family)
Clematis virginiana L. Virgin's Bower. Woody vine. 1 a, c, g, e, f; 3 a=I.

Rhamnaceae (Buckthorn Family)
Rhamnus caroliniana Walt. Carolina Buckthorn. Tree. 1 a; 2 a, g=R.

Rosaceae (Rose Family)
Amelanchier laevis Wieg. Smooth Serviceberry. Tree. 1 a, c; 2 a, c; 3 a=I.
Prunus serotina Ehrh. Wild Black Cherry. Tree. 1 a, b, c, g; 2 a, c; 3 a=O.
+* *Rosa multiflora* Thunb. Multiflora Rose. Shrub. 1 a, c, d, e, f, g; 2 a, c; 3 a=O.
Spiraea tomentosa L. Pink Hardtack. Shrub. 1 e; 3 a=I.

Rubiaceae (Madder Family)
Mitchella repens L. Partridge-berry. Suffrutescent Shrub. 1 a, b; 2 b=I.

Salicaceae (Willow Family)
o*Populus deltoides* Marsh. Eastern Cottonwood. Tree. 1 a; 3 a=I.
o*P. grandidentata* Michx. Big-tooth Aspen. Tree. 1 a; 3 a=I.

Simaroubaceae (Quassia Family)
**Ailanthus altissima* (P. Mill.) Swingle. Tree of Heaven. Tree. 1 a, b, e, f; 3 a=I.

Smilacaceae (Greenbrier Family)
Smilax glauca Walt. Glaucous Greenbrier. Woody vine. 1 a, b, c, d; 2 a, b, c, d; 3 a=F.
S. rotundifolia L. Common Greenbrier. Woody vine. 1 a, b, c, d, g; 2 a, b, c; 3 a, b=F.

Ulmaceae (Elm Family)
Ulmus alata Michx. Winged Elm. Tree. 2 b; 3 a, b=R.
U. rubra Muhl. Red Elm. Tree. 1 a, b, d, f; 2 a, c=O.

Tiliaceae (Basswood Family)
Tilia americana L. American Basswood. Tree. 1 a; 2 d; 3 a=R.

Vitaceae (Grape family)

Parthenocissus quinquefolia (L.) Planch. Virginia Creeper. Woody vine. 1 a, b, c, d, f, g; 2 a, b, c, f; 3 a=F.

Vitis aestivalis Michx. Summer Grape. Woody vine. 1 a, b, c, d, f ; 2 a, b, c, d; 3 a=O.

Families:	34	Genera: 53	Total Species:	70

Code: (+) Introduced, planted taxa; (o) Native planted taxa; (*) Naturalized taxa.

Life Form: Suffrutescent shrub; Shrub; Woody vine; Tree.

Relative Abundance Values: R = Rare; I = Infrequent; O = Occasional; F = Frequent; A = Abundant

Habitats:

1=Bench and Plant Communities

a) Mixed hardwoods	f) Wildlife plantings
b) Virginia pine	g) Loblolly pine
c) Black locust	h) Wetland (siltation pond shoreline, spillway, and drains)
d) European alder and grass mix	i) Ruderal (coal haul road and hemp plots)
e) Shrub lespedeza	j) Acid non-planted acid areas

2=Outslope and Plant Communities

a) Mixed hardwoods	d) European alder and grass mix
b) Virginia pine	e) Shrub lespedeza
c) Black locust	f) Wildlife plantings

3=Highwall and Plant Communities

a) Non-planted highwall	b) Virginia pine and grass mix

Forest Plantation Composition

Mixed Hardwoods Plantations. The mixed hardwoods plantations contained a total of 57 woody species (Table 3). Red maple, northern red oak, and yellow poplar were dominant with American sycamore, black locust, Virginia pine, and white oak as important trees. The most important tree species in the sapling layer were red maple, sourwood, yellow poplar, sugar maple, red oak, and white ash (*Fraxinus americana*). In terms of survival, the most successful trees planted were red maple, yellow poplar, northern red oak and American sycamore. Each of these species had canopy trees in the 2-3 dm (8-12 inch) size class, and red maple had a few in the 3-4 dm size class (Table 4).

Mixed Pine Plantations. The mixed pine plantations contained a woody flora numbering 47 species (Table 3). Virginia pine dominated the pine plantings although there was a small area of successful loblolly pine outside the sample transects. Red maple and sourwood were very important invading species in the sapling size class. Virginia pine had a modest amount of reproduction in the sapling layer. Bicolor lespedeza spreading from the wildlife plantings was the most numerous shrub. Green briar (*Smilax* spp.) and poison ivy (*Toxicodendron radicans*) were the most important woody vines. The Virginia pine plantation had the greatest amount of wood production as measured by basal area (Table 4).

Black Locust Plantations. The black locust plantations contained 47 woody species (Table 3). Planted black locust trees largely had been replaced by successional red maple with lesser amounts of sourwood, yellow poplar, and American sycamore. Many broken, dead black locust trees, both standing and down, showed the characteristic damage caused by the locust borer (*Megacyllene robiniae*). There were few black locust saplings, and shrubs and vines were unimportant. The black locust planting had the lowest ground layer cover and species richness of all the plantations.

Plantation Effects on Reproduction and Ground-Layer Vegetation

Tree reproduction varied among the plantation types. Black locust, yellow poplar and Virginia pine reproduction and tree species richness in transects varied significantly among the plantation types (ANOVA, $\alpha = 0.05$, Table 5). However, the total number of saplings and the abundance of red maple, sourwood and flowering dogwood were not significantly different among plantation types.

Ground cover percentage in 1-m^2 plots varied significantly among plantation types (ANOVA, $\alpha =$

Table 4. Number of saplings, trees per hectare in 1, 2, and 3 decimeter size classes, and basal area ($m^2\ ha^{-1}$) in the Fonde mixed hardwoods, mixed pine, and black locust plantations. Number of shrubs and vines per hectare follows tree data. This is based on twelve 5 x 30-m transects for trees $\geq$ 1 dm, and 36 1 x 30-m transects for saplings, shrubs, and vines.

	Hardwoods				Mixed Pine				Black Locust				
Species	sap.	1dm	2dm	b.a.	sap.	1dm	2dm	b.a.	sap.	1dm	2dm	3dm	b.a.
Trees													
Acer rubrum	1750	233	83	6.81	1972	0	17	0.25	2639	267	33	17	6.33
Liriodendron tulipifera	639	317	17	5.15	83	0	0	0	250	183	17	0	4.17
Quercus rubra	306	233	83	6.81	28	0	7	0.25	83	17	0	0	0.29
Platanus occidentalis	194	183	0	2.67	0	33	33	1.89	28	150	33	0	3.55
Oxydendrum arboreum	694	0	0	0	1167	0	0	0	750	0	0	0	0
Acer saccharum	306	0	0	0	0	0	0	0	56	0	0	0	0
Fraxinus americana	222	0	0	0	0	0	0	0	28	0	0	0	0
Cornus florida	167	0	0	0	94	0	0	0	56	0	0	0	0
Liquidambar styraciflua	83	0	0	0	0	0	0	0	28	0	17	0	0.87
Quercus alba	28	17	0	0.28	0	0	0	0	0	0	0	0	0
Prunus serotina	28	0	0	0	0	0	0	0	0	0	0	0	0
Cercis canadensis	28	0	0	0	0	0	0	0	0	0	0	0	0
Pinus virginiana	0	67	0	0.49	444	1450	150	32.10	0	0	0	0	0
Quercus velutina	0	0	0	0	56	0	0	0	0	0	0	0	0
Robinia pseudoacacia	56	67	0	1.38	0	0	0	0	139	100	33	0	3.14
Betula lenta	83	0	0	0	28	0	0	0	167	33	0	0	0.46
Nyssa sylvatica	28	0	0	0	0	0	0	0	111	0	0	0	0
Ulmus rubra	0	0	0	0	0	0	0	0	111	0	0	0	0
Totals	4612	1117	183	23.59	3872	1483	207	34.49	4446	750	133	17	18.81
Shrubs													
Lespedeza bicolor	694				222				0				
Rosa multiflora	28				56				0				
Sambucus canadensis	28				28				0				
Hydrangea arborescens	28				0				0				
Rhus copallinum	0				28				0				
Totals	778				334				0				
Vines													
Parthenocissus quinquefolia	56				167				56				
Vitis aestivalis	28				0				0				
Lonicera japonica	28				28				0				
Smilax rotundifolia	0				333				111				
Toxicodendron radicans	17				222				0				
Smilax glauca	0				83				28				
Totals	129				833				195				

0.05, Table 6). When all plots were pooled by plantation type, open areas were found to have the highest percent ground cover and black locust plantations had the lowest percent cover. Species richness (herbaceous plus woody species) was significantly lowest in black locust plantations. The number of tree species and tree seedlings was significantly greatest under mixed pine, and lowest in black locust and the open area.

Canopy Species and Soils Effects on Ground-Layer Vegetation

Percent ground cover (including herbs and tree seedlings), and to a lesser extent species richness, varied significantly among soils when tested separately under three different tree species: Virginia pine, red maple, and yellow poplar (ANOVA, $\alpha = 0.05$, Table 7). Mine soil

Table 5. Success of tree reproduction (saplings present in 1x30 m transects) among plantations. There is no control for soil quality within plantations. Means followed by the same letter are not significantly different (Tukey's means test after ANOVA, $\alpha = 0.05$).

Planting	Saplings per Transect	Species Richness	ACER	ROBP	LIRT	CORF	OXYA	PINV
hardwoods	13.8 a	5.3 a	5.3 a	0.2 ab	1.9 a	0.5 a	2.1 a	0.0 b
mixed pine	11.9 a	3.4 b	5.9 a	0.0 b	0.3 b	0.6 a	3.5 a	1.3 a
black locust	13.3 a	3.6 b	7.9 a	0.4 a	0.8 ab	0.2 a	2.3 a	0.0 b

ACER = *Acer rubrum*, red maple
ROBP = *Robinia pseudoacacia*, black locust
LIRT = *Liriodendron tulipifera*, yellow poplar
CORF = *Cornus florida*, flowering dogwood
OXYA = *Oxydendrum arboreum*, sourwood
PINV = *Pinus virginiana*, Virginia pine

Table 6. Ground cover, total species richness, number of tree species, and number of tree seedlings in 1-m² plots. Means followed by the same letter are not significantly different.

Plantation	Cover (%)[1]	# Species[1]	# Tree Species[2]	# Tree Seedlings[1]
hardwoods	30.1 b	7.3 a	1.8 b	12.8 b
mixed pine	32.3 b	6.3 a	3.1 a	24.9 a
black locust	8.7 c	3.2 b	1.5 bc	4.0 c
open area	91.1 a	8.5 a	0.5 c	1.9 c

[1] Tukey's means test after ANOVA, $\alpha = 0.05$.
[2] Dunn's Method all pairwise comparisons ($\alpha = 0.05$) after Kruskal-Wallis ANOVA on ranks.

Table 7. Relationship of understory 1-m² plot mean cover and species richness to canopy tree species on spoil 4. Means followed by the same letter are not significantly different (Tukey's means test after ANOVA, $\alpha = 0.05$).

Overstory Species[1]	Cover (%)	Species Richness
Virginia pine (30)	22.2 c	6.1 bc
red maple (30)	20.7 bc	4.8 c
yellow poplar (30)	44.6 b	8.2 ab
open area (10)	91.1 a	8.5 a

[1] Number of plots is in parentheses.

2 had the highest percent cover and it had the highest calcium and mean pH value (Table 2). Mine soils 1 and 5, containing coal waste, had the least ground cover.

Percent ground cover varied significantly among soils under pine, red maple and yellow poplar, but soil type significantly affected species richness only under yellow poplar (ANOVA, $\alpha = 0.05$, Table 8).

Table 8. Relationship of understory 1-m² plot mean cover and species richness to spoil quality under tree species. Means followed by the same letter are not significantly different (Tukey's means test after ANOVA, $\alpha = 0.05$).

Overstory Species	Mine Spoil[1]	Cover (%)	Species Richness
Virginia pine	2 (7)	51.2 a	7.4 a
	3 (5)	44.8 ab	6.2 a
	4 (16)	22.2 b	6.1 a
red maple	1 (5)	4.4 b	2.0 a
	4 (5)	20.7 a	4.8 a
	5 (17)	4.2 b	2.9 a
yellow poplar	2 (5)	67.2 a	10.4 a
	4 (9)	44.6 b	8.2 b

[1] Number of plots is in parentheses.

The two-way ANOVA of m^2 plot data for soil type, tree canopy, and interaction effects on cover and species richness had to be limited to data from mine soil types 2 and 4 under yellow poplar and Virginia pine. This test also showed soil type and canopy effects to be significant, but interaction effects were not ($\alpha = 0.05$).

Discussion

Forest succession is an active process on the mine as evidenced by the large number of successfully invading woody species as well as the successful reproduction of many of the planted tree species. The Fonde mine is in a middle stage of secondary succession similar to other pre-SMCRA mines in eastern Kentucky (Thompson and Wade 1991; Thompson et al. 1996). The different plantations types varied in the numbers and success of woody species volunteering in them. The mixed hardwoods plantations species richness was 21 percent greater than that of the mixed pine and black locust plantations. SØrenson's index of similarity (IS_S) of the woody species lists in the three plantation types ranged 0.73 to 0.81 with a mean of 0.78 (Magurran 1988).

Our study has not been the only one to find that forest plantation types differentially influence succession on surface mines. Ashby (1964) described differences in succession under adjacent black locust and shortleaf pine plantations in Illinois after 24 years. SØrenson's index of similarity for woody species in those plantations was 0.80, but IS_S was 0.30 for the herbaceous species lists. Ashby characterized the understory of the black locust stand as typical of mesic forested areas of the region but vegetation of the pine stands was more typical of old fields in Illinois. Few individual volunteer canopy trees were found in the black locust stand, but the pine site was more open and had more established canopy trees of other species. A later study of coal mined sites in the U.S. Mid-west also found that the species of planted trees on mines had a differential influence on invading tree species (Ashby et al. 1980).

Increases in tree species richness at Fonde over time paralleled that found by Holl and Cairns (1994) who studied reclaimed coal mines of various ages (<5 to 30 years) in Virginia. These mines had been reclaimed by various methods as reclamation regulations had changed over time. Herb species richness and cover in plots were not significantly different from plots in unmined deciduous forest, but tree species richness and cover increased with time.

Virginia pine has relatively low reproduction in its own plantations compared to the number of red maple and sourwood saplings. The presence of Virginia pine in the hardwoods plantation canopy probably is due to early invasion from offsite seed sources. Virginia pine has also been the first successful invader of the two most acid areas on the mine. The pine plantations had few species in the sapling layer except for red maple and sourwood that were successful volunteers in all three plantation types. The seedling data (Table 6) suggest that in recent years the pine plantations provided the best environment for tree seedling establishment (perhaps not for persistence) and black locust plantations and the open area provided poor habitats for tree invasion.

The black locust plantings were least successful in some ways. Planted trees show extensive damage by the locust borer that probably led to stand breakup during ice storms. This released other pioneering hardwoods like red maple, yellow poplar, and sycamore. Black locust's role in nitrogen fixation is important in ecosystem development, but its tenure here and at Log Mountain (Thompson et al.1996) has been limited. Ashby et al. (1985) discussed the role and importance of borer attack on black locust in opening stand canopies and allowing development of successional forest vegetation. Where timber production is desired on reclaimed lands, it seems that desired commercial species should be planted at the same time as black locust so that they may inherit the canopy position when black locust breaks up. Otherwise the wide-spreading, fast growing red maple may dominate the new forest.

Red maple is the most important invader on the mine. It dominates the sapling layer in all plantation types (Table 4). Understory ground cover and species richness were lowest under red maple and Virginia pine (Table 7). The competitive success of red maple may be due to wind seed dispersal, deep shade under its canopy, thick litter layer inhibiting seed germination or establishment, and very high root density in surface soils – all of which we observed at Fonde. Because of its ability to inhibit invasion by other species, it might be desirable to omit red maple from reclamation plantings where high diversity and future commercial production of other species are desired.

The open grassy area is in the perennial herb, shrub, and vine stage of succession. No trees of sapling or greater size were present and only a few seedlings were found in the 1-m^2 plots. Overall, tree seed rain on the mine has been more than sufficient to drive forest succession in the tree plantations. The lack of effective tree invasion of the open area may indicate that the initial tree plantations facilitated invasion by other tree species.

Ashby et al. (1980) noted that unplanted mine land around experimental tree plots in the Midwest had few invading trees. It may well be that planting trees on mined land is necessary to accelerate the invasion and establishment of other tree species.

The effects of tree plantation type on vegetation development were confounded by canopy tree species and mine soils. Red maple was important in both the black locust and mixed hardwoods plantings. Mine soils varied greatly within the plantations, and different plantations also had some of the same soils in common. There were marked differences in m^2 plot percent ground cover, and to a lesser extent species richness, among the open area and under individual tree canopies of yellow poplar, Virginia pine, and red maple. Light availability is the simplest explanation for this, but species richness in the open area plots had not led to richness in tree species able to reach sapling size during the first 25 years.

Because of high variability in the mine soils, we cannot make generalizations on the effects of mine soils at the scale of the plantations. Marked differences in cover, and to a lesser extent species richness, were manifested among some of the mine soils when we controlled for overstory species. Mine soil 2 with its relatively higher pH and calcium content (Table2) supported the greatest percent ground cover under Virginia pine and yellow poplar (Table 7). Based on soil pH, Ca, and Mg, and cover under Virginia pine and yellow poplar, we can say that mine soil 2 was better for plant growth than soil 4. Species richness under yellow poplar also supports this. There is less difference in chemistry and vegetation response among the group of soils 1, 3,4, and 5.

It is not difficult for propagules of many woody species to reach the mined area. We found some original forest soils mixed into some of the mine soils. Forest topsoil seed banks are important in ecosystem recovery after severe disturbances (Leck et al. 1989) and seed banks have been intentionally used to introduce native species to highly disturbed areas and mine spoils (Farmer et al. 1982; Wade 1989; Wade and Thompson 1990). Propagules of many species undoubtedly washed or fell onto the mine as the highwall wasted and deposited forest soil from above onto the mined area. Many of the woody species have wind-dispersed seeds and we have observed signs of violent wind storms including a circular blow-down of pine on the mine. Seed-eating birds can introduce species that pass intact through the intestine, especially if perches such as trees and shrubs are present (McClanahan and Wolfe, 1993). Off-road vehicles may bring seed onto the mine in mud from other locations. Continually available areas for recruitment on the Fonde mine include the wasting highwall, the moderating acid areas, and the still-disturbed road on the mine. Vegetation cover is still incomplete in many vegetated areas as succession continues. Considering the number of habitats available and the proximity of seed sources, it would be more remarkable if vegetation of the Fonde mine was less diverse.

After the creation of physical habitat diversity through grading and water management on the mine, establishment of different plantation types increased diversity of vegetation and successional processes. The mere planting of trees accelerated successful invasion by other tree species – unplanted areas remained largely treeless. Pine plantations provided year-round canopy cover. Mixed hardwoods and black locust plantations provided seasonal cover but they have differed in persistence of the original plantings and successional trajectory. Black locust also undoubtedly added a significant amount of nitrogen to the mine soils. When we add individual species effects and diversity related to differences in soils, we find a forest with high diversity in terms of function (wildlife habitat, potential products, etc.), composition, structure, and differentiation (beta-diversity) across space and time.

From the successive tree invader species, the mine vegetation overall is progressing toward a mixed mesophytic broadleaf-coniferous forest type.

Why are studies of Fonde and other mines reclaimed by antiquated methods important? Post-SMCRA mines are reclaimed using methods that have not been proved over long time periods. Post-SMCRA mines have characteristics of low species richness, dense herbaceous ground covers, water-exporting topography, and soils often compacted by grading. Pre-SMCRA mines were reclaimed by a variety of methods, some of which approach these modern techniques -- their age allows study of long-term effects. Reclamation results on pre-SMCRA sites shows what kinds of diversity can be achieved on mined lands. Thus, development of vegetation on the Fonde Surface Mine Demonstration Area and other similar pre-SMCRA reclaimed and inventoried mines can be used for evaluating both biodiversity and reclamation methods on post-SMCRA reclaimed mines.

Summary

The vegetation of the Fonde mine shows that forest vegetation can be reestablished after extreme disturbances in Appalachia. The planting of a diversity of tree species in different community types appears to have promoted a diverse forest vegetation with a high species richness and a diversity of vegetation dynamics on mined land.

Black locust, yellow poplar, and Virginia pine reproduction varied significantly among plantation types at Fonde, and the species of individual canopy trees affected ground layer cover, total species richness, number of tree seedling species, and total number of tree seedlings present. Mine soil quality also affected ground layer cover and total species richness.

Vegetation development on this and other pre-SMCRA reclaimed and inventoried mines can be useful for evaluating reclamation success and biodiversity on post-SMCRA reclaimed mines.

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