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Tree recruitment and growth on 20-year-old, unreclaimed surface mined lands in West Virginia

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Surface mining in West Virginia has disturbed large tracts of forested land. In the 1930s to 1960s, reclamation generally involved replanting of trees on mined sites, but revegetation practices gradually evolved into seeding of forages for erosion control as federal and state laws were enacted in the 1970s. Reforestation of mined lands has recently become an important issue and both federal and state regulatory agencies are returning to forestry as a preferred post-mining land use. This study evaluated tree species recruitment and growth on three, 20-year-old, surface mined areas that were not transplanted with trees. Three transects of 150 m at each site extended across three positions: (1) the flat top after coal removal; (2) the outslope down from the flat top where soil and weathered rock materials had been pushed down the hill; (3) the undisturbed forest. Tree canopy cover and herbaceous cover were determined at 1.5 m intervals along the transect line, and tree density and diameter at breast height were measured for each species located in a plot 2.3 m wide along the line. Soil samples were taken to a depth of 25 cm at 15 m intervals along transects. Soils in all positions generally had loam textures, and soil pH ranged from 4.6 to 6.0 on undisturbed and outslope positions to 6.1 to 6.6 on flat tops. Soils were noticeably thinner and denser on flat tops than in other positions. Undisturbed forests averaged 85% canopy cover and were dominated by tuliptree (*Liriodendron tulipifera* L.), red maple (*Acer rubrum* L.) and sugar maple (*Acer saccharum* Marsh.), with minor contributions from red oak (*Quercus rubrum* L.), black gum (*Nyssa sylvatica* Marsh.), sourwood (*Oxydendrum arboreum* (L) DC), sassafras (*Sassafras variifolium* (Nutt. Nees) and hickory (*Carya spp*.). Outslopes had primarily red maple, black birch, tuliptree, sourwood and black locust (*Robinia pseudo-acacia* L.). Flat areas were dominated by herbaceous cover with red maple and black locust being the dominant trees. Areas seeded with herbaceous plants showed low numbers and cover by trees, while areas not seeded with herbaceous plants were almost as heavily covered by trees as undisturbed areas. New guidelines are being developed to aid survival and growth of mid- to late-successional trees on newly reclaimed sites. These include

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less compaction of soil materials and seeding less aggressive forage species where trees will be planted.

Keywords: Forestry; Mining; Reclamation; Succession

1. Introduction

Coal mining has disturbed approximately 2.4 million ha (6 million acres) since 1930 in the United States. In Appalachia, the vast majority of land mined for coal was originally forest land. Laws were passed in Ohio, Pennsylvania and West Virginia during the late 1930s and 1940s requiring mine operators to register with the state and pay bonds to ensure some reclamation would take place after mining. Reclamation prescribed in these early laws directed soil, subsoil and overburden (the geologic material overlying the coal) be used to refill the excavated area. Backfilling and levelling of the land was specified, and then trees and shrubs were to be planted in the regraded areas.

Reports of surface mine revegetation with trees began in the 1940s. Black locust (*Robinia pseudo-acacia* L.) was the most extensively studied and successful species (Brown and Tryon 1960). Other species such as autumn olive (*Elaeagnus umbellata* Thumb.), Virginia pine (*Pinus virginiana* Mill.), red pine (*P. resinosa* Ait.) and white pine (*Pinus strobus* L.) grew well in many of those early studies (Chapman 1947, Tryon 1952, Potter *et al.* 1955, Brown 1962). Hardwoods like oaks (*Quercus spp.*) and cherry (*Prunus spp.*) failed to grow, usually because such trees encountered rodent damage.

During the ensuing decades, laws and regulations governing surface mine reclamation in the eastern USA evolved into seeding grasses and legumes rather than establishing trees. The rationale for this change was that forage species controlled erosion, provided a quick economic return to land owners through hay sales or grazing of livestock, and was aesthetically pleasing. These laws hindered tree planting because these laws allowed partial release of reclamation bonds as soon as the ground cover requirement was met. The cover requirement could be achieved by herbaceous plants, and planting of woody plants became an added reclamation expense to mining companies. In addition, the herbaceous cover competed with planted tree seedlings, resulting in high tree mortality.

Under management, most mined areas in the eastern USA are capable of highly productive, sustained forage crops. However without management, reclaimed hay and pasture land ultimately returns to forest. Woody species will become established by natural secondary succession if given the opportunity and sufficient time, especially where the reclaimed site is surrounded by native forest. However, establishment of a forest of commercially valuable trees by natural succession on these reclaimed pastures is extremely slow and can sometimes take several decades to develop, if it does at all. The succession process is well known on disturbed forest land in West Virginia, and progresses through a series of pioneer and early-successional species such as red maple (*Acer rubrum* L.), black locust, black birch (*Betula lenta* L.), black cherry (*Prunus serotina* Ehrh.), autumn olive, crabapple (*Prunus coronaria* L.) and hawthorn (*Crataegus spp.*). Gradually, ash (*Fraxinus spp.*), tuliptree (*Liriodendron tulipifera* L.), sugar maple (*Acer saccharum* Marsh.), oak, hickory (*Carya spp.*), and other mid- to late-successional trees become established in the understory and replace some of the early-successional trees, or at least the plant community is composed of both types of trees. Soil properties, aspect, subsequent disturbance, local climate/weather patterns and wildlife are common factors that could influence the specific species and plant community that will develop on the site.

Most large-scale surface coal operators in southern West Virginia have reclaimed their mined areas with grasses and legumes. Fewer operations have established tree plantings or wildlife habitat plantings. Given the current emphasis on large-scale surface mining in West Virginia's low-sulphur coal fields, coal operators, regulators, the public and scientists are interested in the development of sustainable forests on reclaimed mines. The objective of this study was to identify and determine the size of tree species that naturally colonised surface mine sites after 20 years with no initial tree planting. The trees naturally colonising on disturbed sites may indicate which tree species should be transplanted on these sites and those which have the greatest chance for survival and growth.

2. Materials and methods

2.1 *Site descriptions*

Three sites, which represented the major coal mining areas in southern West Virginia, were selected: (1) the Mynu mine, 23 years since reclamation; (2) the Zapota mine, 22 years since reclamation; and (3) the Amherst mine, 19 years since reclamation (figure 1 and table 1). The three surface mines removed coal from the Kanawha and Allegheny Formations of the Pennsylvanian System. These formations are dominated by the Homewood and Upper Connoquenessing sandstones, and Winifrede shales. Overburden composition can generally be described as 60% sandstone and 40% shale.

The Mynu Mine is located approximately 48 km (30 miles) southeast of Charleston, WV, near the town of Eskdale, on the Kanawha and Boone County line (figure 1). Mining activities of various companies have been ongoing at this site since the early 1960s. Coal seams mined at the site are the No. 5 Block and No. 6 Block (Lower and Middle Kittanning). Much of this area had been previously mined, leaving old highwalls and unreclaimed areas. The current mining operation near this site is owned by Catenary Coal Company, and the company has been mining by mountaintop mining processes.

The specific site studied as a part of this project was mined by Mynu Coal Company between 1971 and 1975. The mountain ridge had been removed to expose the coal and a flat bench

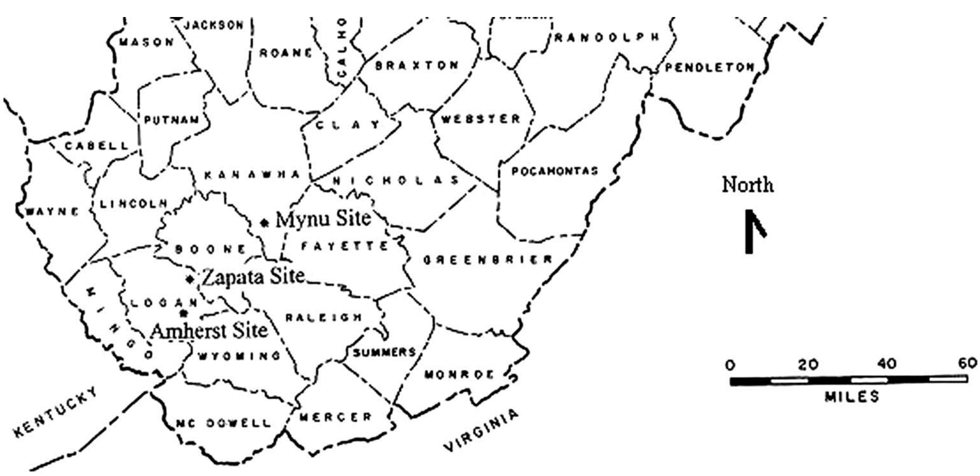

Figure 1. Site location in southern West Virginia for tree growth on surface mines study.

Table 1. Location and description of mountaintop removal surface mines sampled for vegetation characteristics in southern West Virginia.

Characteristic	Mynu	Zapota	Amherst
County location	Kanawha/Boone	Boone/Logan	Logan
Nearest town	Eskdale, WV	Sharples, WV	Yolyn, WV
Coal seams mined	No. 5 Block, No. 6 Block	Stockton, No. 5 Block	Coalburg, Stockton, No. 5 Block
Mining method	Mountaintop Rem.	Mountaintop Rem.	Mountaintop Rem.
Mining dates	1971 – 1975	1973 – 1976	1974 – 1979
Post-mining topography	Flattened top and outslope	Flattened top, valley fill and outslope	Flattened top, valley fill and outslope
Years since reclamation	23	22	19
Revegetation species	Grasses, legumes and black locust	Grasses, legumes and black locust	Grasses, legumes and black locust

was left on the top of the ridge. According to mining personnel, mining equipment at the time included front-end loaders, bulldozers and trucks. The flat top was seeded with a low rate of 20 kg/ha of grasses and legumes, and with 0.25 kg/ha of black locust seed. The outslope was not seeded.

The Zapota Mine is located approximately 64 km (40 miles) south of Charleston, WV, near the town of Sharples, on the Boone and Logan County line. Mining activities began here in 1965. The coal seams mined at the site are the Stockton and No. 5 Block. The latest operation was called the Dal-Tex mine, owned by Arch Coal, and mountaintop removal was the mining technique.

The site studied for this project was mined by Zapota Coal Company (Beebait Branch site) between 1973 and 1976. A flat top was left and the overburden and soil material had been pushed over the side onto the outslope. Mining equipment used here comprised front-end loaders, bulldozers and trucks. Like Mynu, the flat top was seeded with 15 – 20 kg/ha of grasses and legumes and 0.25 kg/ha of black locust seed. The outslope was not seeded.

The Amherst Mine is located approximately 24 km (15 miles) southeast of Logan, WV, near the town of Yolyn, in Logan County. Mining activities began in 1970. The coal seams mined at the site are the Coalburg, Stockton and No. 5 Block. The current operation, called Ruffner, is owned by Arch Coal, and the area is being mined by mountaintop removal surface mining methods.

The site studied for this project was mined by Amherst Coal Company (Jordan Fork site) between 1974 and 1979. A gently rolling terrain was left on the top of some of the area, while another portion had a flattened ridge top. Mining equipment used was a BE 295 shovel, front-end loaders (Cat 988) and trucks (Cat 777). Reclamation at the site involved seeding with a mixture of grasses and legumes (30 kg/ha of seed) and 0.25 kg/ha of black locust seed. Here, the flat top and outslope were seeded with forages.

2.2 *Sampling methods*

At each of the three sites, a point was randomly located at the edge of the flat top and the outslope. At that point, a major compass direction was chosen that was most perpendicular to the direction of the edge and transects were established along that compass direction. We were careful to establish transects on north-facing aspects (NW to NE compass directions).

Each transect extended 50 m on the flat top, 50 m onto the outslope and 50 m into undisturbed woodland. Each site had three 150 m transects.

Along each transect, total canopy cover was estimated (as a percentage) by taking a vertical sighting with a 2.5 cm diameter tube at a height of 2 m every 1.5 m along the transect line (100 sightings/transect or 300 per site). Tree species in the canopy were identified and cover values were also estimated within the sighting tube. Tree density and diameter at breast height (dbh) were determined in plots measuring 2.3 m wide along transect lines in each position (providing an area of about 345 m^2/transect or 1035 m^2/site). All trees found rooted in the plot were identified by species and their dbh determined. Herbaceous cover was determined in 0.25 m^2 quadrats placed on the right-hand side of each transect at 5 m intervals (90 quadrats/site). Total herbaceous cover was estimated, and grasses and legumes contributing to the total herbaceous cover were identified. Plant species names followed the nomenclature of Strausbaugh and Core (1977).

Soil samples were extracted to a depth of 25 cm at 15 m intervals along each transect in each position. Large rocks were discarded and only the <2 mm fraction was analysed for texture by feel, soil pH (pH probe on 1:1 soil paste), cation exchange capacity, base saturation, and phosphorus, potassium and calcium concentrations (Mehlich III extraction). After soil samples were taken, an estimate of soil density and thickness was made by digging further down to a depth of 50 cm at the same locations. On flat tops, soil thickness was often found to be less than 50 cm and the soil tended to be quite dense and hard. These measurements were noted on field sheets.

Average vegetation values (canopy cover, herbaceous cover, stem density and basal area) and soil chemical properties were determined for each position along each transect and these values were compared statistically among positions and sites by analysis of variance (ANOVA). Vegetation and soil means were separated by Tukey's Honestly Significant Difference test.

3. Results and discussion

3.1 *Soils*

Soil textures ranged from clay loams to sandy loams, and in general all soils across sites and positions were loams (table 2). Soil pH varied from 5.8 to 6.6 at the Amherst site to 4.6 to 6.1 at the Mynu site. There were clear soil pH differences among sites and positions, with Amherst having the highest pH, and flat top positions showing high pH values. We wondered if these higher pH values on flat tops were a result of liming. Liming of coal mined sites was not a common practice in southern West Virginia since the regulations did not require liming when soil pH was above 5.5. Amherst, having the highest pH of the three sites, also showed undisturbed and outslope positions to be higher in pH than the other two sites, suggesting that the soils and geologic material at the surface of this site had a higher base status than the other two. Most native soils in this region exhibit pH values from 4.8 to 5.8 due to the high precipitation and the weathered nature of these forested soils (Wolf 1994). These low pH values were found at the undisturbed Mynu and Zapota sites, with a slightly higher pH being found at the undisturbed Amherst site. The outslope soils were largely composed of native soil and weathered overburden material that had been pushed off the top of the ridge in order to access the coal. These materials at outslope positions appeared to strongly reflect the characteristics of the weathered rock and soil on the ridge top, while the flat tops had significantly higher pH due to the influence of the underlying unweathered geologic materials. Geologic materials in this region are composed of sandstones and shales, which generally have a pH of >6.0 immediately after exposure. However,

Table 2. Soil properties of three positions (undisturbed, outslope or flat top) on three mountaintop surface mines in southern West Virginia.

	Mynu			Zapota			Amherst		
Parameter	Und[a]	Outs	Flat	Und[a]	Outs	Flat	Und[a]	Outs	Flat
Texture[b]	L	SL	L	CL	CL	L	L	CL	SL
pH[c]	4.6[d]	5.2[c]	6.1[ab]	5.5[bc]	4.9[cd]	6.5[a]	6.0[ab]	5.8[b]	6.6[a]
CEC[d]	15[bcd]	9[de]	13[cd]	18[ab]	20[a]	12[cd]	11[de]	16[abc]	7[e]
Base Sat.	4[e]	21[de]	78[ab]	32[d]	15[de]	95[a]	70[bc]	56[c]	88[ab]
Phosphorus[e]	0.1[f]	0.1	0.1	0.2	0.1	0.3	0.2	0.4	0.2
Potassium[e]	0.1[f]	0.1	0.1	0.3	0.1	0.2	0.3	0.2	0.1
Calcium[e]	0.3[e]	0.8[de]	1.9[c]	1.7[c]	1.2[cd]	5.2[a]	6.2[a]	3.3[b]	1.5[cd]
Soil thickness[g]	> 50	> 50	46[a]	> 50	> 50	23[b]	> 50	> 50	41[a]

[a]Und = Undisturbed position; Outs = Outslope position; Flat = Flat top position.
[b]L = Loam; SL = Sandy Loam; CL = Clay Loam.
[c]Values within rows with the same letter are not significantly different at the $p < 0.05$ level.
[d]CEC = cation exchange capacity in cmol/kg.
[e]Measured in cmol/kg.
[f]Values within rows are not significantly different.
[g]Average soil thickness in cm.

the pH of these materials decreases as the base cations from broken shales are weathered and leached from the new soil profile (Thomas *et al.* 2001).

Cation exchange capacity varied widely and showed no trends for specific sites or positions (table 2). Base saturation followed the same trend mentioned above for soil pH. No significant differences were found for phosphorus and potassium concentrations, but calcium was significantly different. The calcium data are somewhat hard to interpret. Trees in eastern USA forests are known to recycle calcium at high rates (Johnson and Todd 1990, Lawrence *et al.* 1995) and thereby deposit calcium on the surface with annual leaf litter. The forest at the undisturbed Amherst site had high levels of calcium in the soil, which may be due to uptake of calcium from lower depths and then deposition of the calcium at the surface through leaves. However, the other two undisturbed forests have significantly lower levels of calcium. It was expected that the flat top positions, where base cations may have been released due to geologic materials containing calcium being brought to the surface, would show the highest concentrations. This occurred at Mynu and Zapota, but not at Amherst. The Amherst site had the highest calcium values, which again indicates the higher base status of the geologic materials and soils on the site.

Soil thickness was variable across the sites but clearly soil was the thinnest on the flat top positions (table 2). Zapota had noticeably lower amounts of soil on the flat top with average soil thickness of 23 cm. Six out of nine observation holes, dug to a 50 cm depth or bedrock, were less than 50 cm deep at Zapota. The other two sites also had three holes each where the soil was less than 50 cm deep. In some places, only 5 to 10 cm of soil were found on top of the underlying rock, which was the dense layer under the coal and referred to as the 'pavement'. Digging of the observation holes also confirmed that the most compact and dense soils were located on the flat top positions, compared to less dense soils found on the outslope and undisturbed areas. High amounts of rock fragments were found in all positions and at all sites. In summary, soils at outslope and undisturbed positions were sufficiently deep and loose to aid in tree establishment, and soil pH and other chemical properties were suitable for tree growth. On flat tops, soils were often thin and dense, and tended to be higher in pH, all of which can be detrimental to hardwood tree growth (Torbert and Burger 2000).

3.2 *Tree canopy and herbaceous cover*

Total tree canopy cover for all undisturbed sites was between 84 and 88% (table 3). The outslope positions varied in tree cover from about 70% at Mynu and Zapota to 28% at Amherst. Outslope positions on Amherst had been seeded with grasses and legumes, but not at Mynu and Zapota. Therefore, the seeding of herbaceous plants on Amherst greatly hindered the recruitment of trees in that area. Spoil material had been pushed over the side during mining on Mynu and Zapota, and trees established quickly and grew well in this loose, thick spoil material with no competition from forages. The flat tops on all sites had low amounts of tree canopy cover (varying between 14 and 24%). Because flat tops were seeded with grasses and legumes, trees had a much more difficult time establishing, much like the outslopes at Amherst. The flat tops also had less soil material at the surface that tended to be compacted.

Herbaceous cover was almost opposite to tree cover. On undisturbed positions of all three sites and outslopes of Mynu and Zapota, herbaceous cover varied between 14 and 25% (table 3). On the seeded flat tops and the Amherst outslope, herbaceous cover was greater than 65%. Herbaceous cover of greater than 60% hinders tree establishment (King and Skousen 2003).

3.3 *Tree density and size*

Average stem density of all trees on undisturbed positions varied from 1758 stems/ha at Amherst to 3663 stems/ha at Mynu (table 3). Amherst had significantly lower numbers than the other two sites in all positions, which might be influenced by the higher soil pH at this site. Fewer trees were found on flat positions than on the other positions at all sites, while the highest stem densities overall were found on outslopes at Mynu and Zapota. The mining process, where an abundance of soil and rock materials from the ridge top were pushed over the side in a loose, uncompacted manner and no seeding of forages to present competition, resulted in an excellent opportunity for adjacent tree species to invade and colonise this area. Therefore, both outslope positions, especially Zapota, were covered by numerous small trees. Total basal area of all trees for each site and position is also shown in table 3, and it is noteworthy that the Mynu and Zapota outslope positions had very high tree basal areas in spite of the numerous small trees.

A better understanding of the size of trees on these sites can be discerned by dividing the trees into two size categories (table 4). The undisturbed positions at Mynu and Zapota had around the same number of trees greater than 2.5 cm dbh, but the average dbh of trees in this size category

Table 3. Total tree canopy cover, herbaceous cover, stem density, and basal area on three different positions (undisturbed, outslope, or flat top) for three mountaintop surface mines in southern West Virginia.

	Mynu			Zapota			Amherst		
Parameter	Und[a]	Outs	Flat	Und[a]	Outs	Flat	Und[a]	Outs	Flat
Tree canopy cover (%)[b]	85[a]	70[b]	24[c]	88[a]	72[b]	15[c]	84[a]	28[c]	14[c]
Herbaceous cover (%)	22[b]	14[b]	67[a]	27[b]	25[b]	68[a]	17[b]	85[a]	78[a]
Total stem density (stems/ha)	3663[bc]	4539[b]	2919[c]	3063[c]	6780[a]	1652[d]	1758[d]	1225[d]	795[d]
Total basal area (m^2/ha)	11[b]	18[a]	10[b]	17[a]	17[a]	2[c]	13[b]	3[c]	2[c]

[a]Und = Undisturbed position; Outs = Outslope position; Flat = Flat top position.

[b]Values within rows with the same letter are not significantly different at the $p < 0.05$ level.

Table 4. Stem density of trees >2.5 cm diameter at breast height (dbh) and <2.5 cm dbh with corresponding basal areas at three different positions (undisturbed, outslope or flat top) for three mountaintop surface mines in southern West Virginia.

	Mynu			Zapota			Amherst		
Parameter	Und[a]	Outs	Flat	Und[a]	Outs	Flat	Und[a]	Outs	Flat
Stem density >2.5 cm dbh (stems/ha)[b]	1768[c]	3478[b]	1744[c]	1867[c]	5259[a]	1106[cd]	1042[cd]	765[d]	449[d]
Average dbh of stems >2.5dbh (cm)	8.9[ab]	8.1[ab]	8.6[ab]	10.7[a]	6.4[bc]	4.8[c]	12.9[a]	7.6[ab]	6.6[bc]
Basal area of stems >2.5dbh (m^2/ha)	11[b]	18[a]	10[b]	17[a]	17[a]	2[c]	13[b]	3[c]	2[c]
Stem density <2.5 cm dbh (stems/ha)	1895[a]	1061[b]	1175[b]	1196[b]	1521[ab]	546[c]	716[bc]	460[c]	346[c]
Average dbh of stems <2.5 dbh (cm)[c]	0.38	1.12	1.27	0.74	0.99	1.27	0.66	0.86	0.61
Basal area of stems <2.5dbh (m^2/ha)[c]	0.02	0.10	0.15	0.05	0.12	0.07	0.03	0.03	0.01

[a]Und = Undisturbed position; Outs = Outslope position; Flat = Flat top position.
[b]Values within rows with the same letter are not significantly different at the $p < 0.05$ level.
[c]Values within rows are not significantly different.

was 8.9 cm for Mynu and 10.7 cm at Zapota. This difference in dbh translated into a significant difference in basal area between sites. The undisturbed position at Amherst had fewer trees, but the average dbh of these trees was 12.9 cm, giving a 13 m^2/ha basal area. This indicates a forest with larger trees at Amherst, or simply indicates a different management and forest cutting practice that produced fewer and larger trees. The Mynu and Zapota outslopes had significantly more trees with smaller average stem diameters, while the flat areas on Zapota and Amherst were occupied by fewer and even smaller trees.

The density of trees with stem diameters less than 2.5 cm dbh is also shown in table 4. Surprisingly, undisturbed positions had many small trees in this size category and, in two out of the three cases, had more than corresponding outslope and flat positions. The average stem diameter of understory trees in undisturbed positions was 0.38 cm at Mynu and about 0.70 cm at Zapota and Amherst. The competition for water and light in well-developed forests hinders the establishment of understory trees and keeps the trees that had colonised relatively small. The outslope positions at Mynu and Zapota, as mentioned, had many trees, while the flat positions at Zapota and Amherst had relatively few trees. Of note is the 1.27 cm average size of the smaller tree category at the Mynu and Zapota flat top positions. It suggests that the fewer number of trees in this category are larger than those in this category at other positions, and that these trees are growing at faster rates than those in other positions because of less canopy cover.

3.4 *Tree species composition and size*

The Mynu undisturbed position was dominated by red maple and tuliptree, but also had ten other tree species contributing to the tree community (table 5). The Zapota undisturbed position was dominated by tuliptree, with smaller amounts of sugar maple, pawpaw (*Asimina triloba* (L) Dunae), redbud (*Cercis canadensis* L.), black gum (*Nyssa sylvatica* Marsh.), sourwood (*Oxydendrum arboreum* (L) DC), and sassafras (*Sassafras variifolium* (Nutt.) Nees). The Amherst

Table 5. Stem density (stems/ha) of tree and shrub species over three positions (undisturbed, outslope, or flat top) for three mountaintop surface mines in southern West Virginia.

	Mynu			Zapota			Amherst		
	Und[a]	Outs	Flat	Und	Outs	Flat	Und	Outs	Flat
Box elder								30	
Striped maple	49								30
Red maple	1400	978	617	94	3680	891	501	472	158
Sugar maple	200	42	92	242		30			
Pawpaw				234			30		
Yellow birch				96					
Black birch	168	689	370		62	32		59	
Lespedeza		20							
Hickory								472	
Redbud				531				32	
Dogwood				32	59				
Autumn olive		447						128	104
Hazelnut							32		
Grape	111			32			96		
Tuliptree	790	257		1005	64	30	99	158	59
Magnolia	22								
Laurel									32
Black gum	114	79		158			30		
Sourwood	291	1082	617	237	1679	32	104		99
Paulownia		22						30	
Red pine			62						
Pitch pine		128	499						
Aspen			32						
Black cherry		20	30				59	32	62
White oak			32	30					
Chinq. oak	190	42							
Black oak			62						
Chestnut oak				126					
Red oak				124					
Black locust	44	546	452		1141	637		254	252
Sassafras	304	20		153	62		106	30	
Spicebush							170		
Sumac		20							
Basswood							59		
Hemlock			30						
Elm		20							
TOTALS	**3663**	**4539**	**2919**	**3063**	**6780**	**1652**	**1758**	**1225**	**795**
Total number of species	12	16	12	13	8	6	12	9	9

[a]Und = Undisturbed position; Outs = Outslope position; Flat = Flat top position.

undisturbed position was dominated by red maple and hickory (*Carya spp.*), with small amounts of ten other tree and shrub species, including spicebush (*Lindera benzoin* L.).

Outslope positions at Mynu had a total of 16 different tree and shrub species. The dominant species were sourwood, red maple, black birch, black locust and autumn olive. The very high numbers of trees on outslopes of Zapota were dominated by red maple and smaller amounts of sourwood and black locust. Many of the red maple trees on this site had stem diameters from

1 to 5 cm (average dbh of red maple was 4.3 cm, table 6). Outslopes at Amherst was mostly occupied by red maple, black locust, autumn olive and tuliptree.

On the flat tops of these mountaintop surface mines, red maple and black locust were the most prominent tree species. The Mynu flat position also had many stems of black birch and sourwood (both of which were fairly small trees (average dbh less than 3.3 cm, table 6)) and pines. The pines evidently were planted after forage seeding (but not described in the Mynu mine plan) and they grew well with an average dbh of 25 cm! Zapota flat tops had almost exclusively red maple and black locust. The Amherst flat position simply did not have many trees. This could have been due to competition from the herbaceous cover, the dense soil and high soil pH (tables 1 and 2).

Table 6. Average dbh (cm) of tree and shrub species over three positions (undisturbed, outslope, or flat top) for three mountaintop surface mines in southern West Virginia.

	Mynu			Zapota			Amherst		
	Und[a]	Outs	Flat	Und	Outs	Flat	Und	Outs	Flat
Box elder								5.1	
Striped maple	1.3								6.4
Red maple	0.8	4.3	2.3	5.3	4.3	4.1	9.1	2.3	1.3
Sugar maple	6.6	3.8	1.2	7.9		10.2			
Pawpaw				7.4			0.3		
Yellow birch				2.5					
Black birch	13.5	7.4	2.5		0.2	3.8		11.9	
Lespedeza		1.3							
Hickory								5.1	
Redbud				0.5				10.2	
Dogwood				1.3	1.8				
Autumn olive		3.8						1.0	1.0
Hazelnut							6.4		
Grape	5.1			2.5			5.1		
Tuliptree	10.2	7.9		7.4	13.2	5.1	19.8	2.5	3.8
Magnolia	27.9								
Laurel									0.2
Black gum	6.9	8.9		11.9			11.5		
Sourwood	3.8	4.6	3.3	4.3	2.5	2.5	2.0		1.8
Paulownia		2.5						17.8	
Red pine			25.4						
Pitch pine		16.0	8.6						
Aspen			2.5						
Black cherry		12.7	1.3				8.9	6.4	1.2
White oak			0.2	35.6					
Chinq. oak	0.3	0.8							
Black oak			3.1						
Chestnut oak				10.2					
Red oak				18.5					
Black locust	17.8	10.7	8.1		7.4	4.3		7.4	10.2
Sassafras	1.8	0.3		1.0	5.6		0.2	5.0	
Spicebush							1.5		
Sumac		1.3							
Basswood							13.5		
Hemlock			6.3						
Elm		1.2							

[a]Und = Undisturbed position; Outs = Outslope position; Flat = Flat top position.

3.5 Forest succession

There were substantial differences in species composition among the three sites and positions. The undisturbed sites were dominated by tuliptree, sugar maple and red maple, with minor contributions from red oak, hickory, black gum, black birch and ash tables (4–6). These three dominant species would be expected on north-facing aspects, while more oaks and hickory would be expected on southern aspects. If our transects had been located on more south-facing aspects, it is likely a very different tree community would have been found on undisturbed sites, which would have been reflected in trees found on outslope positions. Outslope positions were dominated by red maple, black birch, tuliptree, sourwood and black locust, which are primarily species represented in the adjacent forest. On flat positions, red maple and black locust were the dominant trees.

Reforestation on outslope positions is progressing much more quickly than on flat top positions. The number of species, density and size of trees on outslopes are generally much greater than on adjacent flat top positions. It appears, based on stem densities alone, that the Mynu and Zapota flat top positions are progressing toward a forest more quickly than the Amherst flat top.

Early forest succession on surface mines is marked by a predominance of black locust, black cherry and red maple, which are adapted to loose, rocky soils common on disturbed sites (Skousen *et al.* 1994). These early-successional species, which colonise and establish quickly on disturbed areas, grow and begin to ameliorate harsh climatic and soil conditions. They reduce soil temperatures by shading the soil, which allows other species to establish in the cooler and wetter soil. They also introduce organic matter into the soil by annual leaf inputs in the autumn. Depending on their ability and success in ameliorating these conditions, other species adapted to less harsh conditions will establish on the site. For example, black locust prepares disturbed areas for the invasion of mid- to late-successional tree species partly because it fixes nitrogen and also dies back after a few decades due to infestation by the locust borer (Skousen *et al.* 1994, Zeleznik and Skousen 1996). In fact, many of the large black locust trees we saw on the flat top and outslope positions were being decimated by the locust borer and many were already dead. The shade, protection and soil building capabilities of black locust were noticeable because many small trees of other species were establishing under the locust canopy. These observations about black locust have been documented by Ashby *et al.* (1985) and Jencks *et al.* (1982) on surface mines. Tree species that colonise after early-successional species are those found in adjacent undisturbed forests. Species that establish on mined lands after initial colonisers are sourwood, black birch, oaks and tuliptree.

The flat top positions are still in an early-successional stage, being dominated by red maple and black locust. It is interesting to note that red maple occurred in all positions including the undisturbed forests at all three sites. Black locust, however, was found on all outslope and flat top positions, but was only documented in the Mynu undisturbed forest. One reason for these positions remaining in an early-succession plant community is primarily due to herbaceous species reseeding themselves annually and providing competition to tree establishment. The soils on these flat tops are also shallow and dense. How quickly the trees are able to overcome flat top site factors such as herbaceous competition and soil compaction remains to be seen. It is clear, however, that on uncompacted outslope positions without seeded herbaceous competition, plant succession is rapid and is, within 20 years, approximating species diversity and growth rates similar to trees on undisturbed soils. In the case of the Mynu and Zapota outslopes, their canopy diversities and total frequencies were similar to those of the adjacent, undisturbed sites.

4. Summary and conclusions

This study compared tree canopy cover and tree species composition, density and stem diameter among flat top, outslope and undisturbed positions on three mountaintop surface mines in southern West Virginia. It is apparent that trees establish on mountaintop surface mines even when trees were not planted on the site originally. The soil medium on outslope positions was composed of overburden and soil originally located on the ridge top before mining, which had been pushed over the side during mining. The soil material on the flat tops largely developed from material left after coal had been removed, and it was shallow and dense. Soil pH and other chemical parameters of these materials were found to be suitable for tree growth. Tree cover was around 70% on the Mynu and Zapota outslope positions, where no seeding with herbaceous forages was conducted, and numerous stems of a variety of species occupied these areas. The flat top positions at all sites and the Amherst outslope had only 15–25% tree cover because these positions had been seeded with grasses and legumes. Obviously, competition from forage species was sufficient to hinder the establishment of trees on these sites, and the lower number of trees was not simply due to thin soils and soil compaction.

Red maple and black locust were the dominant plant species on outslope and flat positions at all three mines. This is a common finding of foresters on surface mine sites. Black locust is one of the first species to colonise disturbed sites (especially when a small amount of seed was included in the seed mix), and it has shown its capacity to establish on these sites either naturally or by direct seedings. Many of the black locust trees we saw on outslope and flat positions on our sites were large trees (>5 cm dbh) being decimated by locust borer. As the large black locust trees die back, the saplings under the canopy will be released. Given sufficient time and depending on their occurrence in adjacent undisturbed forests, more mid- to late-successional trees will become established on these disturbed positions.

The three sites selected for this study had all been mined and reclaimed in the mid to late 1970s. So approximately 20 to 25 years had passed since these sites were seeded or left with minimal plant cover (such as the outslope positions). Reclamation practices at the time pushed topsoil and weathered geologic materials over the side, leaving a loose, thick soil on the outslope; little seeding was carried out. These areas were colonised quickly by adjacent tree species. The flat tops had no soil replaced but were generally seeded with grasses and legumes. Areas seeded with herbaceous plants showed low numbers and cover by trees, while areas not seeded with herbaceous plants were almost as heavily covered by trees as undisturbed areas. It is clear that, even on seeded areas, trees will invade and establish in the grass and legume cover as the cover gradually declines, but the time frame for tree invasion and establishment is less clear, and the movement of mid- to late-successional trees into these sites may take decades.

New policies have recently been adopted by the West Virginia Division of Environmental Protection to encourage and increase the number of disturbed acres planted to trees. Several groups are advocating the planting of commercially valuable trees and establishing guidelines for maximising tree survival and growth (for example, the Appalachian Regional Reforestation Initiative, see http://arri.osmre.gov/fra.htm). Such guidelines include: (1) selecting spoil materials most conducive to tree growth that can be placed on the surface; (2) rough grading these materials to avoid compaction; (3) planting compatible, less competitive, herbaceous ground covers; and (4) planting suitable tree species that have high survival and growth rates and that will provide commercially valuable timber in the future. These guidelines fit well with the results of this study.

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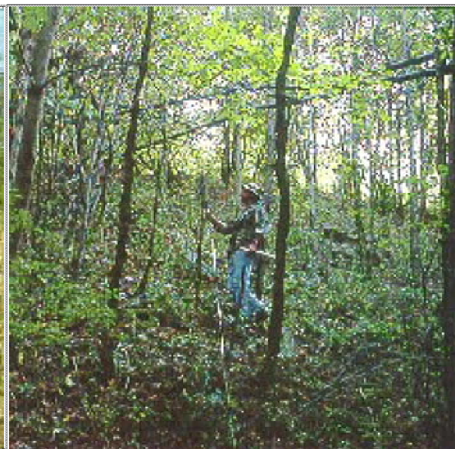
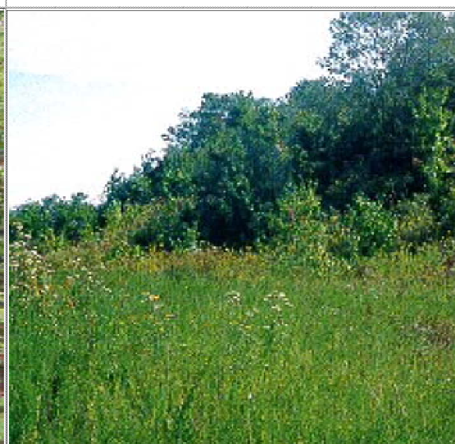
		
A flat top section on the Mynu site showing vigorous herbaceous cover and some trees in the background.	*Part of the outslope area near our transect on the Mynu site.*	*The flat top section on the Zapata mined site covered with grasses, legumes, goldenrod, blackberries and trees.*
		
An undisturbed area adjacent to the Zapata mined site.	*A flat top section on the Amherst site with diverse herbaceous cover.*	*An outslope area on Amherst with large trees and some seeded herbaceous cover.*

The undisturbed area adjacent to the Amherst mined area.