Establishing Hardwood Forests on Appalachian Mine Sites Using the Forestry Reclamation Approach

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Introduction

Soil grading and seeding practices are known to influence forest re-establishment success on Appalachian surface coal mines but much remains to be learned about these influences – especially seeding. The Forestry Reclamation Approach (FRA) specifies soil grading and seeding practices that are intended to aid survival and growth of planted trees and native plant invasion (Burger et al. 2005; Zipper et al. 2011b).

The FRA is comprised of five steps, each of which prescribes a reclamation practice that is based on research findings. The first FRA step is to "*Create a suitable rooting medium for good tree growth that is no less than 4 feet deep and comprised of topsoil, weathered sandstone and/or the best available material*." Native Appalachian trees are sensitive to soil properties, and use of reclamation soil materials that are favorable for tree growth is essential to successful reforestation. Numerous studies have demonstrated that weathered sandstone is a superior growth medium, relative to unweathered spoil materials (Skousen et al. 2011; Zipper et al. 2013). However, use of salvaged soil with residual organic materials is preferred for use in reforestation, when such materials are available (Skousen et al. 2011; Zipper et al. 2013).

The second FRA step is to "*Loosely grade the topsoil or topsoil substitute established in step one to create a non-compacted growth medium*." Compacted soils have limited capacity for water-infiltration and water storage, prevent effective movement and atmospheric exchange of soil gases, and inhibit root growth (Sweigard et al. 2007). Numerous studies have demonstrated that compacted soils inhibit establishment of native trees and reduce tree growth (Andrews et al. 1998; Ashby, 1997; Burger and Evans 2010; Conrad and others 2002; Skousen et al. 2009; Torbert et al. 1988; Torbert and Burger 1990, 1994).

The third FRA step is to "*Use ground covers that are compatible with growing trees*" (Burger et al. 2009). Seeding with fast-growing herbaceous species can hinder survival and growth of planted trees, as fast-growing herbaceous plants compete with young trees for sunlight, soil water, and soil nutrients (Franklin et al. 2012).

The fourth FRA step is to "*Plant two types of trees--early successional species for wildlife and soil stability, and commercially valuable crop trees*" (Davis et al. 2012). While crop trees are intended to grow into commercially valuable timber, wildlife trees are intended to bring birds and other wildlife into the reclamation area for reasons that include their ability to transport and deposit live seed that will facilitate the establishment of volunteer native trees and herbaceous species (Groninger et al. 2007). Appalachian forests are ecosystems with diverse plant communities, and host a range of plant species well beyond those that are purposefully established.

The fifth FRA step is to "*Use proper tree planting techniques*". Guidance documents for the FRA recommend successful execution of all five FRA steps as a means of ensuring reforestation success on Appalachian mine sites.

Goals

Our research goal was to determine how differing combinations of soil selection, grading, and seeding treatments influenced forest tree re-establishment and post-mining plant communities on an Appalachian mine site.

Research Methods

Reclamation Treatments

As a means of learning more about how grading and seeding practices affect plant community development on coal surface mines, an experiment was established on a Virginia surface mine in late 2007 and early 2008. Two grading (conventional smooth grading, vs. loose grading as recommended by the FRA) and three seeding treatments (conventional fast-growing species vs. a tree-compatible seeding mix as recommended by the FRA vs. a "native invasion" seeding of annual ryegrass only; Table 1) were established in all combinations on two experimental sites occupying approximately 12 acres in total. In addition to the species listed in Table 1, *Securigera varia* (crown vetch) occurred as a hydroseeder tank contaminant and was inadvertently seeded in Block 1.

Following application of the grading and seeding treatments, the areas were planted with native trees of 13 species in early 2008 (Table 2).

Table 1. Reclamation areas and their characteristics.

		- - - - - - - Reclamation Area - - - - - - -		
Area feature		Block 1	Block 2	Block 4
Rock type for soil construction		Mix of weathered and unweathered sandstone	Mix of sandstones and siltstones, grayish, mostly unweathered	Hard (likely siliceous) unweathered sandstone, whitish in color
Soil pH in 2008 †		5.7 ± 0.3	7.4 ± 0.2	Not measured
Soluble salts in 2008 †		572 ppm	316 ppm	Not measured
Aspect		South	East	North
Plot Origin		Experimental	Experimental	Operational
Treatments Represented (Treatment Plots)				
Grading	*Seeding*	- - - First Growing Season - - -		
Loose	Annual Ryegrass (AR)	2008	2008	
Loose	Tree Compatible (TC)	2008	2008	2007
Loose	Conventional (CON)	2008	2008	
Smooth	Annual Ryegrass (AR)	2008	2008	
Smooth	Tree Compatible (TC)	2008	2008	
Smooth	Conventional (CON)	2008	2008	2006

† Data from Fields-Johnson et al. (2012)

Table 2. Prescribed seeding and soil amendment application rates.

Seeding Treatment †	Species	Rate (lbs/acre)	(kg/hectare)
Annual Ryegrass (AR)	Annual ryegrass	20	22
Tree Compatible (TC)	Annual ryegrass	20	22
	Perennial ryegrass	10	11
	Timothy	5	6
	Birdsfoot trefoil	5	6
	Ladino clover	3	3
	Weeping Lovegrass	2	2
Conventional (CON)	Rye grain	30	34
	Orchardgrass	20	22
	Perennial ryegrass	10	11
	Korean lespedeza	5	6
	Birdsfoot trefoil	5	6
	Ladino clover	5	6
	Redtop	3	3
	Weeping lovegrass	2	2
Soil Amendments		(lbs/acre)	(kg/hectare)
(all treatments)	Fertilizer Nitrogen	20	22
	Fertilizer Phosphorous	61	68
	Fertilizer Potassium	16	18
	Wood Cellulose Fiber Mulch	1498	1680

Two of the reclamation practices being studied were applied during operations by the mining firm. In late 2005, an area was reclaimed using "smooth grading" and conventional groundcover seeding; this area was planted with native trees in early 2006. An adjacent area with soils constructed with mine spoils that appeared similar was reclaimed the following year using loose grading for soil preparation, followed by seeding with tree- compatible groundcover; and was planted with native trees in early 2007.

Table 3. Prescribed planting rates for trees in Blocks 1 and 2. (Records of Block 4 planting prescriptions cannot be located).

Tree Species	trees/ acre	trees/ hectare	Tree Species	trees/ acre	trees/ hectare
Crop Trees			*Other Trees for Wildlife*		
White Ash	83	205	Gray Dogwood	22	54
White Oak	83	205	Red Mulberry	10	25
Sugar Maple	83	205	Redbud	22	54
Black Cherry	83	205	White Pine	37	91
Red Oak	83	205	Shagbark Hickory	25	62
Chestnut Oak	83	205	*Total Wildlife Trees*	116	286
Black Oak	83	205			
Yellow-poplar	50	124			
Total Crop Trees	631	1559	***All Trees***	***747***	***1,845***

Vegetation sampling

In 2014, plant community status on the two experimental areas (planted with trees in early 2008) and the two operational areas (planted with trees in early 2006 and 2007) was assessed. In spring 2014, all trees growing within sampling plots established on the experimental areas and the operational areas were tallied by species and measured for height and diameter. Five 0.2-ha circular tree-sampling plots were established within each treatment plot. In late summer, 2014, understory vegetation sampling plots were established within the tree-sampling plots, and all vegetation growing within each of those plots was identified by species and by groundcover class. Taxa were classified as “native” or “exotic” referencing USDA (2016). Plant species identified as invasive by Virginia DCR (2013), MAIPC (2016), or KY-EPPC (2013) were defined as invasive for this study. Certain taxa were also identified as noxious weeds while referencing USDA (2016) designations for the lower 48 US states.

Tree community metrics evaluated included numbers of living trees (density); size metrics including basal diameter (D), height (H), and Volume Index (VI, calculated as D^2*H)); and the sum of VIs for all recorded trees within measurement areas calculated as a cumulative biomass indicator (VI sum). Each taxon was classified as native or exotic following USDA (2016). Among recorded taxa was a hybrid of two native species, pitch and loblolly pine (*Pinus rigida x taeda*) which was classified as native. Although classified by USDA (2016) as a shrub, autumn olive (*Elaeagnus umbellata*) was tallied with trees because individuals of this species were among the largest plants recorded.

Four 0.0004-ha circular understory vegetation sampling plots were nested within each tree plot. All vegetation not tallied as trees was considered as understory and identified to the lowest practical taxonomic level, usually species. Visual estimates of groundcover were made for each understory taxon and for overall understory canopy. Total canopy coverage by trees was also estimated for each understory using a spherical densiometer.

In total, 70 tree plots (five per treatment plot) were located and sampled in April (Blocks 1 and 2) and May (Block 4) of 2014. When possible, the locations sampled by Fields-Johnson et al. (2012) were used. In August, 2014, one tree plot in the densely vegetated Block 1 could not be located, so 69 tree plots were sampled for understory vegetation and for soils.

Soil sampling and testing

Soils were sampled in spring 2008, as described by Fields-Johnson et al. (2012). In summer, 2014, soil samples were taken from each understory vegetation sampling plot. The 2014 soil samples were analyzed by the Virginia Tech Soil Testing laboratory (Maguire and Heckendorn 2009).

2.4 Statistical analysis

Data were analyzed using JMP 11.0 (SAS Institute Inc., Cary NC). Three sets of statistical comparisons among tree metrics, understory metrics, and measured soil properties were prepared. Grading and seeding treatment effects were compared within blocks 1 and 2 using a two-factor ANOVA with treatment-plot means (n = 12) and by treating the experimental layout as a split-plot design and setting grading-area split-plots as a random variable. Within Block 4, effects of contrasting treatment combinations were determined using one-way ANOVA with tree plot means (n = 10). Because soil types differed among the three reclamation areas, differences among the three measurement blocks themselves were analyzed using a one-way ANOVA with treatment-plot means (n = 14). Native and exotic species were considered separately when evaluating tree size metrics. Given that innate capacities for growth differ among tree species, native tree size metrics were analyzed using a species-normalized procedure by calculating plot means for each taxon and performing the statistical comparisons using taxon mean values and defining taxon as a random variable. Treatment-plot data representing only single individuals for a given taxon were excluded from this analysis.

Because of reduced statistical power caused by loss of former Block 3, Block 1&2 treatment analyses were interpreted at $\alpha = 0.10$; all other statistical analyses were interpreted at $\alpha = 0.05$. Where effects were found to be significant, mean separations were performed using Tukey's HSD.

Results

Soils

Soil pH did not differ significantly among experimental treatments in Blocks 1&2 but did differ among reclamation areas (Block effects, Figure 1). Mean soil pH was lower in Block 1 (6.2) than in Block 2 (7.4). Within Block 4, soil pH differed between the two treatment plots, with smooth-grading CON-seeding (Smooth/CON) area having a lower mean pH (6.6) than loose-grading TC-seeding (Loose/TC; pH = 7.5). Mean soluble salt concentrations in 2014 were < 140 ppm for all treatment plots and analysis areas and nominally less than levels recorded in 2008 for both Blocks 1 and 2.

Understory

A total of 72 understory taxa were recorded including the eight species prescribed for seeding and the inadvertently seeded crown vetch (Figure 2). Of these taxa, 36 were classified as native, 31 as exotic, and 5 as indeterminate nativity; 25 exotics were classified as invasive, and 11 invasive exotics as noxious. No noxious species were seeded. Four taxa, three natives and the noxious *Lespedeza cuneata*, occurred in all 14 treatment plots, while 35 of the 72 taxa were recorded in 3 or fewer treatment plots.

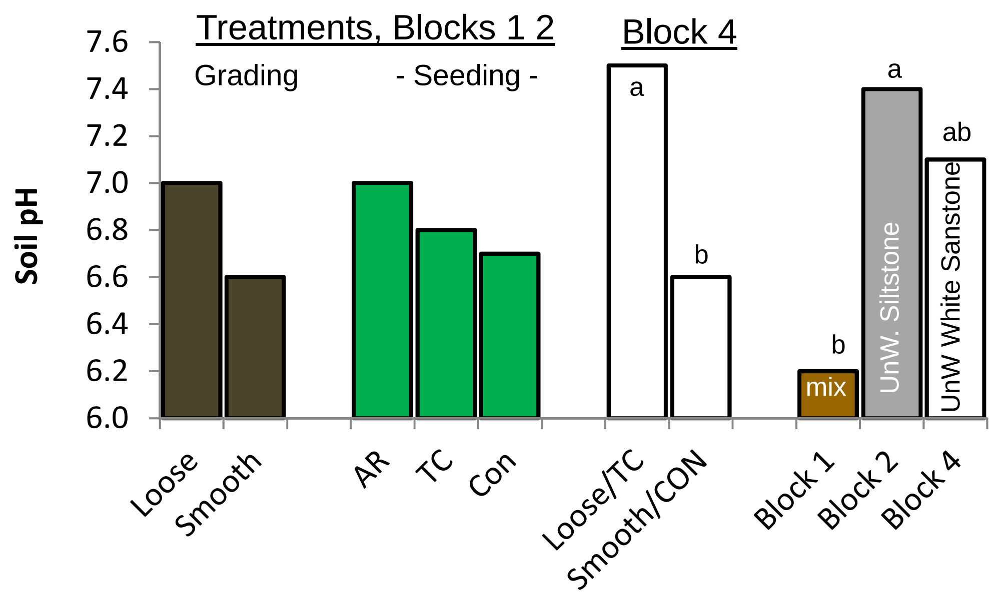

Figure 1. Soil pH on reclamation areas (treatment plot means). Different lower-case letters within groupings indicate statistically significant differences.

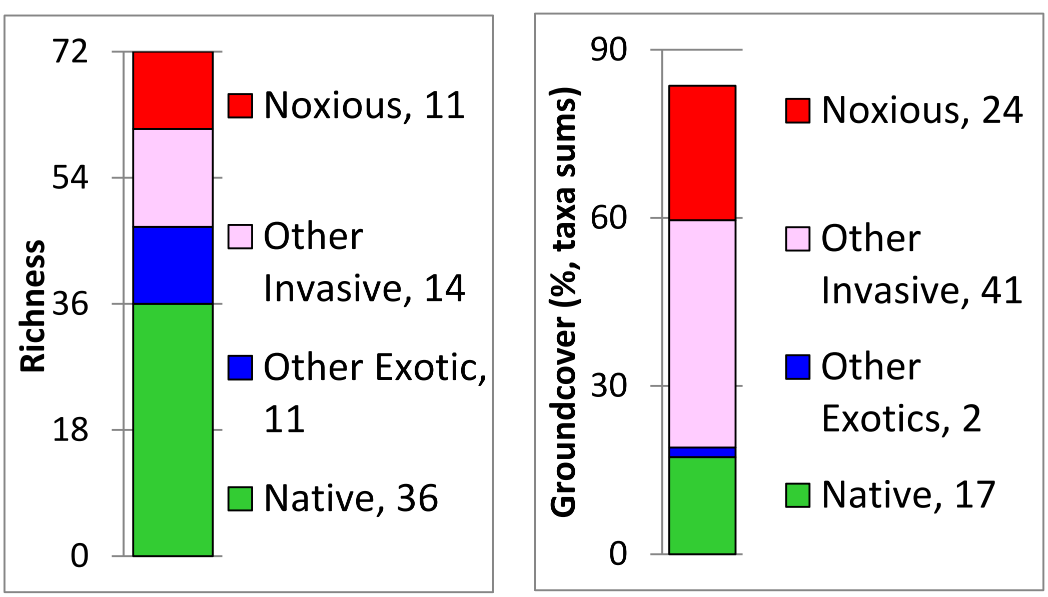

Figure 2. Numbers of taxa recorded (richness) and groundcover over the all measurement areas, by vegetation type. Eight of the species seeded were recorded, providing an average groundcover of 24%. All seeded species are exotic and some are classified as invasive but none are classified as noxious.

A total of 72 understory taxa were recorded. Native taxa (36) constituted half of the 72 observed taxa but provided less groundcover than noxious and invasive taxa (Figure 2). Seeded taxa provided < 50% of cumulative groundcover for all assessment areas except Block 4 Smooth/CON. Within Block 4, overall understory groundcover was greater for Smooth/CON (76.9%) than for Loose/TC (49.9%). Within Blocks 1&2, cumulative native-taxa groundcover was greater for AR than for CON seeding, and cumulative invasive-taxa groundcover was greater for CON than for AR seeding; and cumulative understory groundcover for invasive taxa was greater for CON seeding than for AR seeding (data not shown). Several differences for cumulative groundcover were evident among Blocks: Seeded taxa provided greater groundcover in Block 4 than in Block 2; native taxa provided greater groundcover in Block 1 than in Block 2; and noxious taxa provided greater groundcover within Block 2 than Block 1. On Block 1. Plant community differences related to groundcover seeding remained evident visually in spring 2014, more than six years after seeding (Figure 3).

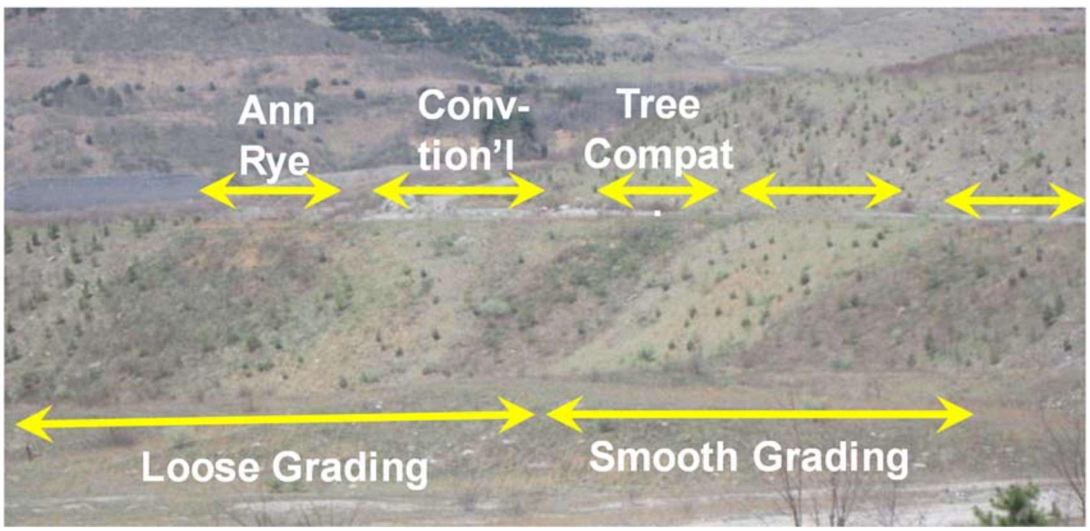

Figure 3. An annotated photograph of Block 1 showing five of the six experimental treatment combinations. The photograph was taken in April 2014.

Trees:

In total, 25 taxa (22 natives and 3 exotics) were recorded as trees. Mean native-tree richness values for treatment plots ranged from 11 to 17 and averaged 14. Mean native-tree richness was greater in Blocks 4 and 1 than in Block 2. Native-tree density within treatment plots ranged from 370 to 2600 trees ha^{-1} and averaged 1452 ha^{-1}. As with richness, native-tree density was greater in Blocks 1 and 4 (2122 and 1625 trees ha^{-1}, respectively) than in Block 2 (724 trees ha^{-1}).

Native-tree basal diameters averaged 2.1 cm while heights averaged 1.4 m and ranged from 0.8 m to 2.5 m when calculated as treatment-plot means (Figure 4). Mean basal diameters, heights, and volume indices were greater for native trees in TC- and AR-seeded areas than in CON-seeded areas of Blocks 1&2 (data not shown); and were greater in Block 1 than in Block 2 (Figure 4). Native trees' VI sum was greater in Blocks 1 and 4 than in Block 2 (0.8 m^3 ha^{-1}).

For exotic trees, treatment-plot mean density ranged from zero (three plots, one in each Block) to 110 trees ha^{-1} (smooth grading, AR seeding, Block 2) and averaged 34 trees ha^{-1}. Of the 48 exotic trees recorded, 42 were of a single species, autumn olive, and 37 occurred within Block 2.

Trees of most species were taller in Block 1 than in Blocks 2 and 4 (Figure 5). Mean heights of trees for most planted species averaged more than 2 m in Block 1, and less than 1 m in Block 2.

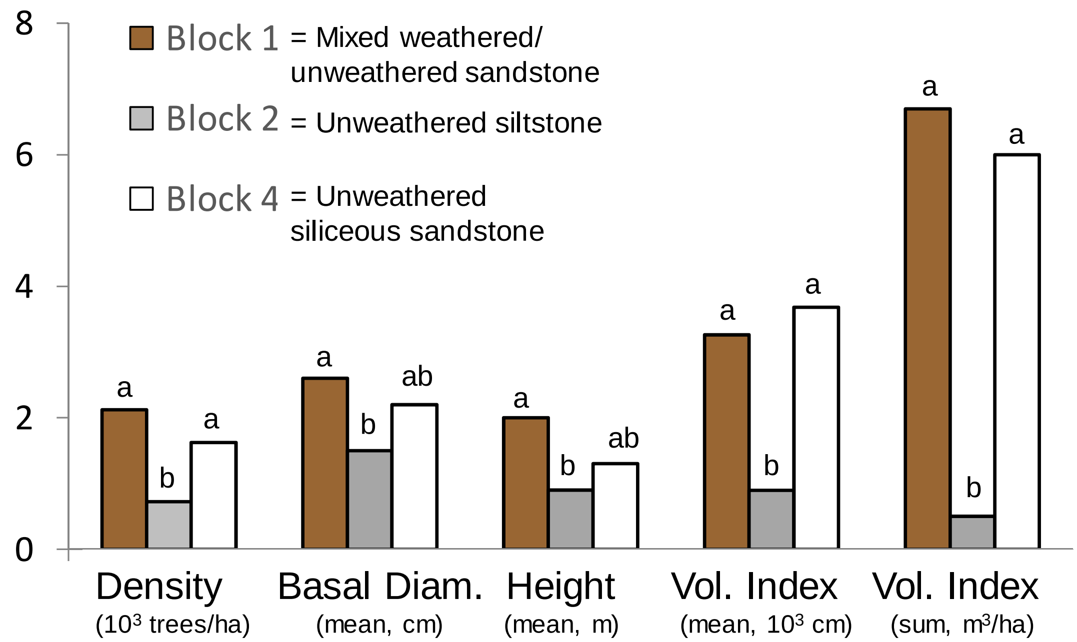

Figure 4. Variation of native tree density and growth metrics among reclamation areas. Data are treatment-plot means.

Discussion

Observed Differences

Clear plant-community differences among reclamation areas were observed. Within Blocks 1&2, native trees were larger in AR- and TC-seeded areas than in CON-seeded areas. Prior research has found that seeding reforestation areas with highly competitive groundcovers, such as those that are often seeded for conventional reclamation, suppresses growth of planted trees (Burger et al. 2008). Our results support those earlier findings

Many prior studies have found that soil compaction causes reduced survival and growth of planted trees (Andrews et al. 1998; Ashby 1997; Burger and Evans 2010; Conrad and others 2002; Skousen et al. 2009; Torbert et al. 1988; Torbert and Burger 1990, 1994). However, such results are not present here. Because negative effects of soil compaction of tree survival and growth have been so well documented elsewhere, we can only conclude that the smooth grading treatment, as applied on the steep slopes of this mine site, failed to compact the soil. The mining firm had been employing loose-grading operationally prior to this experiment. Regardless of this finding, avoidance of soil compaction should be considered as essential to reforestation success.

Sharp differences among plant community metrics were detected when analyzing for Block effects, presumably as a result of soil-property differences. Block 1 had more and larger native trees, and more understory groundcover by native taxa than Block 2; while many tree- and understory metrics were at intermediate levels in Block 4. These patterns are consistent with expectations, given the nature of the mine soils present and findings by prior research. Numerous studies have found mine soils constructed from weathered spoils to be more favorable to native Appalachian plants, including forest trees, than are soils constructed from unweathered spoils (Sena et al. 2015; Skousen et al. 2009, 2011; Zipper et al. 2013).

Recruitment influenced plant communities in all reclamation areas. Most understory groundcover throughout was provided by non-seeded taxa. All native understory groundcover was recruited, as none was planted. Recruitment also appears to have influenced tree communities in Blocks 1 and 2. Sourwood (*Oxydendrum arboretum)*, an early successional species was not planted but was found growing on Block 1. Three planted species (gray dogwood, red mulberry, and ash) were recorded with greater frequencies in Block 1 than would be expected based on prescribed planting rates, suggesting in-situ regeneration (gray dogwood) and, perhaps, off-site recruitment. Across all reclamation areas, approximately half (~46%) of cumulative understory groundcover was provided by exotic invasive taxa that were not seeded.

At the treatment plot level, native understory groundcover corresponds with tree-canopy groundcover with native-tree volume index. Reclamation areas with greater tree canopy tend to have more native understory groundcover than do areas lacking such tree canopy. These findings suggest that establishing native trees under conditions that allow survival and growth can aid the recruitment of native understory species on reclamation areas. This finding is not surprising given that many of the region's native species occur in forested areas, while many of the invasive exotics that are frequently on mines are light-demanding and grow well in full sunlight.

Assessment: Observing Differences among Reclamation Areas

Following the planned data analyses, *post hoc* assessment areas were defined to aid understanding of plant community patterns (Figures 5 and 6). It is clear that the plant communities of Blocks 1 and 2 are very different from one another, and that seeding practices also appear to have influenced both tree and understory communities within both areas. Block 4 tree communities also differ from those of Blocks 1 and 2. Although the mean VI sums recorded for native trees were similar for Blocks 4 and 1, species compositions differ as black locust (*R. psuedoacacia*) is a major component in Block 4; while oaks (*Quercus* spp.), generally a dominant late-successional taxon in area forests, are more prominent in Block 1. Black locust is an early successional N-fixing tree species that establishes and grows well on Appalachian coal surface mines; however, the species' growth rates often slow as it matures, and black locust is a minor component (~1% of mature trees) in Appalachian mixed mesophytic forests (Burns and Hokala 1990) which occur near the study area. Tree communities also differ between the two treatment areas of Block 4, with greater VI sums recorded for black locust in the Smooth/TC treatment area and for two non-oak crop-tree species (black cherry and ash) in Loose/CON.

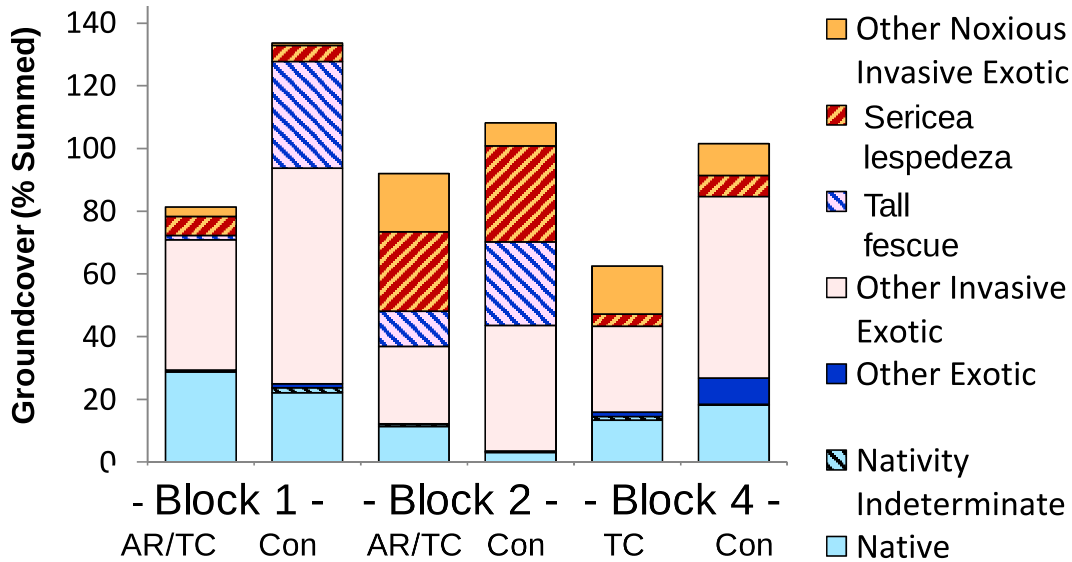

Figure 5. Cumulative understory groundcover metrics by vegetation type for assessment areas (AR/ TC are annual rye and tree compatible seeding areas, and CON are conventional seeding areas).

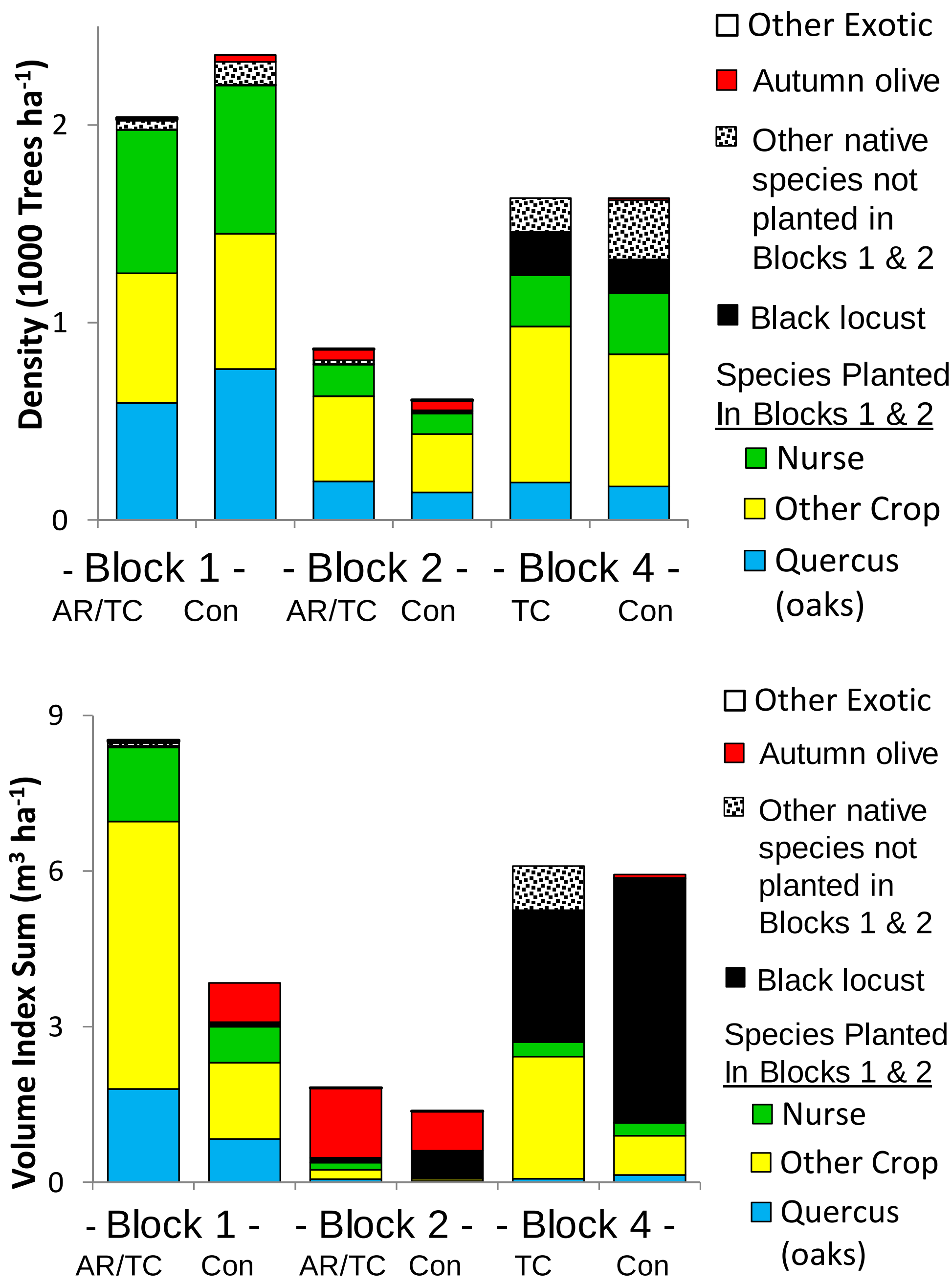

Figure 6. Tree density (top) and tree volume (lower), and understory groundcover (low) metrics by vegetation type for assessment areas (AR/ TC are annual rye and tree compatible seeding areas, and CON are conventional seeding areas). "Crop" and "Nurse" refer to tree species planted in Blocks 1 and 2, as per Table 3.

In Block 1, the use of weathered spoils has produced soils with moderately acidic pHs that are similar to those occurring in the natural environment, and the plant-community appears to be developing towards a resemblance of natural forest conditions. Even within those areas that received AR and TC seedings, however, full restoration of native plant communities is not guaranteed because certain exotic species present (including sericea lespedeza and autumn olive) are able to persist in forest understories if tree canopies are not fully closed. Nonetheless, the plant communities present appear to be on a development path toward a structure resembling native forest.

In contrast, non-native plants are dominant woody species and in the understory in Block 2 which was reclaimed using alkaline siltstone spoils. Autumn olive can form dense and persistent canopies that inhibit establishment of native trees (Evans et al. 2013). Two other exotic trees observed in this area, tree of heaven (*Ailanthus altissima)* and Paulownia (*Paulownia tomentosa*), have also been observed on other Appalachian mine sites (Evans et al. 2013; Zipper et al. 2012). Two plant species present in the understory, sericea lespedeza and tall fescue, are widespread on mine sites in the Appalachian coalfield (Zipper et al. 2011a).

The plant community in Block 4 appears as transitional and on a developmental trajectory that is difficult to predict. While soil conditions and understory vegetation do not appear as major obstacles to establishment of planted trees, the soil conditions created by unweathered mine spoils are clearly not favorable to most native Appalachian trees' growth. On Block 4 areas, the primary exception is black locust (*R. pseudoacacia)*, which has a relatively open canopy, fixes atmospheric nitrogen, and is subject to premature decline. These conditions indicate the plant community in Block 4 as likely subject to invasion by additional and may be more dynamic than in other areas.

Conclusions

The Forestry Reclamation Approach (FRA) is a method for re-establishing forest plants on Appalachian coal mines through reclamation. The first three steps describe procedures for preparing the mine site in advance of tree planting. This research has demonstrated that both Step 1 (use of materials that are suitable for forest trees) and Step 3 (seeding with tree-compatible groundcovers) influence forest tree reestablishment success.

Seeding with tree-compatible groundcovers is a practice that can be applied on Appalachian mines for little (if any) additional cost relative to conventional seeding. Reclamation areas seeded with tree-compatible groundcovers had larger native trees, and areas seeded with annual ryegrass only (which also provides minimal competition) had more understory groundcover provided by native plant species than areas seeded conventionally.

The largest observed differences among plant communities occurred in response to differences among mine spoils used for soil construction. An area with soils constructed from partially weathered sandstone spoils, as recommended by the FRA, had more and larger trees of species that are characteristic of the region's mature forests than areas with soils constructed from unweathered mine spoils.

Successful reforestation of Appalachian mine sites requires execution of all five steps of the FRA. On this mine site, planted trees established and grew well where both seeding practices and soil materials were applied as recommended by the FRA. However, on the alkaline siltstone spoils described by FRA guidance as unfavorable for reforestation, planted trees established and grew poorly and exotic taxa dominated plant communities; these results occurred in response unfavorable soil conditions even where loose grading and tree-compatible groundcovers were applied.

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Appendix A. Understory taxa recorded, with classification and average groundcover (%GC) as recorded within understory sampling plots and as averaged over all experimental areas.. .

Taxon	Growth Habit[†]	Classification[‡]			%GC
		Nati -vity	Invas- ivity	Nox- ious	
Amaranthus retroflexus L. (redroot amaranth)	F/H	N	NI	NN	<0.1
Andropogon virginicus L. (broomsedge bluestem)	G	N	NI	NN	0.9
Arnoglossum reniforme (Hook.) H. Rob. (great Indian	F/H	N	NI	NN	<0.1
Artemisia vulgaris L. (common wormwood)	F/H, Ss	Ex	Ind	NN	0.5
Asclepias syriaca L. (common milkweed)	F/H	N	NI	NN	<0.1
Asplenium platyneuron (L.) Britton, Sterns & Poggenb. (ebony spleenwort)	F/H	N	NI	NN	0.3
Aster L. (aster)	F/H	Ind	NI	NN	0.5
Bidens frondosa L. (devil's beggartick)	F/H	N	NI	NN	<0.1
Buddleja davidii Franch. (orange eye butterflybush)	S	Ex	I	Nox	1.8
Calystegia sepium (L.) R. Br. (hedge false bindweed)	F/H,	Ind	NI	NN	<0.1
Carex L. (sedge)	G	N	NI	NN	<0.1
Chamerion angustifolium (L.) Holub (fireweed)	F/H,	N	NI	NN	0.5
Cheilanthes Sw. (lipfern)	F/H	Ind	NI	NN	<0.1
Cichorium intybus L. (chicory)	F/H	Ex	I	Nox	<0.1
Cirsium arvense (L.) Scop. (Canada thistle)	F/H	Ex	I	Nox	0.2
Cirsium vulgare (Savi) Ten. (bull thistle)	F/H	Ex	I	Nox	0.2
Clematis virginiana L. (devil's darning needles)	V	N	NI	NN	0.7
Dactylis glomerata L. (orchardgrass)	G	Ex	I	NN	5.0
Daucus carota L. (Queen Anne's lace)	F/H	Ex	I	Nox	2.9
Dichanthelium clandestinum (L.) Gould (deertongue)	G	N	NI	NN	<0.1
Eragrostis curvula (Schrad.) Nees (weeping lovegrass)	G	Ex	I	NN	3.1
Erigeron annuus (L.) Pers. (Eastern daisy fleabane)	F/H	N	NI	NN	<0.1
Erigeron philadelphicus L. (Philadelphia fleabane)	F/H	N	NI	NN	0.9
Eupatorium perfoliatum L. (common boneset)	F/H	N	NI	NN	0.4
Impatiens capensis Meerb. (jewelweed)	F/H	N	NI	NN	<0.1
Kummerowia stipulacea (Maxim.) Makino (Korean clover)	F/H	Ex	I	NN	0.4
Lactuca biennis (Moench) Fernald (tall blue lettuce)	F/H	N	NI	NN	0.3
Lactuca canadensis L. (Canada lettuce)	F/H	N	NI	NN	1.5
Lactuca serriola L. (prickly lettuce)	F/H	Ex	NI	NN	0.1
Lespedeza cuneata (Dum. Cours.) G. Don (Sericea lespedeza)	F/H, Ss	Ex	I	Nox	14.8
Lobelia inflata L. (indian tobacco)	F/H	N	NI	NN	<0.1
Lobelia spicata Lam. (palespike lobelia)	F/H	N	NI	NN	1.9
Lolium perenne L. (perennial ryegrass)	G	Ex	NI	NN	0.7
Lolium perenne L. subsp. multiflorum (Lam.) Husnot (Italian ryegrass (annual ryegrass))	G	Ex	NI	NN	0.2
Lotus corniculatus L. (bird's-foot trefoil)	F/H	Ex	I	NN	3.7

Medicago sativa L. (alfalfa)	F/H	Ex	NI	NN	<0.1
Melilotus officinalis (L.) Lam. (sweetclover)	F/H	Ex	I	NN	<0.1
Mentha arvensis L. (wild mint)	F/H	N	NI	NN	<0.1
Oenothera biennis L. (common evening primrose)	F/H	N	NI	NN	0.2
Oxalis montana Raf. (mountain woodsorrel)	F/H	N	NI	NN	<0.1
Oxalis stricta L. (ommon yellow oxalis)	F/H	N	NI	NN	0.1
Panicum L. (panicgrass)	G	Ind	NI	NN	<0.1
Parthenocissus quinquefolia (L.) Planch. (Virginia creeper)	V	N	NI	NN	0.1
Penstemon canescens (Britton) Britton (eastern gray beardtongue)	F/H	N	NI	NN	<0.1
Phleum pratense L. (timothy)	G	Ex	I	NN	0.1
Physalis virginiana Mill. (Virginia groundcherry)	F/H	N	NI	NN	0.2
Phytolacca americana L. (American pokeweed)	F/H	N	NI	NN	0.3
Plantago lanceolata L. (narrowleaf plantain)	F/H	Ex	I	Nox	<0.1
Polystichum acrostichoides (Michx.) Schott (Christmas fern)	F/H	N	NI	NN	0.6
Potentilla canadensis L. (dwarf cinquefoil)	F/H	N	NI	NN	<0.1
Rosa multiflora Thunb. (multiflora rose)	Ss, V	Ex	I	Nox	<0.1
Rubus allegheniensis Porter (Allegheny blackberry)	Ss	N	NI	NN	2.4
Rubus occidentalis L. (black raspberry)	Ss	N	NI	NN	0.3
Rudbeckia fulgida Aiton (orange coneflower)	F/H	N	NI	NN	0.3
Rudbeckia hirta L. (blackeyed Susan)	F/H	N	NI	NN	0.1
Schedonorus arundinaceus (Schreb.) Dumort., nom. cons. (tall fescue)	G	Ex	I	NN	12.2
Securigera varia (L.) Lassen (crownvetch)	F/H, V	Ex	I	NN	10.3
Setaria italica (L.) P. Beauv. (foxtail millet)	G	Ex	NI	NN	<0.1
Smilax rotundifolia L. (roundleaf greenbrier)	S, V	N	NI	NN	<0.1
Solidago canadensis L. (Canada goldenrod species complex)	F/H	N	NI	NN	4.9
Sonchus asper (L.) Hill (Spiny sowthistle)	F/H	Ex	NI	NN	<0.1
Sorghum halepense (L.) Pers. (Johnsongrass)	G	Ex	I	Nox	<0.1
Taraxacum laevigatum (Willd.) DC. (rock dandelion)	F/H	Ex	I	NN	<0.1
Taraxacum officinale F.H. Wigg. subsp. Officinale (common dandelion)	F/H	Ex	I	NN	0.3
Tridens flavus (L.) Hitchc. (purpletop tridens)	G	N	NI	NN	<0.1
Trifolium hybridum L. (alsike clover)	F/H	Ex	I	NN	0.4
Trifolium pratense L. (red clover)	F/H	Ex	I	NN	1.5
Trifolium repens L. (white clover)	F/H	Ex	I	NN	2.9
Tussilago farfara L. (coltsfoot)	F/H	Ex	I	Nox	3.9
Verbascum thapsus L. (common mullein)	F/H	Ex	I	Nox	<0.1
Viola sororia Willd. (common blue violet)	F/H	N	NI	NN	<0.1
n/a (unknown grass) (unknown grass)	G	Ind	Ind	Ind	<0.1
Sum					84

† Growth habit as classified by USDA ((2016): F/H = Forb/Herb; G = Graminoid; S = Shrub; Ss = Subshrub; V = Vine. Some taxa listed with multiple growth habits.

‡ Nativity: N = native, Ex = Exotic; Ind = indeterminate. Invasivity: I = invasive; NI = not classified as invasive; Ind = indeterminate. Noxious Status: Nox = noxious weed; NN = not noxious.

§ B = Block; AR, CON, and TC = seeding treatments (see Table 2).

Appendix B1: Numbers trees recorded within tree-sampling plots for each treatment plot, by species.

Block		1	1	1	1	1	1	2	2	2	2	2	2	4	4	All
Trt Plot		1	2	3	4	5	6	1	2	3	5	6	7	3	4	All
Grading Treatment		Ls	Ls	Ls	Sm	Sm	Sm	Ls	Ls	Ls	Sm	Sm	Sm	Ls	Sm	All
Seeding Treatment		AR	Con	TC	Con	TC	AR	AR	Con	TC	Con	TC	AR	TC	Con	All
Sampling Area (ha)		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1.4
Crop Tree Species Planted in Blocks 1&2																
Sugar maple	Acer saccharum Marsh.	12	6	15	7	8	8	1	5	5	3	8	-	7	11	96
Ash	Fraxinus L.	32	30	31	17	25	23	10	16	24	3	13	20	20	27	291
Tulip poplar	Liriodendron tulipifera L.	9	16	7	20	14	12	3	9	11	2	9	10	3	6	131
Black cherry	Prunus serotina Ehrh.	19	19	23	22	16	9	6	14	13	7	11	29	49	23	260
White oak	Quercus alba L.	13	23	27	21	8	24	1	1	14	5	8	7	4	9	165
Chestnut oak	Quercus prinus L.	19	18	13	26	15	13	1	4	5	3	4	9	1	1	132
Northern red oak	Quercus rubra L.	9	1	15	14	12	12	2	-	3	5	-	5	6	1	85
Black oak	Quercus velutina Lam.	9	21	16	29	21	11	1	8	10	2	2	6	8	6	150
Wildlife Tree Species Planted in Blocks 1&2																
Shagbark hickory	Carya ovata (Mill.) K. Koch	3	4	2	4	4	1	-	-	1	-	-	-	1	1	21
Easteren redbud	Cercis canadensis L.	3	2	9	6	6	4	3	7	5	-	1	-	3	4	53
Grey dogwood	Cornus racemosa Lam.	48	39	92	76	28	60	9	3	2	-	12	2	21	21	413
Red mulberry	Morus rubra L.	-	1	6	3	1	6	1	1	3	2	1	2	-	1	28
White pine	Pinus strobus L.	5	6	1	9	4	7	-	5	3	3	9	10	1	4	67
Other Native Trees																
Red maple	Acer rubrum L.	1	-	2	-	1	2	1	-	-	1	-	5	3	29	45
Hawthorn	Crataegus L.	-	-	-	-	-	-	-	-	-	-	-	-	1	1	2
Crabapple	Malus Mill. (sub.)	-	-	-	-	-	-	-	-	-	-	-	-	3	-	3
Sourwood	Oxydendrum arboreum (L.) DC	8	16	-	6	-	2	-	-	-	-	-	-	-	-	32
Pitch-loblolly pine	Pinus rigida × taeda (hybrid)	-	-	-	-	-	-	-	-	-	-	-	-	10	-	10
Virginia pine	Pinus virginiana Mill.	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1
American sycamore	Platanus occidentalis L.	-	-	-	-	-	2	-	-	-	-	1	-	-	-	3
Sumac	Rhus L.	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1
Black locust	Robinia pseudoacacia L.	1	1	-	-	-	-	1	1	-	1	-	-	22	17	44
Exotic Trees																
Tree of heaven	Ailanthus altissima	3	-	-	-	-	-	-	1	-	-	-	1	-	-	5
Autumn olive	Elaeagnus	-	2	-	5	1	1	6	2	-	8	6	10	-	1	42
Paulownia	Paulownia tomentosa	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1

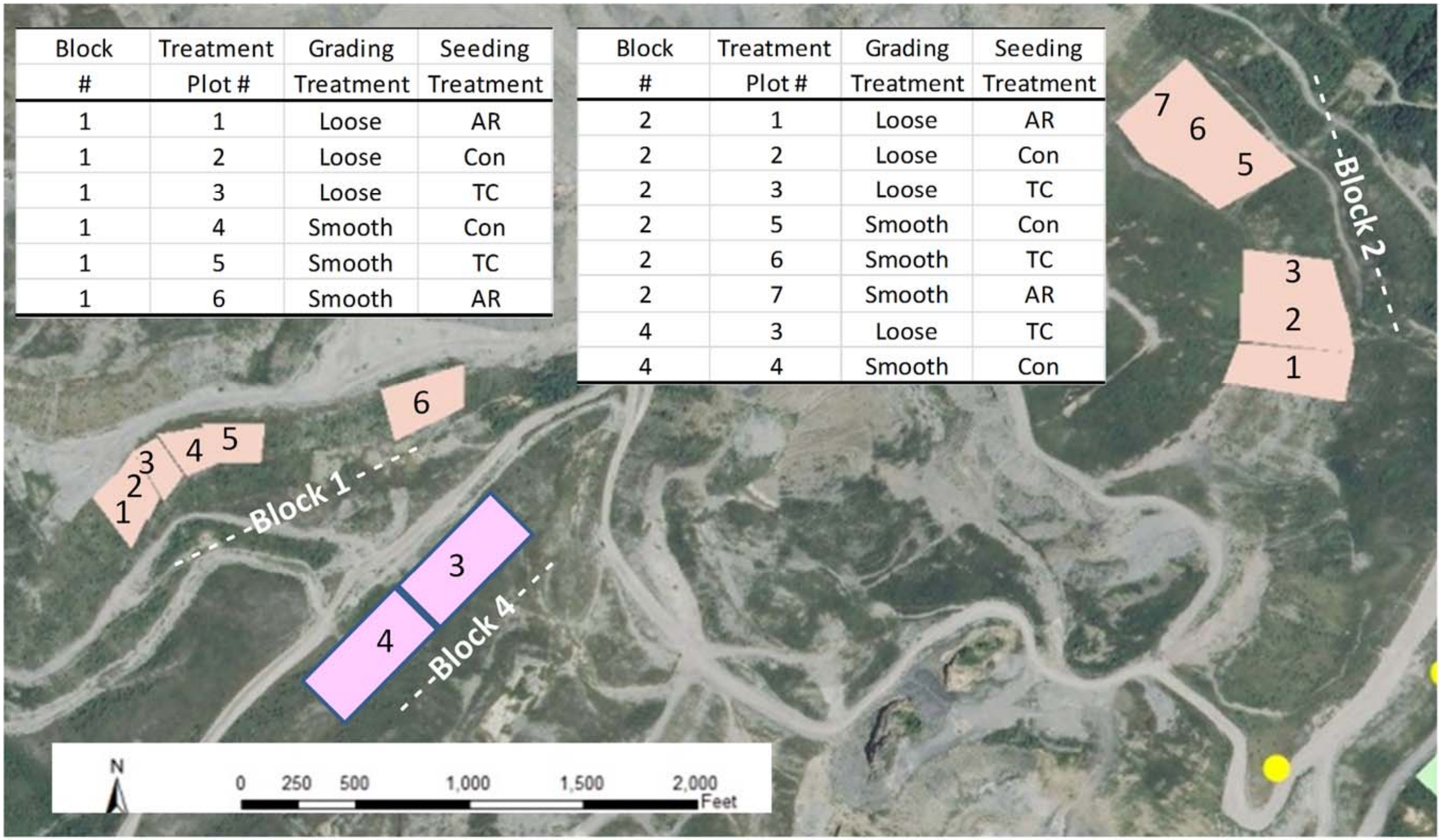
Appendix B2: Mean heights (m) for trees recorded within tree-sampling plots for each treatment plot, by species..

Block		1	1	1	1	1	1	2	2	2	2	2	2	4	4	All
Trt Plot		1	2	3	4	5	6	1	2	3	5	6	7	3	4	All
Grading Treatment		Ls	Ls	Ls	Sm	Sm	Sm	Ls	Ls	Ls	Sm	Sm	Sm	Ls	Sm	All
Seeding Treatment		AR	Con	TC	Con	TC	AR	AR	Con	TC	Con	TC	AR	TC	Con	All
Sampling Area (ha)		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1.4
Crop Tree Species Planted in Blocks 1&2																
Sugar maple	Acer saccharum Marsh.	1.7	1.4	2.0	1.1	1.5	1.9	1.3	0.3	0.6	0.5	0.7		0.9	0.7	1.3
Ash	Fraxinus L.	2.3	1.4	2.8	1.4	2.4	2.6	1.2	0.8	1.5	2.2	0.9	0.9	2.3	1.5	1.8
Tulip poplar	Liriodendron tulipifera L.	2.1	1.9	3.0	1.5	3.7	2.7	0.8	0.4	1.2	0.6	0.6	0.7	2.0	1.1	1.8
Black cherry	Prunus serotina Ehrh.	3.1	2.4	3.3	1.8	3.5	3.1	0.9	0.6	1.1	0.8	1.0	1.1	1.7	1.4	1.9
White oak	Quercus alba L.	1.7	1.5	2.5	1.3	1.7	2.7	0.8	0.4	0.7	0.7	0.7	0.6	1.3	1.0	1.6
Chestnut oak	Quercus prinus L.	1.6	1.5	2.1	1.8	2.3	2.5	0.7	0.3	0.9	0.8	0.7	1.0	0.3	1.2	1.7
Northern red oak	Quercus rubra L.	1.8	2.7	2.5	1.4	2.0	2.7	0.2	-	1.2	0.6	-	0.6	1.0	1.3	1.7
Black oak	Quercus velutina Lam.	1.5	1.2	2.2	1.3	1.4	2.3	0.6	0.4	0.7	1.0	0.5	0.8	0.7	0.6	1.3
Wildlife Tree Species Planted in Blocks 1&2																
Shagbark hickory	Carya ovata (Mill.) K. Koch	1.2	0.7	0.7	0.8	1.3	0.8	-	-	0.6	-	-	-	0.1	0.3	0.9
Easteren redbud	Cercis canadensis L.	2.2	1.7	2.6	1.7	2.7	2.3	0.9	0.5	1.4	-	0.6	-	1.8	1.2	1.7
Grey dogwood	Cornus racemosa Lam.	1.8	1.6	1.9	1.0	1.8	2.3	1.3	0.9	2.4	-	0.8	0.4	1.4	0.9	1.6
Red mulberry	Morus rubra L.	-	1.1	3.0	1.7	2.8	3.3	0.7	0.4	1.4	1.0	1.2	1.3	-	1.6	2.1
White pine	Pinus strobus L.	1.6	2.2	3.4	2.1	2.2	2.2	-	0.7	1.9	0.8	1.0	0.9	2.8	2.2	1.6
Other Native Trees																
Red maple	Acer rubrum L.	1.4	-	1.3	-	1.6	0.9	0.2	-	-	0.3	-	0.6	0.2	0.3	0.4
Hawthorn	Crataegus L.	-	-	-	-	-	-	-	-	-	-	-	-	0.9	1.2	1.1
Crabapple	Malus Mill. (sub.)	-	-	-	-	-	-	-	-	-	-	-	-	1.0	-	1.0
Sourwood	Oxydendrum arboreum (L.) DC	1.1	0.6		0.8		0.9	-	-	-	-	-	-	-	-	0.8
Pitch-loblolly pine	Pinus rigida × taeda (hybrid)	-	-	-	-	-	-	-	-	-	-	-	-	2.1	-	2.1
Virginia pine	Pinus virginiana Mill.		0.6	-	-	-	-	-	-	-	-	-	-	-	-	0.6
American sycamore	Platanus occidentalis L.	-	-	-	-	-	3.6	-	-	-	-	1.1	-	-	-	2.8
Sumac	Rhus L.	-	-	-	-	-	-	-	-	-	-	0.4	-	-	-	0.4
Black locust	Robinia pseudoacacia L.	4.1	4.0	-	-	-	-	3.5	4.3	-	5.2	-	-	1.5	2.0	2.0
Exotic Trees																
Tree of heaven	Ailanthus altissima	1.9	-	-	-	-	-	-	0.3	-	-	-	0.9	-	-	1.4
Autumn olive	Elaeagnus	-	3.4		3.4	3.0	2.9	3.4	1.7	-	2.0	2.6	2.3	-	3.1	2.6
Paulownia	Paulownia tomentosa	-	-	-	-	-	3.5	-	-	-	-	-	-	-	-	3.5

Appendix C. Plot locations and layouts, and experimental Design.

Block #	Treatment Plot #	Grading Treatment	Seeding Treatment
1	1	Loose	AR
1	2	Loose	Con
1	3	Loose	TC
1	4	Smooth	Con
1	5	Smooth	TC
1	6	Smooth	AR

Block #	Treatment Plot #	Grading Treatment	Seeding Treatment
2	1	Loose	AR
2	2	Loose	Con
2	3	Loose	TC
2	5	Smooth	Con
2	6	Smooth	TC
2	7	Smooth	AR
4	3	Loose	TC
4	4	Smooth	Con



Plot layout with treatment designations. Underlying image is 2012 NAIP (National Aerial Imagery Program, U.S. Department of Agriculture). Block 4 plot locations are approximate.

Coordinates of Treatment Plot Corners:

Blk	*Plot #*	*Latitude*	*Longitude*	*Blk*	*Plot #*	*Latitude*	*Longitude*
1	1	37.0052609765	-82.7163659572	2	1	37.0073748084	-82.6991939392
1	1	37.0055441454	-82.7160323022	2	1	37.0072753900	-82.6974409320
1	1	37.0050307677	-82.7155532734	2	1	37.0066882213	-82.6975704667
1	1	37.0046499783	-82.7157570389	2	1	37.0068934441	-82.6994192211
1	2	37.0055441454	-82.7160323022	2	2	37.0079794481	-82.6991503657
1	2	37.0058339167	-82.7157666454	2	2	37.0077774322	-82.6975589627
1	2	37.0052744840	-82.7153301924	2	2	37.0072753900	-82.6974409320
1	2	37.0049930766	-82.7155168994	2	2	37.0073804654	-82.6991982623
1	3	37.0058339167	-82.7157666454	2	3	37.0085123964	-82.6991279803
1	3	37.0060157225	-82.7153867944	2	3	37.0083969717	-82.6978027005
1	3	37.0055377363	-82.7149498244	2	3	37.0077812682	-82.6975891814
1	3	37.0052271003	-82.7152932250	2	3	37.0079794481	-82.6991503657
1	4	37.0060366895	-82.7154059622	2	5	37.0099722222	-82.6990000000
1	4	37.0061441099	-82.7147279381	2	5	37.0095277778	-82.6983611111
1	4	37.0056975926	-82.7144889418	2	5	37.0089722222	-82.6995277778
1	4	37.0055377363	-82.7149498244	2	5	37.0093055556	-82.7000555556
1	5	37.0061601216	-82.7147365082	2	6	37.0103055556	-82.6994444444
1	5	37.0061939763	-82.7137915309	2	6	37.0099722222	-82.6990000000
1	5	37.0057223979	-82.7138329002	2	6	37.0093055556	-82.7000555556
1	5	37.0056900002	-82.7144848780	2	6	37.0095555556	-82.7006388889
1	6	37.0066277985	-82.7120663895	2	7	37.0108055556	-82.7000555556
1	6	37.0069507408	-82.7108352499	2	7	37.0103055556	-82.6994444444
1	6	37.0064282511	-82.7107836270	2	7	37.0095555556	-82.7006388889
1	6	37.0060000000	-82.7118333333	2	7	37.0100277778	-82.7010833333

Notes: (1) Adjacent plots share the same points as corners (2) Block 4 coordinates were not recorded.

Field Measurements