REFORESTATION GUIDELINES FOR UNUSED SURFACE MINED LANDS: DEVELOPMENT, APPLICATION AND ADOPTION[1]

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Abstract. More than 600,000 hectares of mostly forested land in the Appalachian region were surface mined for coal under the Surface Mining Control and Reclamation Act. Today, these lands are largely unmanaged and covered with persistent herbaceous species, such as fescue and serecia lespedeza, and a mix of invasive and native woody species with little commercial or ecological value. Some landowners and surrounding residents would like to restore native forests on some of these lands for the valuable products and services they provided prior to mining. For these lands to become productive forests, intervention is needed to loosen compacted mine soils, correct chemical or nutrient deficiencies, and replace the current vegetation. Reforestation guidelines to restore native forests on mined lands that are unoccupied, unmanaged, and unproductive were developed. Practices include land clearing, mine soil tillage, fertilization, tree planting, weed control and monitoring. The recommended practices were tested on a 35-ha mine site, originally reclaimed to grassland and bond-released in 1997. After the second growing season mean stocking of 885 ha^{-1} was achieved. Five of the six primary planted species (black, white, and red oak, tulip poplar, black cherry) had statistically equivalent stocking, but tulip poplar and black cherry had the highest mean height and biomass. Volunteer trees occurred on most measurement plots; most volunteer trees were native but invasive shrubs were also present. The pre-existing vegetation proved to be persistent and competitive, demonstrating the importance of vegetation control and strategic nutrient application to reforestation success. Under leadership provided by the Appalachian Regional Reforestation Initiative, a group formed by the Office of Surface Mining and seven state regulatory authorities, these procedures have been adopted and applied by watershed improvement groups, forestry and fish/wildlife agencies, coal companies, environmental groups, and an electrical generating company pursuing carbon credits.

Additional Key Words: Appalachian coal fields, ecosystem restoration, nine reforestation, ARRI, tree planting

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Introduction

More than a half million hectares of mostly forested land in the Appalachian region were surface mined for coal under the Surface Mining Control and Reclamation Act. Most of this land was reclaimed using practices intended to stabilize the surface, prevent erosion, and establish vegetation suitable for domestic livestock or wildlife. Today, these lands are largely unmanaged and covered with persistent herbaceous species, such as fescue and serecia lespedeza, and a mix of invasive and native woody species with little commercial or ecological value. Some landowners and adjacent publics would like to restore native forests on some of these lands for the valuable products and services they provided prior to mining. Re-establishing productive forests on otherwise unused and non-productive mined lands will generate economic value for landowners and communities, and will enhance environmental quality by accelerating restoration of ecosystem services – such as watershed protection, water quality enhancement, carbon storage and wildlife habitat – that are typically provided by native forests on non-mined landscapes.

Today, lands being actively mined in several Appalachian states are often reclaimed using the Forestry Reclamation Approach (FRA) (Burger and Torbert, 1992; Burger et al. 2005), which establishes productive forest as a post-mining land use in accord with SMCRA. In 2004, the Office of Surface Mining and the seven state regulatory authorities in Appalachia created the Appalachian Regional Reforestation Initiative (ARRI) to advocate and promote the use of this FRA to reestablish healthy, productive forest habitat in the eastern coal fields (Angel et al., 2005; Burger et al., 2005). The reforestation guidelines in this publication are different; they are intended for lands mined and reclaimed without the FRA that are not forested and not under active management. They are intended for application on *unused* mined land, including those acres mined since 1980, reclaimed to satisfy SMCRA guidelines, bond released, and now under landowner control. Land mined before 1980, some of which has been identified as "abandoned mined land" could also be reforested using these guidelines. For these lands to become productive forests, intervention is needed to loosen compacted mine soils, correct chemical or nutrient deficiencies, and replace the current vegetation.

This purpose of this paper is to 1) describe a set of practices that can be applied to restore native forests on *unused* mined lands that are unoccupied, unmanaged, and unproductive; 2) show the results of these practices on a prototype reforestation effort on a 35-ha unused mined site two years after they were applied; and 3) show the extent to which these reforestation guidelines have been adopted and applied on mined sites by ARRI foresters and various partnering organizations and landowners.

Reforestation Guidelines for Unused Mined Land

Forest restoration on unused mined lands typically requires a sequence of steps or procedures over several years. In a Virginia Tech Cooperative Extension Bulletin, Burger and Zipper (2011) describe the process within the context of "four Ps": "Plan, Prepare, Plant, and Protect": Assess site conditions and develop a forest restoration *plan*; *prepare* the site to make it more favorable for forest establishment; *plant* a combination of valuable, native trees or plantation species; and *protect* the site and new planting with follow-up management, including weed control, fire prevention, and animal and human trespass. The logic for each step is briefly described.

Develop a Reforestation Plan

Step one entails assessing site conditions and writing a reforestation plan. Based on this assessment and written plan, contractors or other entities can be sought for completing the needed reforestation operations. In consultation with the landowner, the plan should include a detailed map of the site, a vegetation survey, a test and evaluation of mine soil physical and chemical properties, the forest type and species to plant, weed control methods to be used, and procedures for monitoring post planting conditions and success.

A GIS map or an aerial or satellite photo is useful to determine acreage and to record the assessment survey, as well as a record of the application of all reforestation procedures. Aerial imagery that is freely available on internet mapping sites can be used to prepare a base map and to estimate areas. Herbaceous plants and woody shrubs, many of them non-native and invasive, often dominate reclaimed post-SMCRA mine sites (Zipper and others 2007, and Fig. 1). Successful reforestation requires that existing vegetation be eliminated or controlled. Thus, the reforestation plan must include a strategy for control of competing vegetation. The site should be surveyed in advance of reforestation to determine where deep tillage will be needed and how it will be applied. Deep tillage of dense mine soils will produce a favorable soil condition where roots can extend easily and access needed water, nutrients and air. Sampling mine soils and sending the samples to a state or private testing lab for chemical analyses can provide information on soil chemical properties and to determine if corrective measures are needed. The site map can show where specific tree species mixes will be planted. Tree species selection should be based on land owner objectives and the capability of the site. In most cases, mined land will be suitable for mixed native hardwoods.

Prepare the Mined Site for Planting

Preparing the mined site for planting usually requires three steps: 1) removing and controlling existing undesirable vegetation; 2) improving the mine soil's chemical properties by adding lime and fertilizer; and 3) improving the mine soil's physical properties by deep tilling with a dozer to alleviate mine soil compaction and consolidation.

It is essential that the pre-existing vegetation be controlled because it will otherwise compete for sunlight, water, and nutrients needed by tree seedlings to survive and grow. Because the pre-existing vegetation has well-established rooting and physical stature, it has an advantage over newly planted seedlings. If pre-existing vegetation is not controlled, it will quickly overtop and out-compete planted tree seedlings, and those seedlings will not survive. Woody stems that will interfere with reforestation operations should be killed and removed prior to soil preparation. Herbicides should be applied to control herbaceous vegetation both before and after planting tree seedlings.

Soil fertility is essential to the planted trees' growth, and soil pH affects plant availability of soil P. In the short term, access to essential nutrients will enable quick early growth of planted seedlings; this is desirable because post-planting herbicide applications can cease once the planted seedlings overtop their competition. Over the longer term, adequate fertility is essential to forest productivity. Apply lime (only if necessary) and fertilizer as needed to improve the mine soil's fertility and chemical properties. Lime is usually easy to apply with standard, commonly-available equipment. However, fertilizers must be applied strategically to restrict availability to the planted trees and to prevent the fertilizer application from stimulating competition by undesirable vegetation.

When mine soils have become dense, soil loosening is needed to allow normal rooting, water infiltration, soil drainage, and movement of air into the soil surface, all of which are required for productive tree growth. Compacted mine soils can be loosened with a soil ripper, sub-soiler, or other specialized tillage device. Because forest trees require at least 1.5 meters of rooting depth for adequate growth, ripping compacted mined sites to at least one meter is recommended. This deep tillage operation will typically require a large dozer such as a Cat D-8, but the equipment should be transportable via public roads. Application of deep tillage to active mines is described by Forest Reclamation Advisory No. 4 (Sweigard et al., 2007); these practices can be adapted for use on older mined sites.

Plant the Site with Selected Tree Species

Over many decades, native hardwoods are likely to re-establish on unused Appalachian mined lands through natural processes, but natural processes are hindered by the vigorous, non-forest vegetation that occurs on most mine sites. Natural invasion by the heavy-seeded tree species – including oaks and hickories – will occur even more slowly, especially on larger mine sites, because these species' seeds are not carried by wind or birds. Plant trees of species suited to reforestation goals. If the goal is to reestablish the native forest, plant a mix of native hardwoods, these trees should be commercially viable hardwoods that will provide multiple benefits including wood products, carbon sequestration, wildlife habitat, and watershed control.

Protect and Survey the Site and Trees

Young, planted trees are vulnerable to a variety of hazards, especially through their first year. Competing vegetation will prevent seedlings from accessing the sunlight, water, and nutrients that they will need to survive. Perhaps not so obvious, rodents such as voles will use a heavy sod cover for winter shelter and de-bark the tree seedlings for a winter food source, killing the trees. Control competing vegetation with herbicides, which is essential to reforestation success on virtually all reforested sites.

Stocking surveys are needed to determine success of the reforestation effort. To foresters, the term "stocking" means the number of living trees per unit area at a given point in time, and is usually expressed as trees/hectare. A planting rate for mixed hardwoods on mine soils is commonly 1700 trees/ha (700 trees/ac). Expected average survival in the region is 80% at the end of the first growing season and should level off at 70% by the end of the second growing season when trees should be fully recovered from transplanting shock and growing freely without excessive competition. At this stage minimum stocking should be approximately 1200 trees/ha. If stocking is inadequate after the first growing season (fewer than 1360 trees/ha) from poor survival due to droughty summer conditions, additional planting can be done the following winter.

If the reforestation steps were applied according to these guidelines, significant effort and money were spent to clear, till, and fertilize the area. A stocking survey followed by re-planting, if and where needed, will take advantage of the work already applied at significant expense. In September of the planted trees' first year, assess tree survival and stocking by determining the number of trees/acre still living. Mid-summer of the trees' first growing season is their most critical period; trees that survive the mid-summer heat and drought will generally make it through the fall and winter and into the next growing season. Assess site stocking (trees/acre) after the mid-summer heat has passed but while the trees still have their leaves, so living trees are easy to identify.

When the guidelines described above are applied appropriately, productive Appalachian forests can be restored on unused mined lands. Detail on how to apply these guidelines is provided in Virginia Tech Cooperative Extension Bulletin 460-144 (Burger and Zipper, 2010).

Test of Reforestation Guidelines for Unused Mined Land

These guidelines for reforesting unused mined land were tested on a mined site managed by the Nature Conservancy near St. Paul, VA. In 1996, 91 hectares were mined for coal and reclaimed by using blasted rock as soil substitute, seeding with grasses and legumes, and planted with trees and shrubs. On areas with compacted soils, survival by planted late-successional trees was poor, producing vegetation dominated by *Festuca arundinacea* (tall fescue), *Dactylis glomerata* (orchardgrass) and other grasses; an exotic invasive shrub (*Elaeagnus umbellata*, autumn olive); and *Robinia pseudoacacia* (black locust), an early-successional native tree that often forms dense thickets (Fig. 1). In 2007, a prototype version of the guidelines (Burger and Zipper 2010) was applied with the goal of restoring the carbon sequestration and watershed protection services of forested ecosystems.

Methods

Thirty-five hectares were cleared of woody vegetation in summer, 2007, shredding stems and stumps with a rotary ax. As a first step, the guidelines recommend killing existing vegetation with herbicides prior to removal of woody stems, but no pre-planting herbicides were used in this case. In autumn, 9 Mg ha^{-1} pelletized lime and 74, 95, and 56 kg ha^{-1} of elemental N, P, and K (as urea, triple super phosphate, and potassium chloride), respectively, were broadcast applied. The liming rate was set to achieve an average mine soil pH of 6.0. Fertilizer rates were based on guidelines in Burger and Torbert (1992). In December, the site was treated with a heavy disc harrow to break up surface turf and tilled with a 1 m deep-ripping shank to alleviate soil compaction at 2.8 m spacings; large disks mounded loosened soils over the deep rips and two smaller shanks, one on each side, tilled to 30 cm. In early 2008, ten forest tree species (see below) were planted as 1-0 bare-root seedlings on the mounds. In May, a 0.5 m radius around each seedling was spot-sprayed with herbicide (glyphosate, 2,4D, dicamba, pendimethalin). Areas with poor survival were replanted and all planted trees were spot-sprayed again in 2009.

Figure 1. Two views of the reforestation site in June, 2010: A tulip poplar, with spot-sprayed area visible around its base, in the foreground, located in an area where primary competition is herbaceous (above), and emerging planted trees in a landscape segment also occupied by autumn olive shrubs (below).

Prior to tillage, soils were sampled to 30 cm depth at 31 points on a gridded pattern. Coarse fragment content (CF%) was determined as a fraction of soil mass and characterized for major rock type. Soil fines (<2mm) were tested for pH and soluble salts (SS) (Mullins and Heckendorn 2009).

In March 2010, planted and volunteered trees were evaluated and measured within 0.02 ha circular plots at each soil sampling point. Each tree was identified by species and as "planted" or "volunteer"; measured for height (ht) and ground-line diameter (gld); and rated visually for browse damage, rodent damage, and herbaceous competition (Table 1). The density of competing vegetation was relatively uniform; therefore competition classes were based on height, which was roughly correlated with the amount of competitive biomass. Tree biomass volume was estimated as (ht x gld^2) for each living tree and summed to estimate plot totals.

It is important to note that reforestation procedures detailed by Burger and Zipper (2010) were followed except that existing vegetation was not killed using pre-planting herbicides prior to site tillage, and that fertilizer was broadcast applied instead of strategically placed in the tree row as recommended.

Table 1. Damage / competition rating scales applied to planted trees.

Browse Damage†	Rodent Damage to Lower Stem	Herbaceous competition in growing space (radius around tree = tree height)
0= No damage		
1 = 1-20% of tree height damaged	1 = less than 1/3 of diameter girdled	1 = Little or no vegetation
2 = 21-40%	2 = more than 1/3 of diameter girdled	2 = veg less than half way up stem
3 = 41-60%		3 = veg height ½ to ¾ of stem height
4 = 61-80%		4 = veg height >¾ of stem height but < stem height.
5 = 81-100%		5 = veg taller than tree

† if top has been removed by browsing, extent of removal is estimated based on remaining stem ground line diameter and taper.

Results

Two years after establishment, mean planted tree survival was 43%, resulting in a mean stocking of 885 ha^{-1} (Table 1). Five of the six primary planted species (black, white, and red oak, tulip poplar, black cherry) had statistically equivalent stocking, but tulip poplar and black cherry had the highest mean height and biomass. Volunteer trees occurred on 22 of the 31 measurement plots; most were native (Table 2). Volunteer stocking was variable, as 63% occurred in two plots (Table 2) and 71% as two species, black locust and sourwood. Black locust occurred on 7 plots and was responsible for 75% of the site's total tree biomass. Autumn olive, the dominant volunteer shrub, occupied >5% of total area (Table 3), but was not sampled in a manner that allowed biomass estimation.

Table 2. Tree planting rates, and stocking and growth metrics calculated from measurement plot means.[†]

Species	Planted Yr 1	Planted Yr 2	Stock-ing	Survi-val	Plots Where Occur-ring	Mean Height	Mean Biomass (per tree)	Total Biomass
	------ (Trees ha^{-1}) ------			(%)		(cm)	(cm^3)	(cm^3 ha^{-1})
Planted:								
Black cherry *(Prunus serotina)*	247	49	127 [a]	43%	27	71 [a]	106 [a]	13,882 [ab]
Black oak *(Qurecus velutina)*	247	49	169 [a]	57%	27	41 [bc]	29 [b]	5,184 [b]
Red oak *(Quercus rubra)*	247	49	134 [a]	45%	28	40 [bc]	24 [bc]	3,372 [b]
Sugar maple *(Acer saccharum)*	247	49	57 [b]	19%	21	29 [c]	17 [c]	978 [c]
Tulip poplar *(Liriodendron tulipifera)*	247	49	163 [a]	55%	28	73 [a]	120 [a]	18,096 [a]
White oak (*Quercus alba)*	247	49	188 [a]	63%	30	43 [b]	29 [b]	5,377 [ab]
Dogwood *(Cornus florida)*	62	0	6	10%	2	55	59	300
Shagbark hickory *(Carya ovata)*	62	12	10	13%	3	74	98	992
Redbud *(Cercis canadensis)*	62	0	30	49%	11	35	24	618
All Planted [††]	1,730	321	884	43%	31	51	56	48,799
Volunteer								
Ash *(Fraxinus sp)*			43		15	68	157	8,009
Black locust *(Robinia pseudoacacia)*			274		7	179	1,024	433,836
Red maple *(Acer rubrum)*			77		12	85	480	21,587
Sassafras *(Sassafras albidum)*			104		2	108	134	22,350
Sourwood *(Oxydendrum arboreum)*			304		8	57	58	28,999
Other [†††]			14		4	111	904	14,691
All Volunteer			816		22	96	554	529,471
All Living Trees			1,700		31	66	192	578,270

[†] All stocking, height, and biomass means followed by followed by the same letter are not significantly different ($\alpha = 0.05$).

[††] Includes crab apple (*malas* spp.) (62/ha planted year 1) and red mulberry (*Morus rubra*) (12/ha planted year 2), none of which were observed in the measurement plots.

[†††] Includes white, black, and red oak; eastern redcedar (*Juniperus virginiana*); Virginia pine (*Pinus virginiana*), and one each of two invasive exotics: tree of heaven (*Ailanthus altissima*) and princess tree (*Paulownia tomentosa*).

Measured soil properties were typical for non-acidic Appalachian coal mines. Generally, pH (plot mean ± standard error = 6.3 ± 0.2, range = 4.6 – 7.7) and SS (63 ± 5 ppm, range = 38 - 166) were correlated positively but with one outlier, a sample with the highest SS and lowest pH that likely contained acid-producing minerals (pyrites) and was excluded from further analyses involving soil properties. Weathered sandstone, generally favorable to reforestation on Appalachian mines (Angel et al. 2008; Emerson et al. 2009), was the primary rock type on 19 plots, with unweathered sandstones, siltstones, and shales also present. Browse damage was frequent and rodent damage infrequent, affecting ~50% and ~5% of surviving planted trees, respectively.

Table 3. Stocking and size metrics for non-planted shrubs.

Species	Total Observed†	Plots Where Occurring	Mean Height (m)	Mean Crown Radius (m)
Autumn olive *(Elaeagnus umbellata)*	323	29	1.32	0.47
Mountain laurel *(Kalmia latifolia)*	4	2	0.25	0.25
Willow (*Salix* spp.)	1	1	1.5	0.5

† Observed units included both individual shrubs and multiple-stem "clumps," for which average height and estimated crown radius were recorded.

Planted tree stocking had no significant correlations with measured soil factors (Table 4), but pH was negatively correlated with mean planted tree height; CF% (38 ± 2, 18 – 77) and pH were negatively correlated with non-black locust native volunteers (NBNV) stocking. Autumn olive cover correlated positively with vegetative competition, and with planted tree height (Table 4) and biomass. Competition/damage ratings were not correlated with planted tree metrics at the plot level, but the herbaceous competition and browse ratings exhibited negative relationships with planted tree heights and biomass (Spearman's rho = -0.37 and -0.30, respectively; $p<0.0001$ for both relationships) $p<0.0001$) in individual-tree regressions. Browse and competition ratings correlated with one another positively at both the plot (rho = 0.36, $p<0.05$) and individual tree (rho = 0.13, $p<0.01$) levels.

Table 4. Spearman correlations of planted trees' stocking, height, mean and total biomass volume indices; woody volunteer metrics (non-black locust native stocking, summed tree biomass, and autumn olive crown cover); planted trees' damage/competition ratings; and soil properties (coarse fragment content, pH, and soluble salts). †

	Stocking	Height	NBNV N	Aut Ol
Planted Trees:				
Stocking		-0.10	0.07	-0.19
Ht	-0.10		0.12	***0.37***
Mean Bio	-0.07	***0.82***	0.12	***0.48***
Tot Bio	***0.45***	***0.62***	-0.02	0.25
Volunteers:				
NBNV N	0.07	0.12		0.06
Vol Bio	-0.16	0.07	***0.80***	0.17
Aut Ol	-0.19	***0.37***	0.06	
Damage/Comp:				
Browse	0.25	-0.14	0.31	0.10
Rodent	-0.14	-0.11	-0.21	0.17
Herb	-0.16	0.12	0.01	***0.36***
Soils: ††				
CF%	0.21	-0.31	***-0.47***	-0.07
pH	0.06	***-0.47***	***-0.41***	-0.10
SS	-0.11	-0.29	-0.18	-0.17

† ***Bold italics*** indicate significant correlations at p < .05; ***underline*** indicates p< .01.
†† The pyritic sample is excluded from correlations with soil parameters.

Discussion

Overall planted tree survival was poor, less than the 70-to-80% often achieved in active coal mine plantings (e.g. Emerson et al. 2009). We attribute this effect to the vigor of the herbaceous competition, given that soil properties are at levels considered favorable to planted trees based on expectations from active mine plantings (Emerson et al. 2009). This shows the need for aggressive control of existing vegetation using multiple strategies beginning with the application of a multi-spectrum herbicide to kill undesirable woody trees and shrubs and many types of herbaceous species. Based on observations of broadcast fertilized and unfertilized areas (outside the experimental area) of the site, the herbaceous competition was stimulated by the applied fertilizer making it all the more difficult to control with post-planting weed control methods.

Even if pre-planting herbicides had been applied, a germinating herbaceous seed pool will still create a near-total herbaceous ground cover, but, compared to already established grasses and legumes, its juvenile condition is controllable with post-planting herbicides. The aggressive growth of the existing ground cover stimulated by broadcast fertilization illustrates the importance of applying fertilizer in narrow bands in the tree row, or as fertilizer pellets adjacent to each planted tree seedling as recommended in the guidelines (Burger and Zipper, 2010).

Emergence by planted trees from the thick groundcover of grasses, the non-native legume *Lespedeza cuneata*, and invading herbaceous plants such as *Aster* sp. is a critical ecosystem development stage, as emergent trees gain competitive advantage over herbs by casting ground shading. The correlation of competition and browse ratings suggests an indirect herbaceous effect via preferential attractiveness of dense and vigorous herbs to white-tailed deer (*Odocoileus virginianus*), a prominent local browser.

With low survival (43%), the average planted-tree stocking of 884 trees ha^{-1} was less than the 1000 ha^{-1} targeted in the restoration plan. Stocking varied, but planted trees occurred in all plots and was distributed over the site. If they survive, we would expect a mixed-species forest with a desirable component of mid- and late-successional species by crown closure and beyond. Natural invasion by native trees can also aid in forest restoration. Most observed volunteer trees were early-successional native-forest components that, except for black locust, are desirable given our reclamation goals. Volunteer stocking, however, was highly variable across the site.

N accumulation is an essential ecosystem process after extreme disturbance, and dominance by N-fixing species on early-successional disturbed lands is common (Bradshaw 1983; Finegan 1984). Two prolific woody species, autumn olive and black locust, are N fixers; both likely remained on site as live roots and viable seed despite the restoration treatment. Although native and an appropriate site occupant at this successional stage, black locust is not seen as desirable for our restoration goals because its rapid growth in thickets often inhibits site occupation by slower-growing forest trees, causing arrested succession (Groninger et al. 2007). Black locust is an exotic invasive elsewhere (ISSG 2010).

Proliferation of autumn olive, also an exotic (ISSG 2010), appears to be driving some ecosystem development processes. Invasion by a strongly competitive alien is common on disturbed sites with productive soils (Prach and Hobbs 2009). We consider it likely that its density variations are driven by pre-disturbance distributions as no other site influences are apparent. The positive correlations of planted tree biomass and height with autumn olive cover suggest a response to autumn-olive cycled N, a finding that is consistent with such effects in tree plantations (Pashke et al. 1989; Pedlar et al. 2006). With mean height >2x planted trees, rapid growth, and typically broad and dense crown, autumn olive has the potential to overtop and outcompete planted trees. Our data demonstrate that effect at higher densities, as planted tree stocking correlates negatively with autumn olive cover when cover is >5% (ρ=0.63, p=.02), while planted stockings for 3 plots with >11% autumn olive cover are among the 6 lowest recorded. The correlation of planted tree growth with autumn olive cover may also have been due to similar responses to unmeasured soil conditions.

Soil pH was correlated with planted tree height and NBNV stocking (Table 4). These findings, combined with known mine soil property effects on active mines' reforestation success, suggests mine soil properties may be influencing site's response to restoration treatments. In the Appalachians, mine soils with moderately acidic pH's (~5-6.5), low SS, and low CF% are generally favorable to planted tree growth (e.g. Showalter et al. 2007; Angel et al. 2008; Emerson et al. 2009) and to site invasion by native volunteers (Angel et al. 2008).

Two years after treatment, the restoration is progressing; some areas appear to be reverting to autumn olive and black locust dominance due to prolific stump sprouting. Pre-restoration plant communities and soil properties appear as primary influences on restoration progress to date. Managing these dynamics is especially challenging on older mine sites where, unlike new sites with freshly constructed soils, a plant community, many of which are non-native and exotic, are already in place and able to influence ecosystem development unless intentionally suppressed. Timely, judicious, herbicide treatment, before (broadcast spray) or after (stump treatment) mechanical removal of aggressive, undesired species, may be required. Prior research demonstrates that soil tillage to alleviate compaction will increase survival and growth of trees planted on previously reclaimed Appalachian coal mines (Fields-Johnson et al. 2008; Skousen et al. 2009). Soil density and nutrient deficiency mitigation, however, can also stimulate the pre-existing plant community making it more competitive.

The results of this prototype application of reforestation guidelines for unused mined land demonstrate the importance of pre-planting cultural treatments when restoring forest on previously reclaimed Appalachian coal mines. Mine soils are commonly deficient in essential nutrients, especially N; planted trees require these nutrients to emerge from competition, but broadcast applications may have stimulated that competition which was largely responsible for the low initial survival of the planted trees. Strategic nutrient applications targeted to planted trees, such as band application in the ripping row and/or as pellets in the rooting zone, may increase planted trees' survival and early growth while minimizing stimulation of herbaceous competition. Herbicide application prior to site clearing could also slow competition from site occupants capable of live-root propagation. These results suggest that strict adherence to the timing and order for applying the sequence of reforestation practices is important for reforestation success. Pre- and post-planting control of competitive, existing vegetation is critical; nutrients added to improve forest productivity must be applied in ways that do not exacerbate the proliferation of unwanted vegetation.

Application and Adoption of Reforestation Guidelines for Unused Mined Land

In 2004, the Office of Surface Mining and the seven state regulatory authorities in Appalachia created the Appalachian Regional Reforestation Initiative (ARRI) to reestablish healthy, productive forest habitat on active and abandoned mine lands in the eastern coal fields (Angel et al., 2005). Since 2004, approximately 70 million trees have been planted on FRA sites and approximately 41,683 ha restored to forests on newly mined land. ARRI informs and works with the active mining industry and regulatory personnel to apply the FRA to reclaim new surface mine disturbances to forests. ARRI is also 'looking backward' at the estimated 300,000 ha of non-forested unused mined lands that could be available for reforestation in the Eastern US. The reforestation guidelines for unused mined land (Burger and Zipper, 2010) have been applied by ARRI to selected mined sites for restoring unused mined land to native forests.

In 2009 and 2010, ARRI partnered with state and federal agencies, watershed groups, coal operators, conservation groups, environmental organizations, faith-based groups, and numerous universities, colleges, and high schools to coordinate 22 volunteer tree planting projects/events throughout Appalachia (Tables 5 and 6). These events involved 156 ARRI partner organizations and over 2,500 ARRI volunteers and resulted in the planting of over 175,000 trees on about 96 ha of previously reclaimed mine sites where reforestation was not attempted, or where the results were undesirable. ARRI's role in these endeavors is to facilitate communication and provide technical assistance to all partners involved in the tree planting projects. ARRI foresters coordinated site selection and evaluation, herbicide treatments, ripping activities, species selection, tree planting, and follow-up surveys as close to the Virginia Tech methodologies described above as available resources and funding would permit.

This post-reclamation reforestation effort has the additional benefit of outreach and awareness that is being created for proper mine land reforestation with the public, industry, and regulatory authorities. Ripping and tree planting partnerships with several mining companies on some of their previously reclaimed mine lands have led them to embrace the FRA on their active mining operations. Many state and federal regulators involved in the volunteer tree planting projects have expressed positive attitudes for the forestry post-mining land use and employing the FRA on the 'front-end' of the reclamation process instead of as an 'after the fact' process. It is also creating research opportunities for further refinement of the reforestation guidelines.

After two years of piecing together tree planting projects with donated trees, in-kind services, volunteer tree planters, and very limited funding, the ARRI tree planting events are now evolving into large scale projects funded by grants, cost share programs, utility companies seeking carbon credits and corporate donations. Most of this funding is used for site preparation and purchasing seedlings. In many situations volunteer tree planters will still be needed. Over 500 ha of pervious reclaimed mine lands in Appalachia are being prepared for spring tree planting in 2011, representing a fivefold increase over the acreage planted in 2010; and in three years (2009, 2010, and 2011), the ARRI tree planting projects will have planted over 1 million trees on post-bond released *unused* mined land (Table 5).

Table 5. ARRI tree planting projects on post-bond released mine lands in Appalachia: Trees and area planted; 1st and 2nd year survival and growth (where recorded), by year.

Year, Job, Location	Planted: Area (ha)	Planted: Trees	Survival: 1st Year	Survival: 2nd Year	Avg Ht (cm): 1st Year	Avg Ht (cm): 2nd Year
2009						
Flying Rooster Farm (P1) , Whitley Co, KY	1.9	5,700	85%	85%	40.6	45.2
Little Beaver Creek Land Foundation (Phase 1) , Columbiana Co, OH	1.4	3,500	82%	82%	38.1	48.3
Schuylkill Headwaters Association (MTM Phase 1), Schuylkill Co, PA	0.8	2,000	80%	79%	38.1	45.2
Plum Creek , Webster Co, WV	3.2	9,440	76%	77%	40.6	43.2
Crane's Nest, Wise Co, VA	2.4	4,500	78%		43.2	
Appalachian Coal Country Watershed Team , Boone Co, WV	1.6	3,650	88%	89%	35.6	45.7
Splashdam , Dickenson Co, VA	0.8	1,825	78%		30.5	
Headwaters, Inc (WVB) , Letcher Co, KY	2	4,200	88%		40.6	
Total planted; survival, height averages – 8 sites	14.1	34,815	82%	82%	38.4	45.5
2010						
Flying Rooster Farm (P2), Whitley Co, KY	8.5	14,280	75%		43.2	
Headwaters, Inc, Letcher Co, KY	13.8	29,821	90%		45.7	
Dollar Branch (P1), Harlan Co, KY	10.4	17,500	82%		38.1	
Larry York Farm, Morgan Co, KY	15.4	25,900	89%		43.2	
Appalachian School of Law, Buchanan Co, VA	0.8	1,360				
Appalachian Coal Country Watershed Team Tree , Boone Co, WV	4.1	6,800	86%		40.6	
Cliffs Natural Resources , Wyoming Co, WV	3.3	5,508	86%		43.2	
Garrett County & Savage River Watershed Associations , Garrett Co, MD	16.2	27,200				
Barnsville Area Reforestation Kommittee, Belmont Co, OH	2	3,400				
Little Beaver Creek Land Foundation (Phase 2) , Columbiana Co, OH	2.9	4,828	86%		38.1	
Pine Branch Coal Company, Perry Co, KY	0.4	680				
House Fork , Dickenson Co, VA	1.6	2,720				
Schuylkill Headwaters Association (MTM Phase 2), Schuylkill Co, PA	0.8	1,360	84%		38.1	
Schuylkill Headwaters Association (DVE) , Schuylkill Co, PA	1.6	2,720	85%		35.6	
Total planted; survival, height averages – 15 sites	81.8	144,077	85%		40.6	

Table 5 Continued

Year, Job, Location	Planted Area (ha)	Trees
2011		
Yatesville Lake, Lawrence Co, KY	6.1	10,200
Fishtrap Lake , Pike Co, KY	9.3	15,640
Dollar Branch (Phase 2) , Harlan Co, KY	3.2	5,440
Flying Rooster Farm (Phase 3) , Whitley Co, KY	1.6	2,720
Premier Elkhorn Coal Company, Letcher/Pike Co, KY	47.3	79,560
Sierra Club Fishtrap Lake Watershed , Pike Co, KY	91.1	153,000
Southern Appalachian Mixed-Mesophytic Initiative, Eastern Kentucky coal fields	60.7	102,000
Columbiana County Park District, Columbiana Co, OH	75	125,800
Indiana University of Pennsylvania , Clinton/Centre Co, PA	84.6	142,120
Roaring Run Watershed Association, Armstrong Co, PA	10.1	17,000
Schuylkill Headwaters Association (MTM Phase 3), Schuylkill Co, PA	0.8	1,360
Schuylkill Headwaters Association (RA), Schuylkill Co, PA	0.8	1,360
Virginia Division of Forestry, Dickenson Co, VA	2	3,400
Friends of Cheat River, Preston Co, WV	2	3,400
Forest Service Mower Branch , Randolph Co, WV	36.4	61,200
Plum Creek , Webster Co, WV	32.4	54,400
Appalachian Coal Country Team , Boone Co, WV	4	6,800
Cliffs Natural Resources , Logan Co, WV	4.1	6,800
Alabama Division of Forestry , Alabama coal fields	60.7	102,000
Total Planned Plantings - 19 Sites	532	894,200

Note: For some sites, acreages and tree planting totals are approximate.

Table 6. ARRI Partners on tree planting projects on post-bond released mine lands in Appalachia in 2009, 2010, and 2011.

Partner	No. Sites	Partner	No. Sites
AFLAC Agent Chad Hutchinson	2	Maryland Dept. of the Environment	1
Alabama Div. of Forestry	1	McClure River Restoration Project	1
Alpha Natural Resources	1	Miller, Mary	1
American Bird Conservancy	1	Morehead State University	2
American Forest Hertitage	1	Mountain Assoc. for Community Econ. Dev.	1
American Municipal Power	1	Mountaintop Mining	3
AmeriCorp	1	Mullens Ministerial Association	1
Appalachia – Science in the Public Interest	1	National Civilian Community Corps	6
Appalachian Coal Country Watershed Team	28	National Park Service	1
Appalachian Joint Venture	1	Natural Resource Conservation Service	2
Appalachian Regional Reforestation Initiative	40	Norfolk Southern Foundation	1
Appalachian School of Law	1	Northern Kentucky University	1
ArborGen	8	Oakbrook Church in Reston, VA	2
Armstrong Conservation District	1	Office of Surface Mining, USDI	40
Barnesville Area Reforestation Kommittee	1	Ohio Dept. of Natural Resources	4
Bates, Dr. Artie Ann	1	Ohio State University	3
Bates, William Van	1	Oxford Mining	2
Beaver High School Environmental Club	1	Patriot Coal Company	3
Berea College	6	Penn State Schuylkill Biology Club	4
Bereans for Appalachia	2	Penn's Corner RC&D Council	1
Boy Scouts of America	3	PA Dept. of Conservation & Nat. Res.	7
Cabot Oil and Gas Corporation	1	PA Dept. of Environmental Protection	7
Camp Dawson National Guard	1	PA Game Commission	7
Camp Robert C. Webb	1	Pine Branch Coal Company	1
Campus Christian Center	2	Pine Mountain Grill	1
Carter Caterpillar	1	Pine Mountain Settlement School	2
Central App. Spruce Restoration Initiative	1	Plum Creek Timberlands, L.P.	2
Cliffs Natural Resources, Inc.	2	Premier Elkhorn Coal Company	1
Clintwood Elkhorn Coal Company	1	Reading Anthracite	1
Coal Heritage Highway Authority	1	Richwood High School	1
Coldwell Timber Consulting	3	River City Drum Corp	1
Columbiana Co. Fed. of Conservation Clubs	2	Roaring Run Watershed Association	1
Columbiana County Park District	3	RPM Ecosystems LLC	1
Columbiana Soil & Water Conservation Dist.	2	Ruffed Grouse Society	2
Conservation Services, Inc.	31	Rural Appalachian Improvement League	1
Crystal, Denny and Merrill	1	Savage River Watershed Association	1
Delaware Valley Earthforce	2	Scenic Rivers Program (ODNR)	2
Dickenson County School System	1	Schuylkill Conservation District	5
Drew University	1	Schuylkill County Commissioners	5
DriWater, Inc.	1	Schuylkill Headwaters Association	5
Eastern Coal Regional Roundtable	3	Shavers Fork Coalition	1
Eastern KY University	1	Shell Heirs	2
Flatwoods Job Corps	1	Sierra Club – Bluegrass Chapter	6
Flying Roster Farm	3	Sproul State Forest	1

Table 6 Continued

Partner	No. Sites	Partner	No. Sites
Foundation for Pennsylvania Watersheds	1	Starbucks	1
Friends of Cheat River	1	Tampa Electric Company	1
Friends of Coal, Ladies Auxiliary	3	Terra Tech Engineering	1
Friends of the Russell Fork	2	The American Chestnut Foundation	40
Frostburg Pizza Hut	1	The Baum Foundation	1
Frostburg State University	1	The Forest Management Company	1
Garrett County Watershed Association	1	The Nature Conservancy	1
GenOn Energy, Inc.	1	Union Concrete, Division of RBS Inc	5
Girl Scouts of America	1	Unitarian Universalist Fellowship of Cumberland	1
Groundwork Wyoming County	1	United Nations Environmental Program	1
Guest River Restoration Project	1	United States Fish and Wildlife Service	2
Headwaters, Inc.	3	United States Forest Service	20
Highlandtown Wildlife Area (ODNR)	2	University of Kansas	1
Hill Creek Nursery	1	University of Kentucky	29
Huntington Bank	2	University of Notre Dame	1
ICG Eastern, LLC	1	University of the Cumberlands	3
Indiana University of Pennsylvania	1	University of Vermont	1
Interfaith Youth Core	2	Upper Guyandotte Watershed Assoc.	1
James River Coal Company	2	Upper Tennessee River Rountable	1
Jeffco Resources, Inc.	1	US Army Corps of Engineers	2
JTW Gas Well Service	1	VA Dept. of Mines and Minerals Energy	4
Ken and Coy	1	VA Division of Forestry	3
Kent State University	1	VA Tech	1
KY Dept. of Fish and Wildlife Resources	13	Wal-Mart (Frostburg, MD)	1
KY Div. of Abandoned Mine Lands	12	Wal-Mart (Schuylkill, PA)	1
KY Div. of Conservation	1	WV Dept. of Environmental Protection	9
KY Div. of Forestry	12	WV Division of Forestry	7
KY Div. of Mining Reclam. Enforcement	14	WV University	1
Kiski Realty Company, Inc.	1	WFA	5
Larry York	1	Western Maryland RC&D Council	1
Little Beaver Creek Land Foundation	3	Woman's Club of Morgan County	1
Lonesome Pine Soil & Water Conserv. Dist.	1	Woodland Community Land Trust	1
Lowe's Home Improvement - Beckley, WV	1	Wyoming County Board of Education	1
Loyola University	1	Young Men's Club of America	1
		Young Professionals of Eastern Ky., Inc.	1

ARRI foresters intend to return to each planting site after planting to measure survival, productivity, and natural regeneration, and to see what they can learn from the projects that will help them get better success on future projects. Initial observations show that ripping a site prepares a seedbed for natural succession. Succession on most sites had been heretofore arrested or substantially slowed because of the mine soil compaction and aggressive herbaceous competition. An immediate response in plant community succession on ripped tree planting sites has been observed. Early successional species such as red maple, sycamore (*Platanus occidentalis*), cottonwood (*Populus deltoids*), dogwood, black locust, big tooth aspen (*Populus grandidentata*) are frequently observed volunteers. We have also noted vigorous colonization of non-woody plants and native and non-native forbs such as, horseweed (*Conyza canadensis*), ragweed (*Ambrosia artemisiifolia*), aster (*Aster* sp.), goldenrod (*Solidago canadensis*), lambsquarter (*Chenopodium berlandieri*), wild carrot (*Dacus carota*), andcoltsfoot (*Tussilago farfara*). The biodiversity on the planting sites increases rapidly; instead of 2-3 dominant non-native grasses and legumes, there is an invasion of a myriad number of native plant species due to the site preparation conducted for each project. For planted trees, 83% survival was calculated for the first year on sites planted in 2009 and 2010 (Table 5). Second year survival on sites planted in 2009 was 83%. Although initial survival is very promising, reforestation success on these sites is a function of the trees' ability to grow freely above the competing vegetation, avoiding hazards including animal brose and rodent damage, and tolerating adverse mine soil conditions that could not be ameliorated. After only two years of experimentation, it is too early to determine the overall success of these forest establishment efforts. ARRI foresters will continue to monitor these sites in an attempt to test and refine the reforestation methodologies established by Virginia Tech for previously reclaimed sites (Burger and Zipper, 2010).

Conclusions

There is an opportunity to reforest thousands of hectares of unused mined land in the Appalachian region for the products and services the original forests provided prior to be removed by surface mining. Most of these unused land areas are covered with non-native and exotic vegetation that provide few products and services to landowners and surrounding communities. The Office of Surface Mining's Appalachian Regional Reforestation Initiative in cooperation with state authorities is actively working with various landowners, conservation groups, and financial sponsors to restore native forests. Reforesting these sites is challenging due to the nature and condition of these mined lands. Burger and Zipper (2010) developed specific procedures that are being applied by ARRI and its cooperators on various sites throughout the Appalachian coalfields. The first attempt by the Nature Conservancy in Virginia to restore a native forest on an unused mined site appears to be successful, but it showed that aggressive control of competing vegetation and strategic application of nutrients, so as to stimulate height growth by planted trees while minimizing stimulation of competition, are important components of the unused mined lands' reforestation strategy.

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