NATIVE TREE SURVIVAL AND HERBACEOUS ESTABLISHMENT ON AN EXPERIMENTALLY RECLAIMED APPALACHIAN COAL MINE[1]

S.C. Koropchak[2], C.E. Zipper, J.A. Burger, and D. M. Evans

Abstract: On a surface coal mine in southern West Virginia, the forestry reclamation approach was applied while quantifying the effects of substrate type and seeding prescription on survival and growth of native tree species and herbaceous vegetation. Four substrates were used: weathered sandstone (brown), unweathered sandstone/shale mix (gray), mixture of weathered and unweathered rock (mixed), and a mixture of the soil solum and unconsolidated soil parent material (soil). Each substrate treatment was split into two subplots; one seeded with a tree-compatible herbaceous seed mixture and one unseeded. Trees were planted in March 2012, measured for initial height in June 2012, and measured for height and survival in late October 2012. Herbaceous groundcover and species richness were measured during the growing season. After one growing season, mean percent survival and growth of planted trees differed among tree species and seeding treatments. There were no differences in tree survival among substrate treatments. Of planted tree species, survival was higher for hawthorn and black cherry (~85%) than for most other species and lowest for Eastern white pines (25.3%) and shagbark hickory (24.3%). Unseeded treatments had higher tree survival (70.4%) than seeded treatments (56.4%). Of the trees which survived the first growing season, black cherry, red oak, sugar maple, and white oak showed differences in height growth related to experimental treatments. Black cherry and red oak trees grew more in the unseeded treatment, compared to the seeded treatment. White oaks grew the most in the brown sandstone treatment. Sugar maples grew the most in the seeded mixed treatment. Gray and soil substrate treatments had the highest total herbaceous richness and the soil treatment had the highest volunteer richness. Seeded treatments had less bare ground and higher mean herbaceous species richness than unseeded subplots. Leaving the landscape unseeded facilitated tree establishment, but the impact of seeding on the future understory community remains unclear. Soil appears superior to rock spoils for re-establishing a diverse understory. We expect that the influence of substrate and seeding treatments will become clearer after additional growing seasons.

Additional Key Words: Forestry reclamation approach; seeding; tree establishment

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Introduction

The southern Appalachian region supports some of the greatest biodiversity in the United States and is a source for many valuable resources, such as timber and coal (Stein et al., 2000; Riitters et al., 2000; Turner and Daily, 2008). One of the major disturbances in this region over the last 150 years has been coal mining, particularly after surface mining became an important means of coal extraction starting in the 1960s (Hibbard, 1987). Increased surface mining transformed vast areas of the montane forested landscape into other land covers; much reclaimed mine land is not used productively (Zipper et al., 2011). After the passage of the Surface Mining Control and Reclamation Act (SMCRA) in 1977, the coal mining industry became legally obligated to re-contour the landscape and establish a land use capability that is "equal to or better than" what the landscape originally supported. Often, these novel landscapes were not reclaimed with the intent to restore native forested land cover (Angel et al., 2005). The Forest Reclamation Approach (FRA) was thus developed under SMCRA to provide protocols for reclamation to support forested land uses (Angel et al., 2005). The primary goal of these guidelines was to restore the ecological value of the landscape in a cost-effective manner as well as to recreate ecosystem function and economic value (Burger et al., 2005). This study investigates the effects of cover crops and various substrates on the reclamation of surface mines with tree species native to the Appalachian forests.

Although seeding herbaceous cover crops is common SMCRA protocol in coal mine reclamation, there have been concerns about the net impacts on the establishment of focal tree species. In several cases, seeded herbaceous species, even those classified as "tree-compatible," have been found to persist on reclamation sites, negatively impacting tree establishment and growth through competition for resources (Fields-Johnson et al., 2012; Franklin et al., 2012). Fields-Johnson et al. (2012) further demonstrated that tree survival and growth may improve when planted with less competitive groundcover, but there have been few (if any) studies investigating the effects of applying no seed to tree plantings. Furthermore, although the FRA guidelines recommend 1.2 m of the 'best available' rooting medium, others have recommended that native forest soil is essential to reforestation success (Burger et al., 2009; Skousen et al., 2011; Zipper et al., 2013). However, there are limited large-scale experimental studies using native forest soil, and even fewer in this category that are surrounded by disturbed land (Hall et al., 2010). There are also no studies examining how these two factors, substrate selection and seeding prescription, interact to affect native tree survival and growth.

Additionally, as forest reclamation involves the return of a native forest understory community in addition to native trees, substrate and seeding prescriptions should be selected that maximize recruitment and establishment of desirable plants. The use of native forest soil has the potential to introduce a native species pool from the existing seed bank (Koch, 2007; Hall et al., 2010).

Here, we address the following questions:

Q1a. How does a tree-compatible seeding prescription affect tree establishment and growth compared to an unseeded treatment after one growing season?

Q1b. How is establishment and growth of tree species affected by various substrates which span a weathering gradient?

Q1c. How do seeding and substrate treatments interactively affect establishment and growth of a variety of tree species?

Q2. Does the use of soil as a planting medium result in more volunteer species compared to other substrates after one growing season?

Methods

Site description and construction

To answer the aforementioned questions, a 6.5 hectare study site was established near Yolyn, WV (37°49′45″N 81°51′40″W) on the North Rum permit of the Apogee Coal mining complex. In winter 2011/2012, 1.6-hectare blocks (n = 4) of substrate treatments were constructed, each containing four 0.4-hectare substrate treatment plots (Fig. 1). Each 0.4 ha plot was constructed using one of four substrate treatments across a gradient of weathering such that each block received one replicate of each of the following treatments:

Gray: Mostly gray/unweathered sandstone with some unweathered siltstone and shale.

Mixed: A 50/50 mix of the brown and gray substrates. Materials expected to weather to soil-like materials with pH<7 were preferentially selected.

Brown: Weathered brown sandstone with some weathered siltstone and shale.

Soil: Soil was harvested after forest clearing and was not stockpiled or mixed before placement. Includes solum and unconsolidated parent material.

Substrates were loosely placed to a depth of ~1.2 to 1.8 m without any efforts to compact the material.

Substrate analysis

Substrate samples were collected and characterized in the lab to quantify the variability within and among treatments. Composition of the treatment substrates was determined by sieving the substrate (2 mm mesh) and weighing coarse fragments. Coarse fragments were then characterized as weathered sandstone, unweathered sandstone, weathered shale, unweathered shale, weathered siltstone, or unweathered siltstone. Coarse fragments for each of these categories were weighed and percent mass was calculated.

The Virginia Tech Soil Testing Lab (Maguire and Heckendorn, 2009) did soil (fine fragment) chemical analysis. Analysis included pH; Mehlich 1 extractable P, K, Ca, Mg, Zn, Mn, Cu, Fe, B; soluble salts; and estimated organic matter content determined via loss on ignition (LOI).

Seed application

Each 0.4 ha substrate plot was split into two 0.2 ha seeding subplots. In each substrate plot, one 0.2 ha subplot was hydro-seeded with a mix of tree-compatible species, mulch, and fertilizer; one 0.2 ha subplot was left unseeded but received the same mulch/fertilizer treatment as the seeded treatment (Table 1) (Angel et al., 2005; Burger et al., 2005).

Tree planting

Across the entire study site, Williams Forestry Associates (Table 2) planted a mix of early and late succession tree species at approximately equal density in March 2012. Planted trees were bare root seedlings with a mean height of 30 ± 15 cm, though the variation among species was much greater (Table 3).

Within plots, tree-planting microsites were selected to avoid ridges/hummocks and hollows so that trees would not be buried or washed away as the substrate settled and eroded. Planted trees within tree plots were identified and recorded in June and October 2012 to calculate the actual trees planted per hectare, because actual planting rates often deviate from prescribed rates (Table 2).

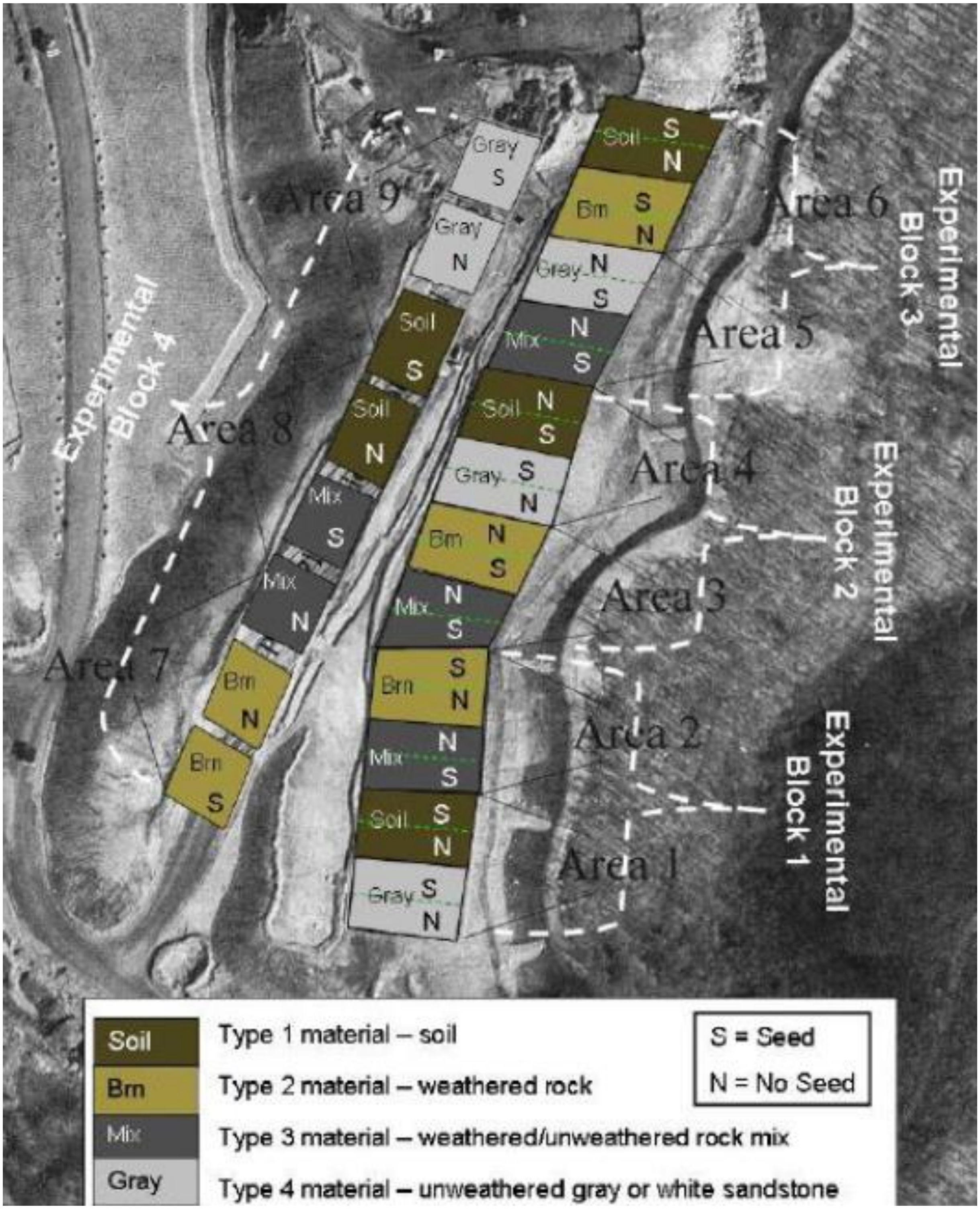

Figure 1. Plot diagram is showing the arrangement of the four-substrate treatments within the four blocks and the placement of the seeded/unseeded subplots. Blocks 1-3 contained rectangular plots located on a steep slope with a southeast aspect and block 4 contained square subplots that were placed on the flat, level surface adjacent to the slope.

Table 1. Application rates of seeded species and amendments in seeded and unseeded subplots.

Species/amendment	**Seeded**	**No seed**
	Application rates (kg/ha)	
Perennial grasses:		
Perennial ryegrass	11.2	0
Timothy grass	5.6	0
Annual grasses:		
Annual ryegrass	5.6	0
Legumes (with inoculant):		
Birdsfoot trefoil	5.6	0
White clover	3.4	0
Fertilizer:		
Nitrogen (N)	56-84	56-84
Phosphorus (as P)	90-112	90-112
Phosphorus (as P_2O_5)	202-258	202-258
Potassium (K)	56-84	56-84
Mulch:		
Cellulose fiber	1681	1681

Table 2. Prescribed tree planting density and actual tree density (trees per hectare) observed in June 2012. Letters in parentheses represent abbreviated species names, which will be used for data presentation.

Species	**Tree planting prescription**	**Trees observed in June 2012**
White Oak (WO)	247	261
Northern Red Oak (RO)	247	198
Chestnut Oak (CO)	247	208
Sugar Maple (SM)	247	202
Black Cherry (BC)	247	221
Shagbark Hickory (SH)	124	79
Tulip Poplar (TP)	124	101
Hawthorn (H)	62	57
Eastern Redbud (RB)	62	59
Gray Dogwood (GD)	62	62
Eastern White Pine (EWP)	62	46
Total trees planted (trees/ha)	1731	1494

Table 3. Mean initial height of planted tree species ± standard deviation.

Species	Mean initial height ± Standard Deviation
Black cherry (BC)	37.1 ± 0.8
Chestnut oak (CO)	31.5 ± 0.5
Eastern white pine (EWP)	24.5 ± 0.7
Gray dogwood (GD)	48.0 ± 1.1
Hawthorn (H)	52.4 ± 1.4
Redbud (RB)	39.0 ± 1.5
Red oak (RO)	31.5 ± 0.4
Shagbark hickory (SH)	7.9 ± 0.3
Sugar maple (SM)	15.1 ± 0.4
Tulip poplar (TP)	32.6 ± 0.9
White oak (WO)	28.4 ± 0.5

Vegetation sampling

Establishing permanent plots In June 2012, 32 permanent transects were established, with one transect bisecting each seeding subplot. On each transect, three permanent, 1/50 ha, circular tree plots were established. Within each tree plot, four, one m^2 square herbaceous quadrats were nested. Herbaceous quadrats were placed directly upslope, directly downslope and both right and left across the slope, 4 m from each tree plot center.

Vegetation sampling methods Initial measurements of tree survival and height took place in June 2012. Initial height was determined by measuring from the ground up to the base of the current year’s new growth. If trees had fallen down, they were picked up and measured as though they were still standing to better assess initial planted height. Dead trees were also recorded and measured. Living trees were measured again at the end of the growing season in late October 2012 to determine year one survival and vertical growth. Individual trees were identified during the measurement process, so change in height for each surviving individual in October, relative to the June measurement, was determined.

Herbaceous plant sampling occurred in June 2012 and in late July 2012. For both sampling dates all herbaceous species, as well as cover of bare ground were recorded and percent cover of each species was estimated visually in cover classes (0, 1-10, 11-30, 31-50, 51-70, 71-90, and 91-100). All species in the unseeded subplots were recorded as volunteers, including those species that were planted in the seeded subplots. Unknown plant species were collected and identified in the Massey Herbarium at Virginia Tech. Total species richness, volunteer richness, total percent cover, and Shannon-Wiener diversity were calculated from the herbaceous data.

Data analysis

Substrate coarse fragment content, coarse fragment rock type, and chemistry were analyzed by analysis of variance (ANOVA) to assess differences within and among substrate treatments (Sigma-plot 11.0, Systat Software, Inc., 2008). All vegetation data were analyzed using SAS 9.2 (SAS Institute, Inc., Cary, NC). Tree survival and growth, herbaceous richness and diversity, and bare ground were analyzed by analysis of variance (ANOVA) using the mixed model procedure to account for random effects, such as blocking. Tree growth was analyzed within each species, as inherent growth rates for each species might otherwise mask treatment effects. Significance was determined with $\alpha = 0.05$.

Bray-Curtis dissimilarity was calculated between each possible pair of herbaceous plots based on abundances of all species (McCune and Grace, 2002). The resulting dissimilarity matrix was used to perform non-metric multidimensional scaling (NMDS) (DECODA, Minchin, 1988). NMDS is a way to visually compare similarity between plots in order to summarize a complex dataset. Dissimilarity, or "distance," between each pair of sampling units is calculated and ranked to approximate how the sampling units would be positioned in space. The further points are relative to one another, the less they have in common. The resulting graph will show clusters of points that ideally correspond to treatment groups. The number of axes used to represent the dataset is decided by how well the positioning of the points in space corresponds to distances between points, also known as stress or the "badness of fit" (scale from 0 to 1). The minimum number of axes where stress was less than 0.2 was selected. Analysis of similarity (ANOSIM) (PRIMER v6) was also performed by ranking all values of the dissimilarity matrix to determine whether communities within treatment groups are significantly different (Clarke and Green, 1988; Clarke, 1993; McCune and Grace, 2002).

Results

Substrate analysis

Analysis of substrate physical properties found minimal differences among substrate treatments (Table 4). The brown, gray, and mixed substrate treatments were not significantly different from one another for any of the measured variables. The soil treatment had lower coarse fragment content than the mixed treatment. Within the coarse fragments, the soil treatment had a greater percentage of weathered siltstone than the gray and mixed substrates. The coarse fragment composition of the soil treatment did not differ significantly from the brown substrate in any of the measured variables.

Table 4. Mean rock type composition of substrate treatments by weight ± standard error. Data are presented as percentages.

		Weathered			Unweathered		
Substrate type	**Coarse fragment**	**Sandstone**	**Siltstone**	**Shale**	**Sandstone**	**Siltstone**	**Shale**
Gray	44.4±3.3[ab]†	48.8±3.2	6.4±2.1[b]	5.6±1.7[ab]	17.2±5.6	7.8±1.4	12.7±3.2
Mix	45.9±0.8[a]	57.0±8.4	4.2±0.9[b]	4.0±0.9[b]	9.8±1.1	10.1±2.6	14.0±4.1
Brown	41.7±2.0[ab]	49.8±12.2	7.5±1.2[ab]	5.5±0.6[ab]	9.7±2.8	12.0±4.5	13.3±5.3
Soil	33.0±2.3[b]	35.1±7.5	13.6±1.7[a]	16.7±4.5[a]	7.5±4.1	12.7±2.7	11.9±2.5

† Substrate mean values for any soil property followed by the same letter are not significantly different from one another ($p < 0.05$).

The fine material (<2 mm fragments) of the soil treatment showed some differences from the gray and mixed substrate treatments (Tables 5a and 5b), but did not differ from the brown sandstone treatment in any of the measured parameters. Fine material from the soil substrate treatment had lower extractable phosphorus, extractable Ca, pH, and base saturation than fines from the gray substrate treatment. The soil treatment had higher percent organic matter than the mixed treatment, although neither differed significantly from the brown or gray treatments.

Table 5a. Mean extractable nutrients for substrate treatment fine materials (mg kg^{-1}).

Substrate	**P**	**K**	**Ca**	**Mg**	**Zn**	**Mn**	**Cu**	**Fe**	**B**
Gray	39.0[a]†	51.0	704.6	196.8	2.2	56.1	1.9	128.8	0.1
Mixed	28.8[ab]	42.6	487.4	168.8	2.1	44.3	1.7	80.5	0.1
Brown	33.8[ab]	54.8	624.6	199.4	2.8	49.8	2.6	82.6	0.1
Soil	21.6[b]	61.2	399.8	177.6	2.7	37.8	3.2	75.0	0.1

† Substrate mean values for any soil property followed by the same letter are not significantly different from one another ($p < 0.05$).

Table 5b. Means of additional chemical analyses of fine materials in substrate treatments. Soluble salts measured as mg L^{-1}, cation exchange capacity as meq (100 g soil)$^{-1}$. Organic matter, base saturation, Ca^{2+} saturation, Mg^{2+} saturation and K^{+} saturation reported as percentages.

Substrate	pH	Organic matter	Soluble salts	Cation exchange capacity	Base Saturation	Ca^{2+} Saturation	Mg^{2+} Saturation	K^{+} Saturation
Gray	7.7[a]†	1.1[ab]	90.0	5.3	100[a]	66.7[a]	30.8	2.5
Mixed	6.9[ab]	0.9[b]	64.0	3.9	99.5[ab]	60.1[ab]	35.8	2.8
Brown	7.0[ab]	1.1[ab]	102.0	5.0	97.2[ab]	61.0[ab]	33.4	2.9
Soil	5.8[b]	1.3[a]	64.0	4.9	73.8[b]	39.3[b]	31.1	3.5

† Substrate mean values for any soil property followed by the same letter are not significantly different from one another ($p < 0.05$).

Tree survival

Tree survival was different between seeding treatments (p<0.0001) (Fig. 2a) and among tree species (p<0.0001) (Fig. 2b). There were no significant effects on tree survival from substrate treatments, nor were there any interactions among treatments (p > 0.05). Tree survival, on average, was higher in unseeded treatments (70.3%) than seeded treatments (56.2%). Mean percent survival also differed among tree species. Hawthorn (85.7%) and black cherry (85%) had the highest mean survival, closely followed by redbud (81.6%) and gray dogwood (80.8%). Survival was lowest for the Eastern white pines (25.3%) and shagbark hickory (24.3%), followed by sugar maples (37.9%). Across all treatments and species, the first year survival rate was 65.9%.

Tree growth

Seeding treatment affected tree growth for two of the eleven planted species; black cherry (p = 0.01) and red oak (p = 0.04), which both grew more in unseeded treatments (Table 6). Tree growth was not significantly affected by seeding treatment for any other planted tree species. Substrate treatment affected the growth of white oaks (p = 0.02) but did not affect any other planted tree species. On average, white oaks grew approximately twice as tall in the brown sandstone treatment, compared to the other substrate treatments (Fig. 3). The growth of one species was affected by an interaction between seeding and substrate treatment; sugar maples grew more in the mixed, seeded treatment (p = 0.03) (Fig. 4).

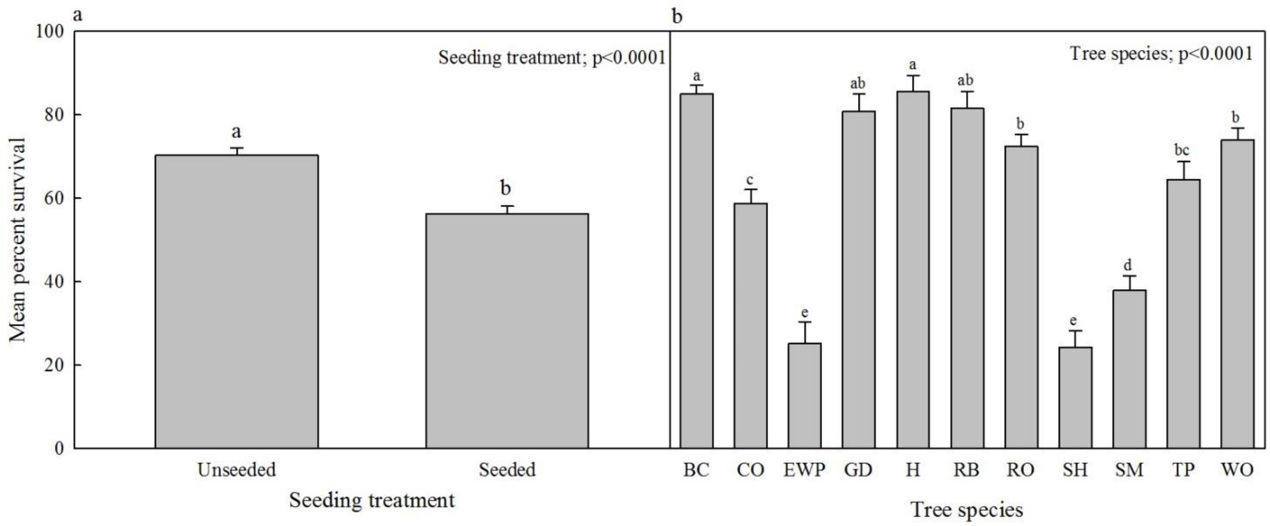

Figure 2. (a) Mean percent tree survival in seeded and unseeded subplots. (b) Mean percent tree survival among planted tree species ± standard error. Different letters (a-e) represent significant differences among treatments as determined from differences in least square means. Species abbreviated names are presented in Table 2.

Table 6. Height growth (cm) means ± standard error for all planted tree species in seeded and unseeded treatments.

	Seeded	Unseeded	p-value
Black Cherry (BC)	16.22 ± 1.55	22.36 ± 1.63	0.01*
Red Oak (RO)	0.15 ± 1.68	5.30 ± 1.71	0.04*
Chestnut Oak (CO)	3.14 ± 1.72	6.21 ± 1.62	0.2
Eastern White Pine (EWP)	10.15 ± 1.96	9.26 ± 2.29	0.73
Gray Dogwood (GD)	13.45 ± 2.65	17.39 ± 2.32	0.27
Hawthorn (H)	14.19 ± 3.55	23.08 ± 3.12	0.07
Redbud (RB)	8.94 ± 2.15	7.00 ± 2.21	0.53
Shagbark Hickory (SH)	2.28 ± 1.43	-0.03 ± 1.18	0.23
Sugar Maple (SM)	8.73 ± 1.15	6.68 ± 1.09	0.2
Tulip Poplar (TP)	7.38 ± 2.05	2.41 ± 1.78	0.07
White Oak (WO)	5.94 ± 0.94	6.76 ± 0.97	0.55

* Height-growth difference between seeding treatments is statistically significant ($p<0.05$).

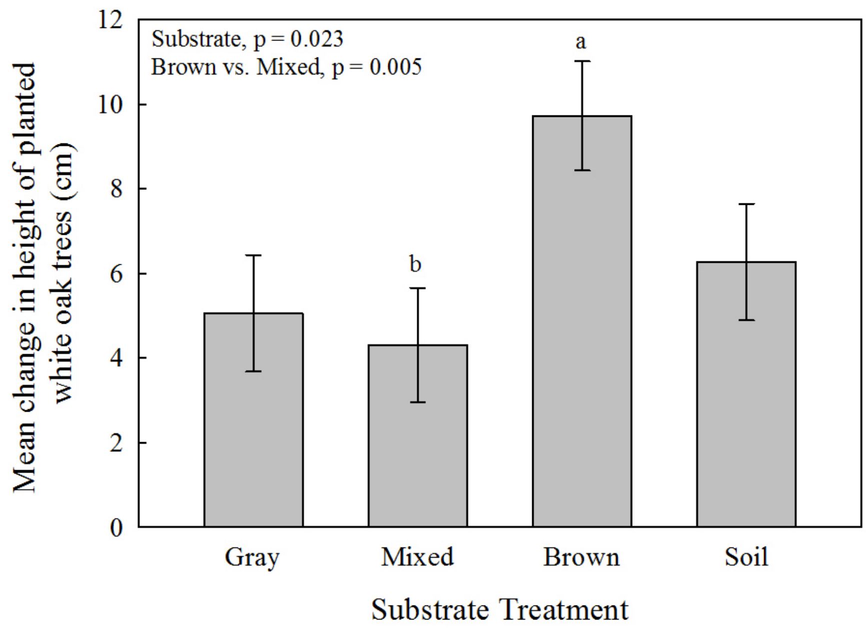

Figure 3. Mean change in height (cm) of live white oak trees in substrate treatments ± standard error. Different letters (a-b) represent significant differences ($p < 0.05$).

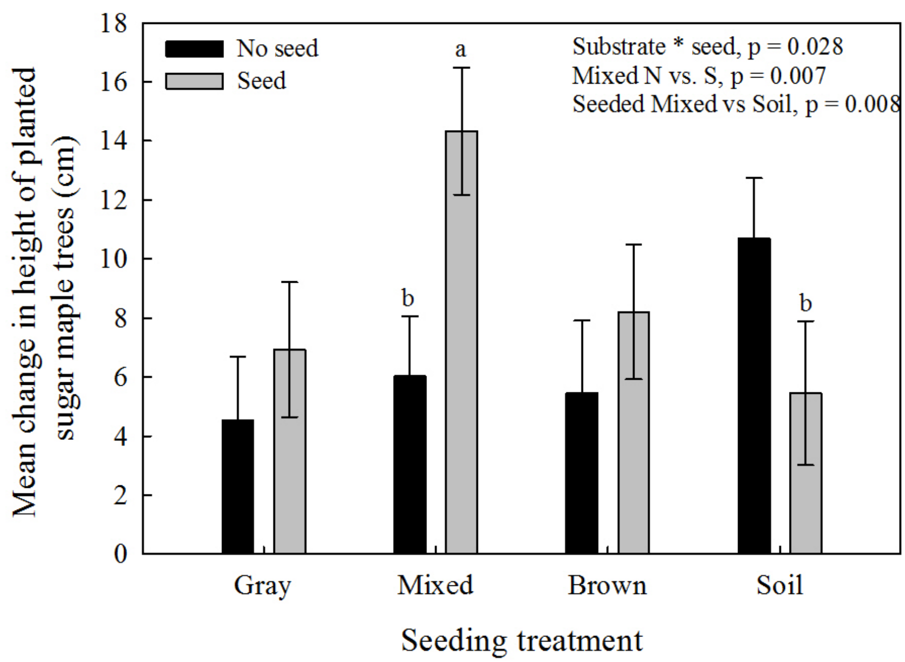

Figure 4. Mean change in height (cm) of live sugar maple trees in seeding and substrate treatments ± standard error. Different letters (a-b) represent significant differences ($p < 0.05$).

<u>Herbaceous species establishment</u>

Total species richness was affected by substrate type ($p=0.0007$) (Fig. 4a) and seeding treatment ($p<0.0001$) (Fig. 4b), but there were no significant interactions among treatments. Among substrate treatments, the soil treatment had the greatest mean species richness (minimum 0, maximum 11, mean 5.6 ± 0.3 species), and richness was lowest in the mixed treatment (minimum 0, maximum 6, mean 4.4 ± 0.2 species). Quadrats in seeded subplots had an average of 6.8 ± 0.1 species per m^2 (minimum 0, maximum 8 species), versus 3.3 ± 0.2 species (minimum 0, maximum 11 species) in the unseeded subplots. Not surprisingly, seeded subplots also had less bare ground than the unseeded subplots ($p< 0.0001$) (Fig. 5).

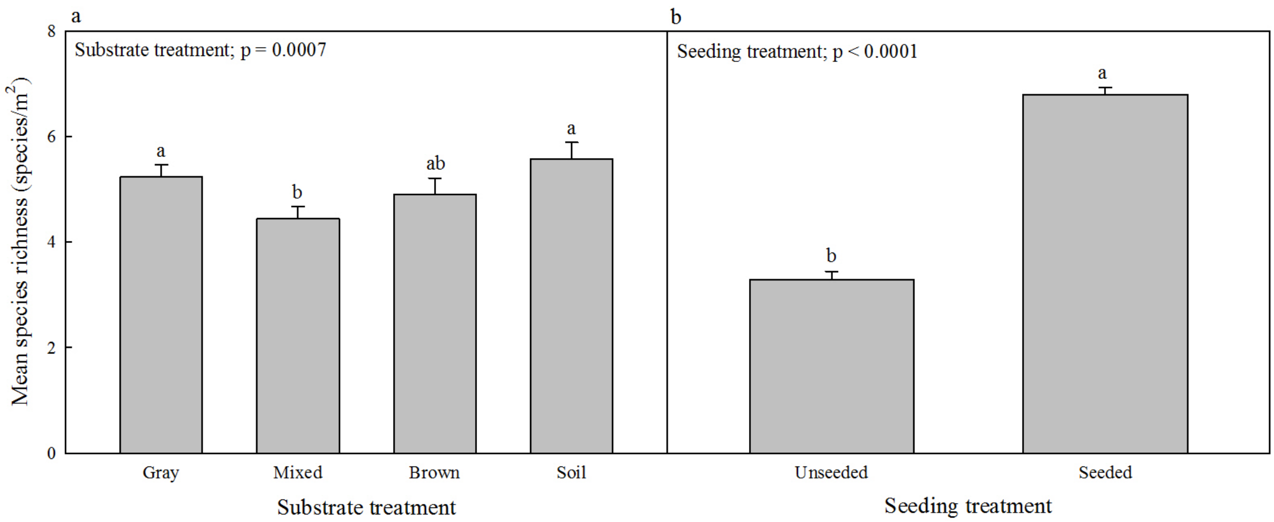

Figure 4. (a) Mean total species richness as affected by substrate treatment. (b) Mean total species richness as affected by seeding treatment ± standard error. Different letters (a-b) represent significant differences ($p < 0.05$).

Volunteer species richness was significantly affected by substrate treatments ($p=0.0006$) (Fig. 6a) and seeding treatments ($p<0.0001$) (Fig. 6b). There were no significant interactions between treatment effects. Soil treatments had an average of 3.1 ± 2.6 species per m^2, compared to 2.7 ± 2.1 species per m^2 in the gray treatment and 1.9 ± 1.5 species per m^2 in the mixed treatments. Unseeded treatments had an average of 3.3 ± 2.2 volunteer species per m^2, compared to 1.8 ± 1.8 species in the seeded subplots.

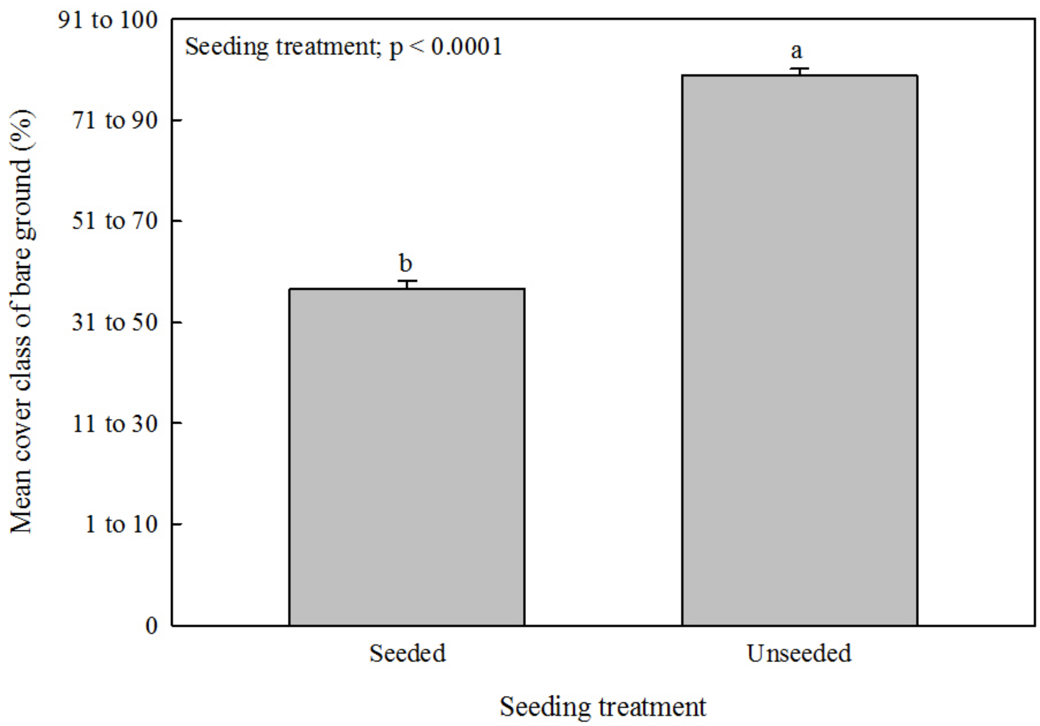

Figure 5. Mean scaled percent cover of bare ground within seeding treatments ± standard error. Different letters (a-b) represent significant differences ($p < 0.05$).

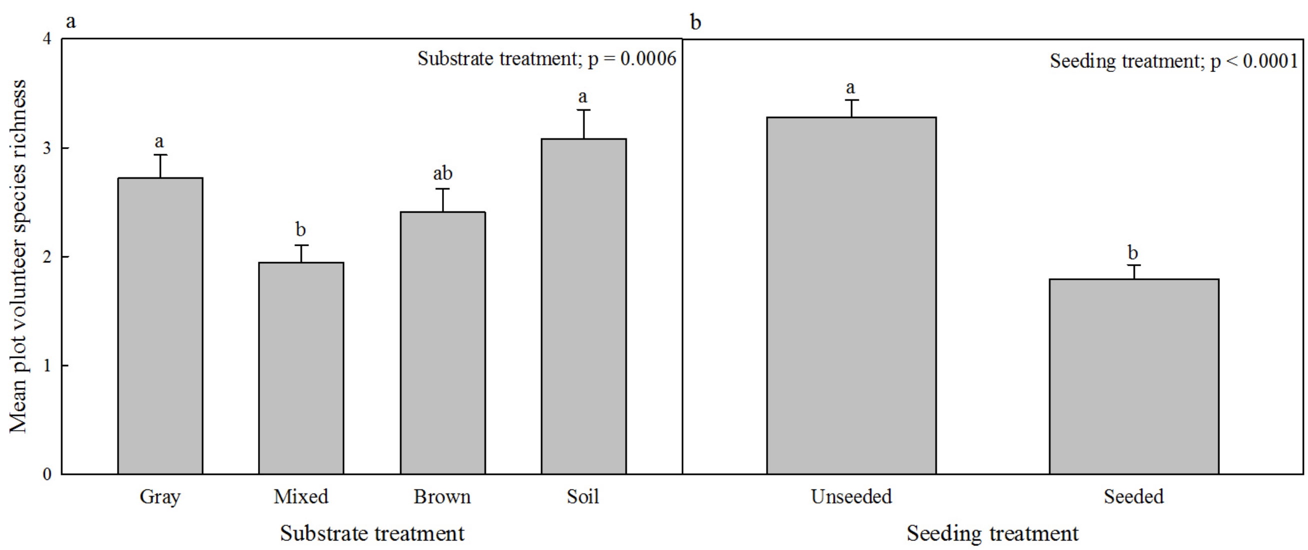

Figure 6. Mean volunteer species richness as affected by (a) substrate treatment and (b) seeding treatment ± standard error. Different letters (a-b) represent significant differences ($p < 0.05$).

Herbaceous community differences

All of the herbaceous communities were clustered together on the scatterplot, indicating that the communities are similar among treatments across the site (Fig. 7a). However, the seeded and unseeded subplots appear to be somewhat different and there does seem to be more variability in herbaceous community composition among the seeded subplots (Fig, 7b). Though unseeded subplots are clustered, likely because many of the plots had minimal or no vegetative cover, the few deviations occurring in unseeded subplots are relatively large. More clustering of the unseeded subplot datapoints compared to the seeded subplots showed that differences among seeded subplots were greater than unseeded subplots, a pattern that was likely driven by differences in cover of the five seeded species.

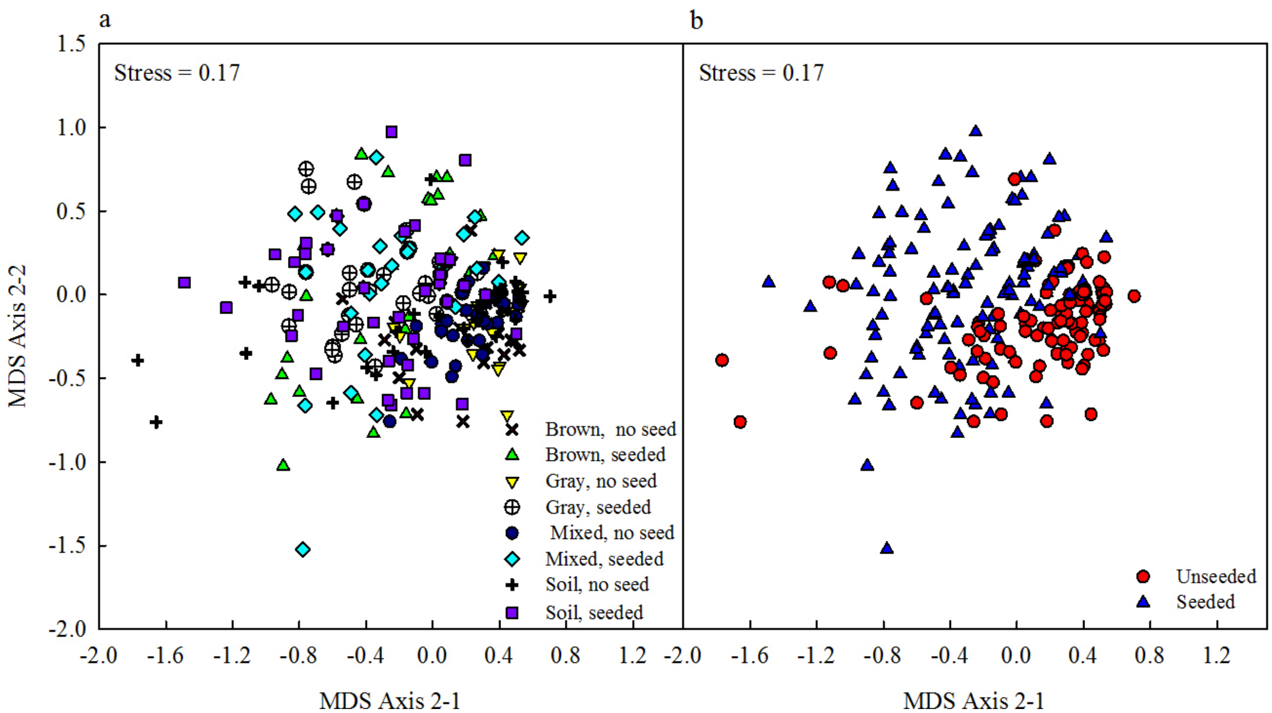

Figure 7. Non-multidimensional scaling of all herbaceous community data for (a) all treatment combinations and (b) seeded and unseeded treatments. Different symbols represent different treatment combinations. Kruskal's stress level = 0.17, $p<0.0001$.

Spatial analysis of the herbaceous community composition shows few patterns among the substrate treatments. Furthermore, the extremely low R-value obtained in the analysis of similarity indicates that there are virtually no differences among substrate treatments ($R = 0.021$, $p = 0.001$) (Fig. 8). Though no differences in community structural composition exist at this time, soil treatments had the highest plant diversity of all the substrates and mixed treatments had the lowest plant diversity (p = 0.007) (Fig. 9).

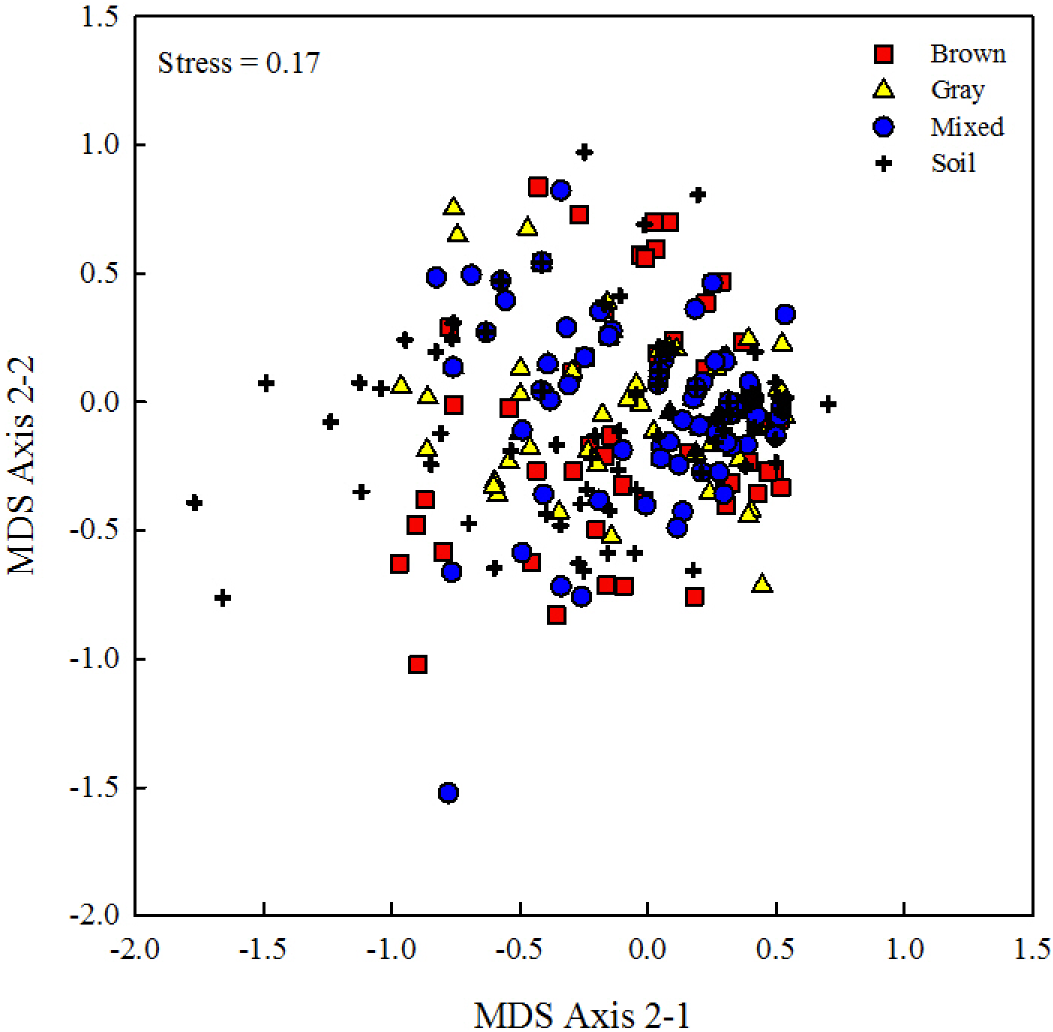

Figure 8. Non-multidimensional scaling of all herbaceous community data for substrate treatments. Different symbols represent different substrate treatments. Kruskal's stress level = 0.17, p<0.0001.

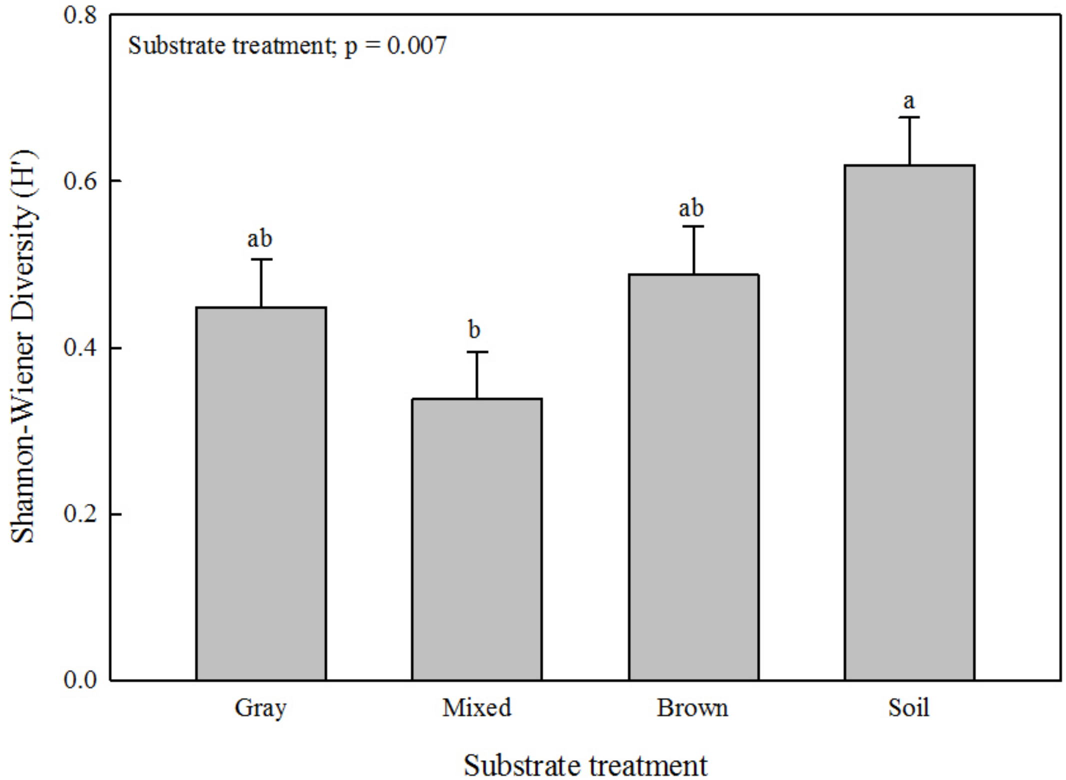

Figure 9. Mean Shannon-Wiener diversity in the four substrate treatments ± standard error. Different letters represent significant differences between treatments ($p < 0.05$).

Generally, within each substrate treatment, the seeded and unseeded subplots form distinct groups (Fig. 10). This assessment is supported by the analysis of similarity, which indicated that the community composition of seeded and unseeded treatments were significantly different groups ($R = 0.317$, $p = 0.001$). The seeded and unseeded treatments within the gray and mixed substrate treatments form more distinct clusters, relative to the seeding treatments of the brown and soil substrates which overlap quite a bit. This indicates that while the seeded and unseeded gray and mixed substrate treatments have more uniform herbaceous vegetation composition, the seeded and unseeded brown and soil treatments are less distinguishable from one another, and more variable overall.

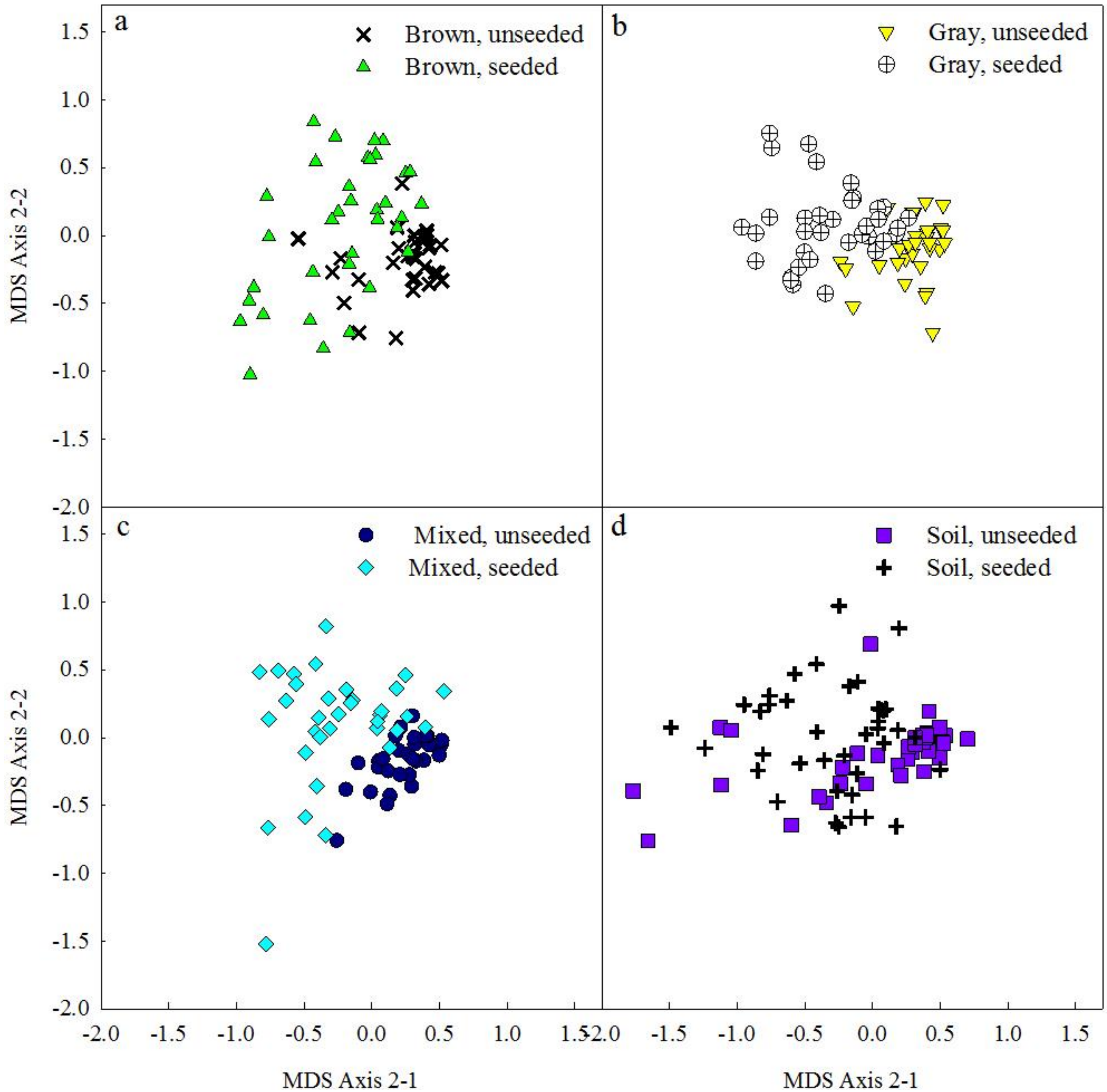

Figure 10. Herbaceous vegetation plots in brown (a), gray (b), mixed (c), and soil (d) substrate treatments, separated into seeded and unseeded treatments. Different symbols represent different substrate treatments. Kruskal's stress level < 0.20, p<0.0001.

Discussion

Tree survival rates on this experimental site (65.9%, on average over all experimental treatments) were low, relative to rates recorded by some other studies (e.g., Angel et al., 2008; Emerson et al., 2009; Miller et al., 2012) but close to at least one other study applied in an active-mine setting (Fields-Johnson et al., 2012). The fact that trees were planted late in the planting season (late March) was likely a contributing factor to reduced survival. It is also possible that the non-optimal soil conditions (i.e. circumneutral to alkaline soil pH across 3 of the 4 substrate treatments) may have contributed to the low survival rates. Herbaceous groundcover (<50%, on average, for both seeded and unseeded treatments) was low across the experiment due to the nature of the experimental treatments, as the seeding treatment was applied intentionally at a low rate relative to rates commonly applied on coal surface mines with the expectation that natural invasion by unplanted species will cause increased groundcover with time. Franklin et al. (2012) noted that high levels of competitive groundcover clearly inhibit survival and growth of young trees planted on coal surface mines. However, these authors also note that scientific literature from non-mining studies suggests lower levels of less-competitive herbaceous groundcover are favorable to tree establishment (relative to no groundcover) due to facilitative functions such as aiding air and water movement between the surface and subsurface. However, such effects have not been studied on reclaimed coal surface mines, and therefore the potential influence by these low groundcover levels on the relatively low tree survival rates observed is not clear.

Seeding treatment effects

After one growing season, total tree survival was higher in the unseeded subplots. This is likely due to reduced competition for resources (e.g., light, water) within the unseeded subplots, which had significantly more cover of bare ground than the seeded subplots (Franklin et al., 2012). Seeding treatment only affected the growth of two species (black cherry and red oak), both of which grew better in the unseeded treatment. Differences in tree survival and growth between seeding treatments are expected to be more prominent after additional growing seasons as herbaceous vegetation cover and competition for resources increases. It is unclear at this point, however, whether planted trees will experience more competition in the unseeded subplots heavily dominated by weed species, or the seeded subplots dominated by persistent planted species.

Not surprisingly, spatial analysis of the herbaceous community data showed that the seeding treatment was a much stronger driver of community composition in the first year, compared to substrate. Many of the unseeded subplots in the brown, gray, and mixed treatments had little or no vegetative cover in the first growing season, regardless of substrate treatment, and so they tended to be similar to one another. The community composition of seeded subplots was more variable, largely due to differences in the percent cover of each of the five seeded species. It is possible that the effects of seeding on community composition will be lessened with time as more volunteer species establish and compete with the planted herbaceous species. It is also possible that seeding effects will persist, as seeded species become established and dominate certain areas within the seeded subplots, hindering further invasion by unseeded species as has been observed in other studies (Fields-Johnson et al., 2012).

Substrate treatment effects

It should be noted that although fine material (<2mm fragments) from the soil substrate treatment had lower extractable P, extractable Ca, and base saturation than fines from the gray substrate treatment, this result was likely an artifact of the soil testing procedure, as the soil testing lab used techniques developed for use in natural soils; while the samples from the brown, gray, and mixed substrate treatments are largely comprised of rock fragments. This result should not be interpreted to indicate that circumneutral-to-alkaline mine soils derived from rock fragments have a greater capacity to supply growing trees with the essential nutrient P. Acidic soil extracts may react with rock fragments by dissolving carbonates and other alkaline minerals preferentially, releasing nutrient elements to the extract solution that may not be easily plant available (Howard et al., 1988; Zipper et al., 2013).

We expected to see responses of tree survival and growth, as well as various measures of herbaceous diversity that paralleled the substrate weathering gradient; more weathered substrates (e.g., soil and brown sandstone) would have more species and greater diversity, as well as better survival and growth than the less weathered treatments (e.g., mixed and gray sandstone treatments). However, no differences in tree survival among the substrate treatments were observed, and white oak and sugar maple were the only species for which growth responded to substrate treatment. This could be due, in part, to the few significant differences in the physical or chemical properties among the brown, mixed, and gray substrate treatments. Johnson et al. (2013) noted that certain weathered rock materials, although similar in chemical properties such as soluble salts (as measured by electrical conductance) and soil pH when obtained from the upper portion of the weathered spoil sequence (directly below the soil), often become more similar in chemical properties to unweathered rocks with increasing depth. The similarities among brown, mixed, and gray substrate treatments indicate that the "weathered" spoils used to construct these experimental plots had chemical properties similar to the unweathered materials; this result may have occurred due to origin of the weathered rocks in the lower portion of the weathered-rock sequence. The similarities between substrate treatments reduced the likelihood that these treatments would influence tree survival or growth. Furthermore, relatively high tree mortality that occurred across the site, likely related to the stressors of transplant, water limitations, and other environmental factors, could have masked more subtle responses to planting medium. It is unclear whether the measured variables (tree growth and survival, herbaceous richness, etc.) will differ more among the substrate treatments in the future as transplant stress is no longer affecting planted trees.

The soil treatment had the highest herbaceous species richness, volunteer species richness, and diversity, compared to the other substrates, and differed statistically from at least one other substrate treatment for each of these metrics. The other three substrates did not differ from one another for these metrics. Although differences in species richness and diversity among substrate treatments were observed, overall community composition was fairly uniform across the site. Plant communities within soil treatments were the most variable, shown in a scatterplot with less grouping than the other three substrates, and the seeded and unseeded treatments had more in common than not. The seeded and unseeded treatments in the brown sandstone looked as though they had a similar relationship to one another, but to a lesser degree than the soil treatment. Overall, this is because the mixed and gray substrate treatments (and to some extent, the brown treatment) tended to host the same volunteer species, whereas novel volunteers tended to occur in the soil treatments, likely present in the soil seed bank (Koch, 2007, Hall et al., 2010). Again, the lack of measured physical or chemical property differences between the brown, mixed, and gray substrates inherently made substrate treatment a less significant driver in community composition. While the differences between the soil treatment and other substrates were not large, other studies have found that seeds present in the seed bank may take several years to germinate and become components of the understory community (Hawkins et al., 2007). We expect that over time, the soil treatment will continue to deviate from the three other substrate treatments as additional volunteers from the seed bank establish.

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