VEGETATION AND SOIL DEVELOPMENT IN PLANTED PINE AND NATURALLY REGENERATED HARDWOOD STANDS 48 YEARS AFTER MINING[1]

J. Frouz[2] and J.A. Franklin[2]

Abstract. Restoration activities at the time of stand initiation can have lasting effects on subsequent recovery of stand structure and function. Here we compared several metrics, with an emphasis on soils, of structure and function in forest stands that had been planted with pine or remained unplanted, and had undergone primary succession over 48 years on mine spoils. These were also compared to reference sites in the adjacent forest, to test the hypothesis that the development of forest functional processes will differ between planted and unplanted sites. Areas planted to pine had a lower basal area, and lower soil and microbial respiration rates than did unplanted areas. Basal area of unplanted sites was comparable or higher than that of reference sites, suggesting that the natural succession of hardwood may lead to better long-term recovery than planting of pine. Differences in root biomass, along with corresponding differences in soil respiration, suggest that below-ground biomass production recovers more slowly than does above-ground productivity. Mined sites had a greater stock of phosphorus than did reference sites. The greater presence of earthworms on mined sites may speed up nutrient cycling, as indicated by faster cellulose decomposition.

Additional keywords: carbon, mining, nitrogen, phosphorus, *Pinus*

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[2] Jan Frouz is a Professor at the Institute for Environmental Studies, Charles University, Benátská 2, Prague, CZ12000, Czech Republic, and Institute of Soil Biology BC ASCR, Na Sádkách 7, České Budějovice, CZ37005, Czech Republic. Jennifer A. Franklin is an Associate Professor in the Department of Forestry, Wildlife and Fisheries, University of Tennessee, 274 Ellington Plant Science, Knoxville, TN, 37996

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Introduction

Tree planting on severely disturbed or degraded lands can speed successional processes, with trees acting as a "catalyst" for ecosystem recovery (Parrotta et al., 1997) and having long-term effects on ecosystem structure and function. Small differences in the arrival time of species can have a significant "founder effect," and the below-ground development of root systems are of particular importance (Korner et al., 2007). Thus, activities such as tree planting may have significant effects on forest growth and development, in part through effects on nutrient cycling and soil development.

Mining causes extensive disturbance, leaving a substrate virtually free of soil biota and propagules to undergo primary succession. Recovery of soil and vegetation is the basic pre-condition for recovery of a functional ecosystem (Bradshaw, 1997) and abandoned mined land may be gradually re-vegetated through the successional sequence, which leads to soil formation and ecosystem re-establishment. However, successional processes are slow, hence restoration approaches have been adopted to speed up ecosystem recovery, but the question of whether these result in long-term ecosystem recovery in a way that is similar to succession alone has not yet been often tested due to the relatively recent growth of restoration science (Prach et al., 2001; Frouz et al., 2008).

There is growing interest in the eastern United States in returning disturbed land to productive forest. Reclamation techniques for coal mines in this area have changed over the past 50 years from a lack of reclamation to the planting of Pinus species and non-native trees, to heavy soil compaction and planting of aggressive grasses. It is now known that soil compaction results in reduced growth and survival of planted tree seedlings (Zipper et al., 2011), and new guidelines recommend the placement of at least 1.2 m of minimally compacted medium for tree growth and seeding with non-competitive ground covers. Although mining and material placement methods differ between the 1950's and today, older mine sites with un-compacted soils may have enough similarities with contemporary sites to be helpful in predicting long-term forest development under new recommendations.

While a number of studies have investigated the development of vegetative and soil communities on minesoils, *this* study was conducted to determine whether reclamation created a long-term effect on ecosystem development. We compared mined areas reclaimed by planting pine species with areas allowed to revegetate naturally, and determined how the major groups of soil biota, vegetation, and soil processes compared to those of the adjacent, minimally disturbed hardwood forest. Because the goal of restoration is to speed ecosystem development, we hypothesize that forest productivity and soil processes on the planted site will be closer to the state of the un-mined reference sites than will be the un-reclaimed areas.

Materials and Methods

Study area

Four sites were selected in eastern Tennessee and southern Kentucky (Table 1). All were mined for coal in the late 1950's, planted with research plots of *Pinus* species (pines), and had a well-documented record of land use since mining with minimal forest management activity. Information on reclamation treatments and soil characteristics at the time of tree planting was obtained from original research notes and publications. Because details of analytical methods were not available in original reports, soil P is shown in units originally reported. Soil chemistry was not available for site three, but this lies on the same coal seam as site two so parent materials are similar. Details on mining methods and material placement were not available, but all sites showed the remains of a pit and steep out slopes, characteristic topography of sites where spoils were loosely dumped and minimal reclamation followed coal extraction. Climate at all sites is similar with a mean annual daily temperature of 10-12.8º C, frost-free period of 181-240 days, and mean annual precipitation of 1.3-1.8 m (National Oceanic and Atmospheric Administration, 2012).

Within each site three forest types, hereafter referred to as treatments, were delineated based on research notes, publications, topography (see Fig. 2, Daniels and Amos, 1985), and the help of researchers involved in initial planting of research plots. Areas that had been planted with any pine species, and still contained pine, were designated as "pine." On these areas the natural succession of pine to hardwood (Gorman et al., 2001) had been hastened by an outbreak of Southern pine beetle (*Dendroctonus frontalis*) around 1996, leaving numerous gaps. Therefore plots were selected to minimize the effect of gaps and capture the long-term effects of planted pine. On each site, three plots were located as far apart as possible, within the largest remaining clusters of mature pines, on the uneven terrain of old spoil piles. Plot centers were placed within a triangle anchored by three dominant pine trees assumed to be from the original planting, avoiding gaps in the immediate vicinity of the plot. Areas also on uneven terrain of the spoil piles, but outside of the area planted as research plots, were designated as "un-reclaimed." These were the same age as the planted plots but had no reclamation treatment after mining, and native hardwood forest had naturally regenerated. Three plots were randomly selected within this area, taking care to avoid flat areas that designated old roads, and areas adjacent to the steep outslope. Another three plots were randomly located in adjacent reference areas containing mixed pine/hardwood forest with large trees assumed to pre-date mining, and are referred to as "un-mined" areas. These were on similar slopes and aspects, but in topographical positions either above or below the mined site. All sampling and field measurements were done in October 2006.

Table 1. Characteristics of study sites, pine species planted on research plots, and soil pH and phosphorus reported at the time of planting. Soil P is listed in the units originally reported.

	Site 1	Site 2	Site 3	Site 4
Location	36º03.0'N 84º27.1'W	36º02.3'N 84º29.5'W	36º02.52'N 84º28.0'W	37º00.3'N 84º02.2'W
Mining ended	1954	1957	1957	1964
Year planted	1957	1964	1959	1965
Species planted	*Pinus strobus* *Pinus echinata* *Pinus rigida* *Pinus virginiana* *Pinus taeda*	*Pinus strobus* *Pinus sylvestris* *Picea abies*	*Pinus echinata* *Pinus taeda* *Pinus strobus*	*Pinus nigra* *Pinus thungergii* *Abies fraseri*
Soil pH	4.1-5.3	4.2-5.2	Not reported	3.4-4.3
Soil P	0.9-5.4 kg/ha available P and 18-130 kg/ha available potash	100 kg/ha total P	Not reported	4.6-9.6 ppm available P
Reference	Kring 1967	Kring 1967		Thompson et al. 1984

Vegetation survey

Overstory and understory vegetation was surveyed to provide a snapshot of persistent vegetation at the time of soil sampling. Within a 5 m radius of plot center, species and diameter at breast height (DBH) of all stems greater than 2.5 cm were recorded. Within a 1 m radius stems of perennial ground cover were tallied, and included tree seedlings and saplings <2.5 cm DBH, shrubs, vines, grasses, ferns, and clubmoss. Species with a high incidence on the plots were identified to species. *Carya* spp. (hickories), *Vaccinium* spp., *Lespedeza* spp., *Rubus* spp., *Lonicera* spp. (honeysuckles), and *Vitis* spp. (grapes) were identified to genus, ferns (Pteridophyta) to phylum, and grasses (Poaceae) to family. The number of stems of each species was counted with the exception of *Lonicera*, *Microstegium vimineum* (Japanese stiltgrass), and *Lycopodium* (a clubmoss), that have a multi-stemmed growth habit for which percent cover is a more accurate estimate of density.

Field measurement of soil respiration

Soil respiration was measured in the field within 1 m of plot center using an infrared gas analyzer fitted with a soil CO_2 flux chamber (IRGA, Model LI-6400, Li-cor Biosciences, Lincoln, NB). The collar was inserted to a depth of 1 cm, and CO_2 was allowed to stabilize for a minimum of 5 min. Three successive measurements were averaged to obtain plot field respiration rate. Soil temperature was measured at 6 cm depth.

Cellulose decomposition

A sheet of filter paper about 2 g in weight was placed in a litter bag (8x14 cm) with a mesh size of 1 mm and 6 large openings, 1 cm in diameter. Litter bags were placed within 5 m of plot centers for six weeks in September and October 2006, in the surface soil layer (2 cm depth). After field incubation, filter paper was dried (24 h at 60^{o} C), weighed, ashed at 600ºC for 5h and resulting ash was weighed. Final mass of cellulose was calculated as the difference between dry mass after calculation and ash mass. Decomposition was expressed as the percentage of mass lost from original mass of cellulose.

Soil sampling and processing

In each plot, three 18 cm deep cores were collected within 1 m of plot center using a corer 11 cm in diameter (95 cm^2). Each 18 cm core was divided into top, middle and bottom sections, each 6 cm thick. The three soil sections belonging to the same depth and plot were combined to yield nine composite samples for each treatment at each site for each depth. An additional core was taken at each plot (near points measured for field respiration), separated into top, middle, and bottom sections as above, and used to measure root biomass and microbial respiration. The sampling hole was further opened by spade, and notes were taken about the appearance of the soil profile. Samples were transported and stored at 4° C until analysis. Soil macrofauna was extracted from composite samples using a Tulgren extractor as described in Frouz et al. (2008). Extracted fauna was hand sorted under a dissection microscope, divided into the lowest practical taxon, and counted.

Dry soil remaining after the Tulgren extraction was weighed, crushed, sieved through a 2 mm mesh, and stored for later analysis. Gravel, which did not fall through the mesh, was weighed. About 5 g of soil was used to determine soil pH in water (1:5 sample/liquid ratio) using a glass electrode (Model 250, Denver Instruments, NY). About 50 g of each sample was finely ground to pass through a 250 µm mesh and used to establish total C, N, and P content. Carbon and N were measured using a CN analyzer (NC 2100 Soil Analyzer, Thermo Quest, Italia). Total P was mineralized by perchloric acid (Sommers and Nelson, 1972) and determined according to Watanabe and Olsen (1965) with modifications (Murphy and Riley, 1962). Concentration was expressed as a weight to weight ratio. To calculate overall stock of the element in a given layer of soil profile, weight to weight ratio was multiplied by the weight of fine soil (<2 mm) in one square meter of a given layer. This was calculated as mass of dry fine soil in one composite sample divided by area of the cores (3 x 0.0095 m^2).

Each layer in the additional, non-composited sample was divided into four equal parts. Two parts were washed under running water on 1 mm mesh to isolate fine roots, which were dried (24 h at 60°C) and weighed. From the rest of the sample visible roots were removed without washing and about 5 g of material was dried, as above, to determine soil moisture. The remaining soil was stored in the refrigerator for one week then used to determine microbial respiration, estimated by the soil incubation method (Schinner et al., 1996). Any CO_2 evolved from the soil during the two-day incubation at 20° C was trapped in NaOH, quantified by HCl titration after addition of $BaCl_2$, and expressed as µg g^{-1} per dry weight of soil (DW) $hour^{-1}$ of C-CO_2, or as mg m^{-2} $hour^{-1}$ of C-CO_2. To express basal respiration per unit area, respiration per g DW was multiplied by the mass of soil in a given soil layer, calculated as above.

Data analysis

One-way ANOVA was used to test for the effect of treatments (un-mined, reclaimed by planting pine, and un-reclaimed) using site as a blocking factor. Analysis of field-soil-respiration rates used soil moisture and soil temperatures as covariates to minimize differences in weather conditions between sampling days. ANOVA, if significant, was followed by a LSD post-hoc to test for significant differences between the three treatments. Where applicable, t-tests were used to compare un-reclaimed and pine-reclaimed treatments. The correlation of field respiration with soil parameters was tested. Species of perennial vegetation that occurred in fewer than 25% of the plots were removed prior to analysis. All computations used SPSS 10.0.

While ANOVA was used to identify treatment effects on individual plant and invertebrate species, a multivariate approach was used to determine the degree of influence of treatments and sites on community composition as a whole. Canonical Correspondence Analysis (CCA) and variation partitioning were used to estimate the amount of data variability in communities of soil fauna and perennial vegetation explained by individual treatments and study sites (Ter Braak and Šmilauer, 1998). A Monte Carlo permutation test with 199 permutations was used to test the significance of individual factors.

Results

Soil C, N, and P

In un-mined soil the surface was covered by a litter and fermentation layer 3-6 cm thick, under which was the mineral horizon. The topsoil appearance in the pine sites was similar, with the litter and fermentation layer consisting of pine needles. In un-reclaimed sites, which were dominated by hardwood, only a thin (1-5mm) layer of litter covered the soil surface and an accumulation of earthworm casts was often visible on the surface of the mineral layer.

Areas reclaimed with pine had concentrations of C and N in the surface mineral layer similar to the un-mined hardwood reference sites, while un-reclaimed plots had lower C and N concentrations (Fig. 1). There was no difference in the overall C and N stock in the top 18 cm (Fig. 2), but un-reclaimed plots had more N stock in the 6-12 cm layer than did pine plots. The concentration of P in the 6-12 cm layer of mined areas was higher than in un-mined soils (Fig. 1). Total P stock in un-reclaimed plots was greater than in un-mined plots due to greater total P stock in the 12-18 cm layer (Fig. 2). Soil pH ranged from 4.3 to 5.0 and did not differ significantly between treatments.

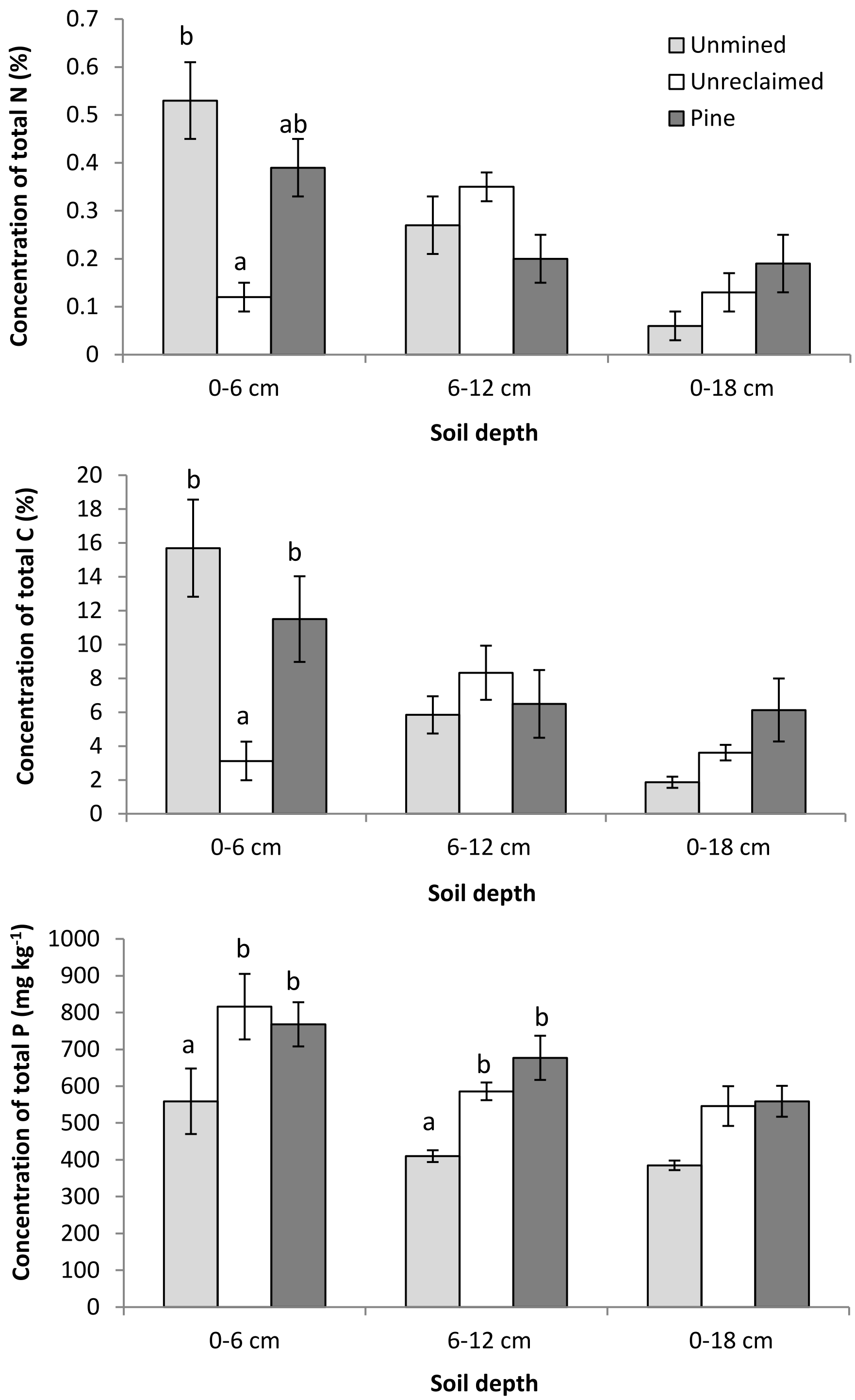

Figure 1. Concentration of total N, C, and P, at two depth ranges and total upper soil (0-18 cm) on three vegetation types. Different letters indicate a significant difference between groups within the same depth (ANOVA, LSD post hoc test). Bars indicate standard error.

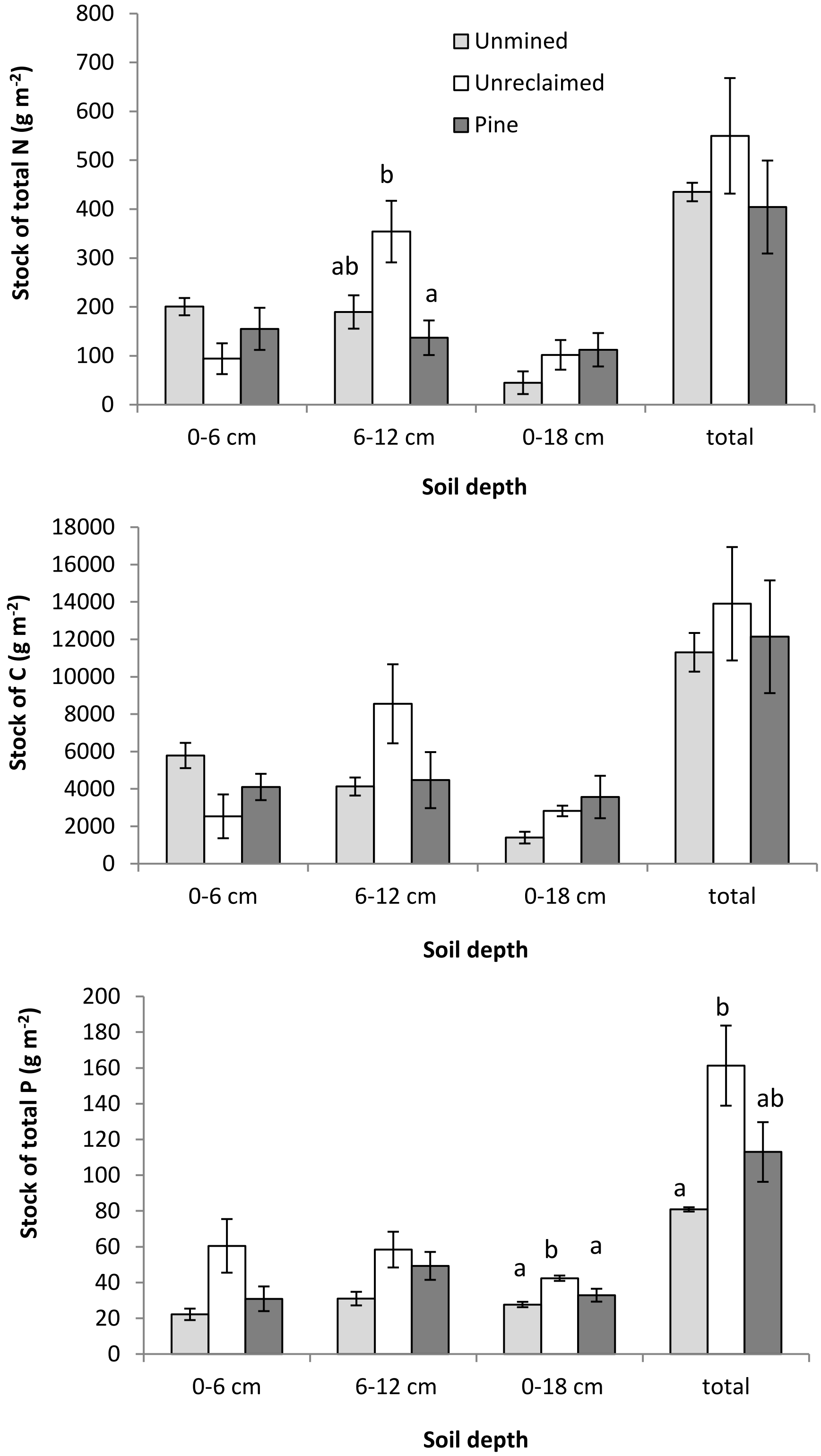

Figure 2. Stock of N, C, and P at three depth ranges on three vegetation types, based on area. Different letters indicate a significant difference between groups in the same depth (ANOVA, LSD post hoc test). Bars indicate standard error.

<u>Soil respiration and root biomass</u>

Biomass of fine roots in the overall profile (0-18cm) was lower in pine, but not in un-reclaimed plots, in comparison to un-mined plots (Fig. 3) due to differences in the upper topsoil (0-6cm) layer. Cellulose decomposition rates were greatest in un-mined plots, but soil respiration rate was greatest in mined, un-reclaimed plots.

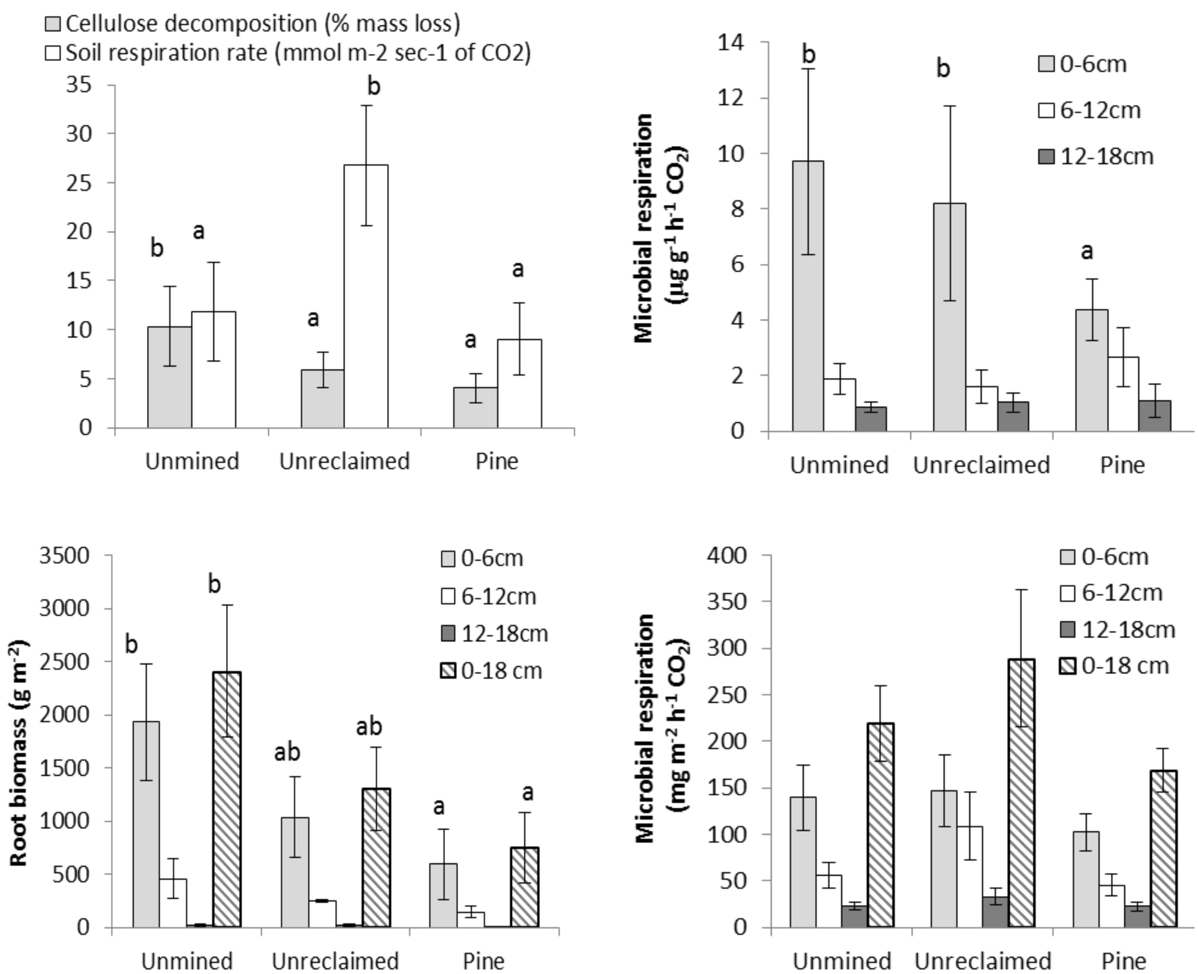

Figure 3. Mean (±SE) field soil respiration and cellulose decomposition rate, microbial soil respiration per g of soil, microbial soil respiration per unit area, and root biomass of mined and un-mined plots. Statistically homogeneous groups of the same row are marked by the same letter (ANOVA, LSD post hoc test); if letters are missing no significant difference was found.

Microbial respiration of soils from pine plots, expressed per gram of soil, was lower than in other treatments. Due to different bulk densities between treatments, we re-calculated microbial respiration for individual layers and expressed these per unit area in order to compare field soil respiration with laboratory measured microbial respiration, but no treatment differences were found within layers or the overall profile. Field soil respiration was positively correlated only with root biomass in the whole profile and in the top 6 cm (Table 2).

Table 2. Correlation coefficient and p value (or ns if not significant) for linear regression between individual parameters and field soil respiration.

Parameter	r	p
temperature at 6 cm	0.307	ns
moisture in 0-6 cm	0.033	ns
root biomass m^{-2} in 0-6 cm	0.485	0.0038
root biomass m^{-2} in 0-18 cm	0.496	0.0030
microbial respiration m^{-2} in 0-6 cm	0.093	ns
microbial respiration m^{-2} in 0-18 cm	0.051	ns
microbial respiration CO^2 g^{-1}	0.327	ns

Vegetation composition

A total of 26 tree species were recorded; 16 within un-reclaimed plots, 18 on reclaimed pine plots, and 20 on un-mined plots. *Acer rubrum* (red maple) had the greatest frequency, present on 86% of plots. These were the dominant overstory on un-reclaimed plots (Table 3) but were abundant in the understory of both pine and un-mined plots (Table 4). Pine plots had a low basal area and were dominated by either *Pinus strobus* or *P. virginiana*, while un-reclaimed plots had the greatest total basal area. *Quercus* species were variable in the overstory of un-reclaimed plots with *Q. montana* (chestnut oak, the only oak present on >25% of plots), *Q. alba* (white oak), *Q. coccinia* (scarlet oak), and *Q. rubra* (northern red oak) having a combined basal area (BA) of 7.21 ±_17.01 m^2 ha^{-1}, but were dominant (23.75 ± 25.0 m^2 ha^{-1}) on un-mined areas. The presence of *Quercus* seedlings and saplings was similar among treatments. The overstory of the un-mined reference areas was comparable to 40-59 year old stands in the surrounding area, which are dominated by various *Quercus* species (BA = 9.00 ± 1.37) with *Liriodendron tulipifera* (BA = 3.05 ± 0.40), soft maples (primarily *Acer rubrum*, BA = 2.46 ± 0.34), and a relatively small component of *Pinus* and other coniferous species (BA = 2.46 ± 1.04) (total mean

Table 3. Mean basal area (m^2 ha^{-1} ±SE) of trees ≥ 2.5 cm DBH, for dominant species and average and total species no. Different letters indicate a significant difference between treatments at p≤ 0.05 (ANOVA, LSD post hoc test) if letters are missing no significant difference was found.

	Un-mined		Un-reclaimed		Pine	
Pinus virginiana	1.30	±1.27 a	0	±0 a	8.33	±3.87 b
Liriodendron tulipifera	0.01	±0.01 a	6.47	±2.50 b	0.03	±0.03 a
Acer rubrum	12.45	±2.55 b	26.15	±4.37 c	3.11	±1.71 a
Quercus montana	18.48	±7.66 b	5.62	±5.62 ab	0	±0 a
Pinus strobus	0.96	±0.55 a	0	±0 a	5.44	±2.55 b
Total	39.60	±8.52 ab	50.63	±8.95 b	19.37	±3.34 a

Table 4. Percentage of plots on which species occurred (freq), and mean stem density (stems per 3.14 m^2 plot ± SE) of seedlings and saplings <2.5cm DBH, and understory shrubs (honeysuckle and lycopodium are expressed in % cover) and persistent perennial species present on ≥25% of all plots during Oct. sampling. Different letters indicate a significant difference between treatments at p≤ 0.05 (ANOVA, LSD post hoc test) if letters are missing no significant difference was found.

	Un-mined			Un-reclaimed			Pine		
Tree species	Freq	Density		Freq	Density		Freq	Density	
Acer rubrum	36	19 ±7	a	14	2 ±1	c	50	9 ±4	b
Prunus serotina	45	1 ±0		18	2 ±0		36	1 ±0	
Quercus rubra	36	2 ±0		32	1 ±0		32	3 ±1	
Other perennial									
Lonicera japonica	0	0 ±0	a	64	12 ±4	b	36	10 ±4	b
Smilax rotundifolia	33	3 ±2		33	2 ±1		33	6 ±5	
Toxicodendron radicans	0	0 ±0	a	77	17 ±5	b	23	1 ±0	a
Goodyera pubescens	57	11 ±5	b	0	0 ±0	a	43	18 ±7	c
Dioscorea oppositafolia	60	5 ±2		10	1 ±0		30	5 ±2	
Parthenocissus quinquefolia	22	1 ±0		56	1 ±0		22	4 ±1	
Poaceae	36	2 ±1		18	5 ±4		45	4 ±1	
Lycopodium obscurum	33	51 ±25	a	67	47±14	a	0	0 ±0	b

BA 23.9 ± 0.89) (United States Department of Agriculture, 2010). CCA and variation partitioning indicated that both site and treatment significantly affect composition of overstory vegetation, with treatments having a slightly higher contribution than sites (Table 5).

Table 5. Percentage of data variability explained by individual treatments and sampling sites using Canonical correspondence analysis and variation partitioning (in all cases both factors are significant for $p<0.05$, Monte Carlo permutation test).

	woody veg.	perennial veg.	soil fauna
Total explained	38.3	31.1	17.3
Treatments	54.1	47.9	41.4
Sites	43.3	47.9	58.3
Interactions	2.6	4.3	0.3

<u>Soil fauna</u>

Neither total density nor individual groups of soil macrofauna showed any significant differences between treatments. However earthworms and pseudoscorpions were recorded only in mined sites, and were not present in un-mined forest soils (Table 6). CCA and variation partitioning indicated that both site and treatment significantly affected the composition of soil fauna, with sites having a slightly greater contribution than treatments (Table 4).

Discussion

Results show that while planting of pine had some long-term effects on forest development, there was no evidence that it accelerated the development of forest soils or productivity on these sites, when assessed at an age of 48 years. Both natural succession and the planting of tree seedlings in ungraded spoil resulted in the development of a forest ecosystem which was, in many aspects, comparable to the un-mined forest (Fig. 4). There were more similarities than differences between planted pine and un-reclaimed sites after 50 years, which is in agreement with European studies indicating that differences between reclaimed and naturally colonized post-mining sites decrease over time (Prach et al., 2001; Frouz et al., 2008). Rapid forest development in this particular case may be facilitated by the relatively small size of mined sites which may speed up natural succession, and the narrow, linear shape of the disturbance that left all parts of the site in relatively close proximity to intact forest. Skousen et al. (1994) also reported rapid reforestation of naturally revegetated sites in West Virginia.

Table 6. Densities of individual groups of macrofauna in post mining sites and adjacent un-mined forest. No differences between sites were found by ANOVA. *indicates a significant difference between post-mining (pine and un-reclaimed) and un-mined sites (t-test, $p<0.05$).

	Un-mined	Un-reclaimed	Pine	
Lumbricidae	0 ±0	26 ±17	32 ±19	*
Aranea	9 ±7	6 ±4	18 ±11	
Opilionidae	0 ±0	6 ±4	0 ±0	
Pseudoscorpiones	0 ±0	20 ±11	15 ±11	*
Chilopoda	67 ±34	53 ±13	44 ±34	
Diplopoda	6 ±4	55 ±33	9 ±7	
Diplura	6 ±4	9 ±7	12 ±5	
Symphyla	12 ±10	23 ±15	50 ±47	
Blatodea	0 ±0	3 ±3	3 ±3	
Isoptera	0 ±0	0 ±0	64 ±65	
Sternorhyncha	0 ±0	3 ±3	6 ±4	
Lepidoptera	26 ±20	35 ±22	6 ±7	
Formicidae	239 ±156	175 ±111	548 ±274	
Colleoptera	178 ±64	140 ±33	131 ±34	
Diptera	38 ±17	26 ±11	6 ±8	
Total macrofauna	580 ±164	580 ±138	942 ±310	

Our finding that naturally regenerated hardwood stands had a higher basal area than planted pine is contrary to results of Gorman et al. (2001) who observed higher forest productivity in planted pine sites in comparison with natural succession after 30 years. However, an assessment of well-stocked forest stands on older coal mine spoils of the eastern and mid-western U.S. showed that planting of pine during reclamation can either increase or decrease forest productivity, depending on the suitability of the pine species to the site (Rodrigue and Burger, 2002), with a maximum productivity of pine at 30-40 years, while hardwood stands matured at 60-80 years. Our results are likely influenced by this difference in temporal dynamics between forest types; pine stands may be in decline by 50 years, while hardwood-dominated sites were approaching maturity. However because the mining process altered the topography of the sites, we cannot rule out potential effects of topography on soil and community development. The difference in overstory between treatments may continue for some time, based on the significantly greater presence of *Acer rubrum* seedlings and saplings in areas planted with pine. Differences in basal area and species composition may also be related to differences in nutrient cycling between treatments.

Figure 4. Hardwood forest on an un-mined reference site (left), and on a naturally re-vegetated mine site after 48 years.

Differences in soil chemistry were found between un-mined and mined land, and between pine and un-reclaimed sites. Influences on C and N were on distribution within soil layers, and only P showed fairly consistent differences between treatments. The native soils in this area are predominantly ultisols, which are highly weathered and low in both total and plant-available P (Cross and Schlesinger, 1994) and some minesoils in this region have a high iron content, which further reduces the availability of P (Daniels and Amos, 1985). Here, mined sites had a larger stock of P than un-mined reference sites. Because soils differed in bulk density, the volumetric units allow for better comparison between soils (Ellert and Bettany, 1995), and may give a better estimate of plant-available P (Doran and Parkin, 1996). Soil nutrient pools may be a poor predictor of tree growth rates (Toledo et al., 2011), and forest soils may be low in available nutrients due to the highly efficient scavenging ability of plant roots; therefore, our measurements were of total N and P stock rather than availability. Mining brings up substrate from layers several meters deep which are less weathered and consequently relatively rich in P. This has been observed on other mining sites, which were enriched in P in comparison with natural systems (Šourková et al., 2005), although in other cases however, post-mining soils may be depleted in P (Daniels and Amos, 1985). The prevalence of pioneer species on mined areas may be just because of disturbance *per se*. However we cannot rule out differences in nutrient availability between mined and un-mined sites, particularly the greater stock of P that may favor pioneer species over late successional species.

Un-mined sites show significantly higher *in situ* soil respiration than mined sites. This seems to result from higher root biomass, as our field respiration rates had a strong positive correlation with root biomass but no correlation with microbial respiration in root-free soil. The contribution of root respiration to total soil respiration reported in literature is highly variable, but typically, root respiration is an important contributor. Of all species studied by Burton et al. (2002) *L. tulipifera* had the highest root respiration rate, nearly double that of pine, and a fine root mass that was more than double that of pine. Differences in our field respiration rate are consistent with these previous findings, and so may be related to differences in stand composition although differences in N availability may have also influenced soil respiration. Greater root mass in un-mined sites may be simply a function of time: a lag in the recovery of soil structure and biomass production exceeding 60 years was found on reforested land in Puerto Rico (Lugo and Helmer, 2004).

Site and reclamation treatment proved to be equally influential on community development, with site factors being a slightly greater influence than planting treatment on the soil faunal community. Both pine and un-reclaimed areas still showed an understory composition indicative of early-successional forests, with *Lonicera japonica* and *Toxicodendron* found predominantly on mined areas. Conspicuous differences in understory vegetation between planted pine and un-reclaimed areas were seen for *Lycopodium* and *Goodyera*. In un-mined hardwood and planted pine areas a thick fermentation layer occurred on the soil surface, but only a thin litter layer and no fermentation layer occurred in the un-reclaimed areas dominated by hardwoods. This may correspond with the high decomposition rate observed in un-reclaimed areas, and with the higher density of earthworms that contribute to soil mixing and incorporation of litter into the mineral layer (Frouz et al., 2006). Earthworms are well known to alter the topsoil layer in North American forests, which consequently affects nutrient cycling and other properties of forest soils (Bohlen, 2004). European studies show that colonization of mining sites by earthworms is rather slow (Pižl, 1999). It would be very interesting to know why, in our study area, mined soil may be more likely colonized by earthworms than surrounding hardwood forest. *Goodyera pubescens,* typically found in late-successional forest, was found in both the un-mined forest and pine sites but was absent from naturally-regenerated hardwood sites. This species is rare where non-native earthworms are abundant due to differences in seed ingestion and increased decomposition rate (McCormick et al., 2008). As earthworms were abundant on both pine and hardwood mined sites, it would be interesting to see whether there are species differences between these, as the high decomposition rates observed on hardwood sites are also more typical of areas in which non-native earthworms predominate.

Conclusion

The planting of trees can have a long-term impact on the development of the forest and soil community. On these narrow sites with an adjacent source of seed, tree planting did not appear to speed the recovery of ecosystem processes when compared to the native hardwood forest that established naturally on the site. Below-ground biomass production may recover more slowly than above-ground productivity, and measurements of root mass or below-ground processes should be considered when developing long-term monitoring plans. Finally, consider the potential that earthworms and other soil biota may be introduced through topsoiling or planting, as these may have long-term consequences on nutrient cycling.

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