Evaluating Tree Growth and Soil Development on Restored Coal Mine Sites in Eastern Kentucky

Madelaine Roberts, Jennifer Richter, Brandi Martin, Colin Peterson, Thanh-Thao Le, Maggie Wiener, Katie Biggert, Salem Dockery

Introduction:

Fueled by the Industrial Revolution, coal became a valued commodity in the Appalachia region of the US. Standard coal mining practices were no longer feasible to support growing energy demands, and mountaintop coal removal became the preferred method of extraction due to the sheer volume of coal that is made available by these operations. Much of Kentucky's eastern Cumberland plateau has been subject to surface coal mining, replacing thousands of acres of Appalachia with barren coal fields. Mountaintop removal accesses coal seams by firstremovingtopsoil and vegetation, drilling down to the coal seam, and inserting explosives that blast hundreds of feet of earth away. The removed mining spoil is deposited into a neighboring valley, creating a valley fill. Therefore, not only does mountaintop removal destroy forested habitats but it also buries thousands of miles of headwater streams, altering the hydrology and water quality within watersheds.

The Surface Mining Control and Reclamation Act (SMCRA) of 1977 (About OSMRE, 2014) was the signature piece of legislation that established the rules for reclaiming land that had been mined. This act required coal mining companies to return the land to an approximate contour of its original state and make it "productive", which meant a variety of land uses were acceptable including industrial, commercial, and residential development, agriculture, as well as grassland and forest ecosystemsThe top priority when resurfacing these coal sites was stabilization of the overburden to prevent erosion and landslides., This was accomplishedby first dumping mine spoil from the valley fills back onto a site, compacting the spoin by running over it back and forth with heavy construction machinery, and then revegetating the site. Spreading grass seed soon became the most common form of revegetation because it was inexpensive, enhanced soil stability, and because grasses were the only type of vegeatation whose root systems could grow in such compacted soil. Consequently, millions of acres of Appalachia that were once forested with temperate hardwood trees had been reclaimed with grasslands.

Fortunately, partnerships have formed between organizations that are hoping to remediate some of the damage done in this region, namely the University of Kentucky, Green Forests Work and the Kentucky's Office of Surface Mining. These organizations, in cooperation with landowners, are attempting to reforest these grasslands by following the Appalachian Regional Reforestation Initiative five step Forest Reclamation Approach (FRA). The idea behind their approach is to create a suitable rooting medium for native hardwood trees by minimizing compaction. This is done using the strike-off method in which mine soil is dumped out of a dump truck and the spoil is leveled off, but not heavily compacted. Then a four-foot ripper shank is pulled behind a bulldozer to cut a grid into the soil, fluffing up the spoil that allows for tree roots to penetrate the soil more easily. In the loosely graded topsoil, they then plant a blend of trees that are both early successional for wildlife and soil stability and commercially valuable (Burger et al., 2005).

The region comprising central and southern Appalachia has been referred to as one of the most biodiverse temperate regions in the world. Much of this reputation is due to the vast amount of plant diversity. The length of the growing season for a forest is inversely related to its elevation. Therefore, plant communities at the base of hill slopes differ significantly in both composition and structure from ones nearer the tops of peaks. Longleaf pine and sycamores are the most common tree species at low elevations; spruce fir, birch, and ash are common near peaks; and in between there is a diverse mixture that includes all of these in addition to dozens more. Saplings, shrubs, flowers, grasses and herbs occupy the understory below the forest canopy, contributing to a variety of ecological ecosystem services offered by the region. Forests are crucial in storing carbon, cycling nutrients, limiting soil erosion, regulating water pathways throughout watersheds, and providing habitats for animals (Zipper et al., 2011). Coal mining inherently reduces the biodiversity levels of the regions in which it is done, because it is not viable to replant all lost plant species during the reclamation stage. The focus for reclamation initiatives, therefore, is on producing soil conditions that facilitate the succession of a productive, diverse forest community.

Another benefit that has come with this initiative is the chance to bring back an iconic species to Appalachia, the American chestnut. Prior to the 1940s the American chestnut comprised nearly 25 percent of Appalachian forests, especially in the Blue Ridge Mountains and on the Cumberland Plateau. The chestnuts produced from trees were used asa food source for hogs, and chestnut timber was some of the most prized in the area. Chestnut wood was used for almost all infrastructure, which is why it was often referred to as a species that carried man "from cradle to grave." In the early 1900s, the region was changed forever with the introduction of the chestnut blight. This blight, having been imported with Japanese chestnut nursery stock, is a pathogenic fungus that enters through wounds in the tree, grows beneath the spread quickly throughout, essentially strangling the tree. Now, there are thought to be only 100 trees left across their former range.

The American Chestnut Foundation saw this mining reclamation project as an opportunity to restore the American chestnut and developed a partnership with Green Forests Work. The foundation has a backcross breeding program, crossing the American and Chinese chestnuts, selecting over generations for expressed American traits with Chinese resistance to the blight. As of now, they have a hybrid that is 15/16 American, and 1/16 Chinese. Hybrid American chestnuts have been added to the types of trees planted at these reclaimed mining sites. And the hope is that a parent population of Chestnut tree can be established in the region (Davis, 2006).

Objectives and Hypotheses:

Our main objective was to assess the development and success of restored forest mine sites in eastern Kentucky by comparing soil characteristics and tree growth of these sites to clear-cut Appalachian forests. This assessment will help guide future restoration attempts on mine sites in Eastern Kentucky.

First we looked at physical characteristics of soil and hypothesized that:

- Soil compaction on mined sites would be greater than forested sites and would decrease with time.
- Soil moisture on mined sites will change with time to reflect the values on forested sites

Next we examined soil chemistry and hypothesized that:

- Soil pH on mined sites would be lower than forested sites and would decrease with time.
- Soil electrical conductivity (EC) would be greater at mine sites than forested sites and would decrease over time to stabilize at a biologically safe range (<1 dS/m).
- Mine soils will have less bioavailable phosphate compared to forested soils
- Soil organic carbon would be greater on forested soils
- Nitrogen concentrations would be less in mined soils
- Nitrogen, Phosphorus, and Carbon would increase on both sites with time

Lastly, we examined tree growth and hypothesized that:

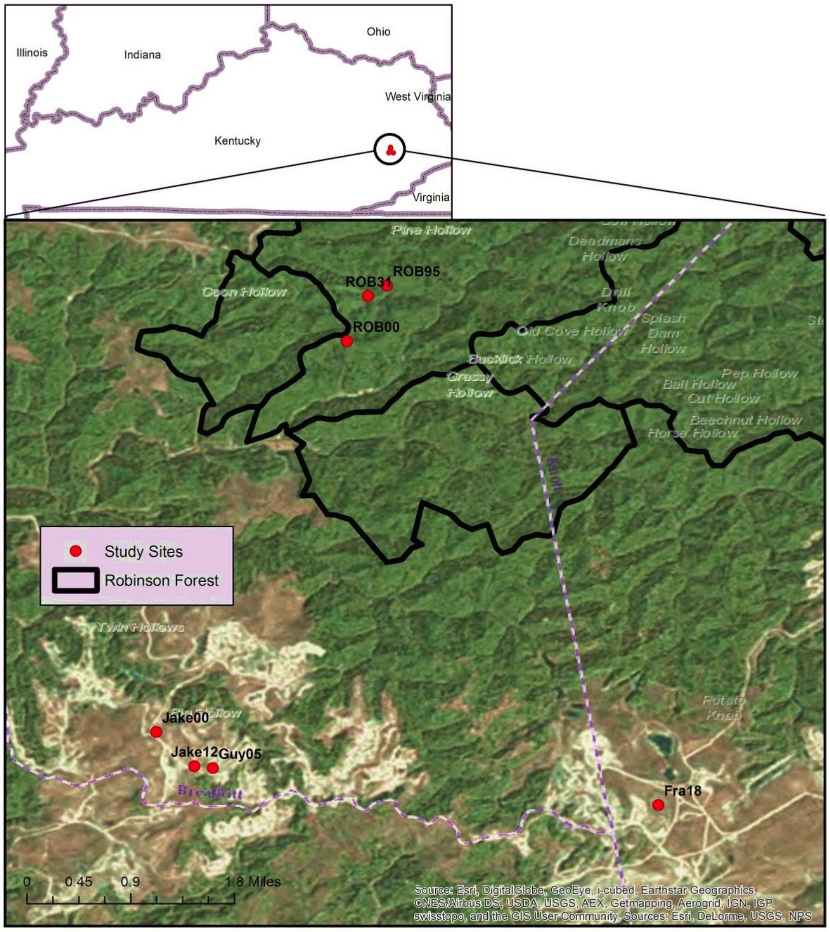
- Tree growth would be faster on forested sites than mined sites for all trees as well as for oaks and poplars.

Methods

This study was conducted in the Eastern Kentucky Coalfield that is part of the Cumberland Plateau. The area is dominated by forested hills and V-shaped valleys. Forests are a diverse mixture of hardwood and softwood species including oak, hickory, and poplar. The region is characterized by high soil acidity and high biodiversity. It resembles peatlands due to the high amounts of soil organic matter, saturated soil, and comparatively poor nutrient concentrations. Climate is mild; average temperatures range from 20.8 °C in January to 29.4 °F in July (Climate, n.d.). Precipitation is heavy in the spring, making up most of the annual 43.9 inches.

We established survey plots at two types of reforested areas, patches of natural forests that had been clear cut and reclaimed coal mine lands, in order to determine if soil succession and tree growth differed between these two disturbance conditions. All our clear cut natural forest sites were within Robinson Forest (Fig. 1). Robinson Forest is 14,786 acres of land that was conveyed in a trust to the University of Kentucky for use in education and research. The last major logging operation took place in 1920. Since then, isolated areas have been cleared using selective harvesting. The area is characterized by winding narrow ridges, steep valley walls, and narrow upland streams. Larger streams are perennial, with many intermittent side branches (Phillippi, 1986). Four sites were chosen within Robinson forest that differed with respect to the time since they were clear cut: 5, 31, and 97 years. We also included a site that was constantly kept clear of trees that was used as an age-zero reference. Although these sites are within the same forest and are not truly independent, they are each in different watersheds so they do not likely interact with respect to soil hydrology and erosion.

Preference for reforested mine sites was given to those closest to Robinson Forest (< 5 miles away). Sampled sites on reclaimed mines were 5,12, and 18 years since reforestation. The 5 and 12 year old sites were from Guy Cove Watershed and Jakes Creek Mine, both mined by Nally & Hamilton Enterprises. These two sites are part of Robinson Forest but were leased for mining. They were mined using mountaintop removal, initially reclaimed with the traditional compaction and grass seeding approach, but then later reclaimed using the Forestry Reclamation Approach and planted with a mix of hardwood and softwood tree saplings including oak, poplar, birch, and white pine.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community, Sources: Esri, DeLorme, USGS, NPS

Figure 1: Location of sampled sites.

The 18 year old site was on Frasure Creek Mine . Frasure Creek Mine has been operating since the early 1980s, and is still active today. The same reclamation techniques were used (except soil was cross ripped) but the trees on this site were planted in rows by individual species in University of Kentucky research plots. The initial study was established to evaluate the success of ripping techniques on tree growth. The two plots we looked at were on oak and poplar sections of the plots. Two plots were established on each site so that the sites are the true replicates for the study. Basic soil type and community composition did not change across the sites.

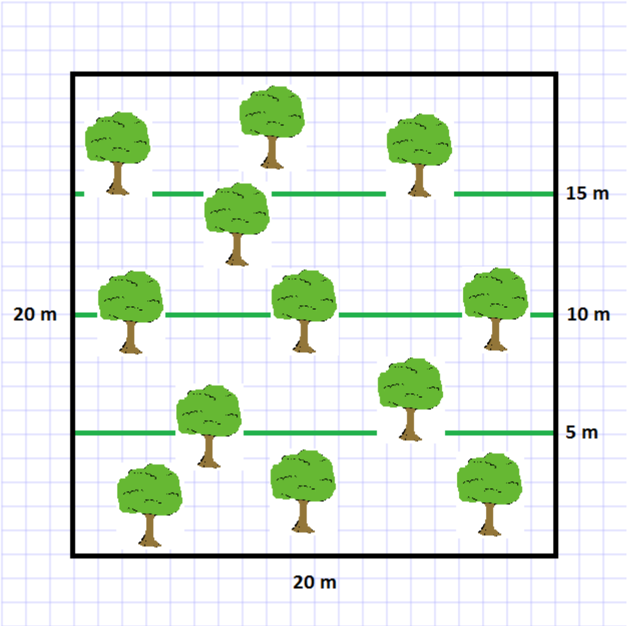


Figure 2: Plot transect set-up for tree sampling.

At six of the eight sites, two 20 m x 20 m plots were set up to measure soil properties and tree size. A single plot was established on the zero-age sites because of the absence of trees. We established each plot by first randomly choosing a point to serve as the bottom right corner and then stretched measuring tape out 20 m in the up slope direction. We set the plot up slope to keep change in elevation standard across all plots. At the 20-m mark we used a compass to orient 90° from the first line and stretch the measuring tape out another 20-m to create the second side of the plot. The plot was finished in this fashion with each corner marked with a flag and the edges outlined with the measuring tape. Inside each plot, 20-m transects were established at 5 m, 10 m, and 15 m from the lowest elevation of the plot (i.e., oriented along the same elevation) to sample trees (Fig. 2). Since each site was a replicate in our statistical model (see below) we averaged our soil and tree data across the two plots.

Five soil samples were collected from each plot to measure soil moisture, pH, mineral nutrients (Nitrogen and Phosphorus), and Carbon. Samples were collected haphazardly throughout the plot in order to get a representative sample (see Fig. 3). Selecting sampling sites purely at random was difficult because some sites within the plot contained large rocks that did not allow our soil auger to penetrate the soil. For instances where a soil sample could not be collected we found the next closest point to the original failed sample location that could be sampled. Each soil sample was collected using an Arts Machine Shop (AMS) 3-¼ in diameter soil auger that was inserted 10 cm into the ground. All five soil samples from a single plot were placed together inside of a gallon Ziplock bag. Each bag was taken back to the lab where they were thoroughly mixed to form a homogeneous mixture for physical and chemical analysis (see below).

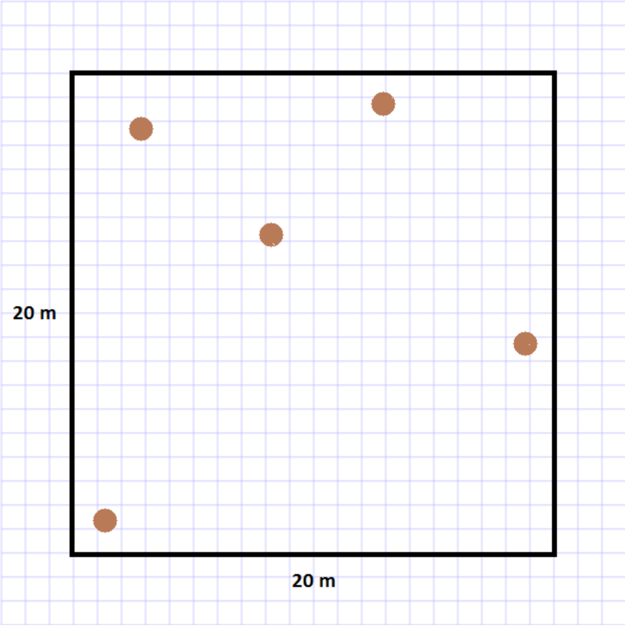


Figure 3: Random locations for auger sampling.

To measure pH we created a 1:1 soil to water ratio soil paste in 50 mL plastic tubes by mixing 10 g of soil with 10 ml of distilled water. Each tube was agitated for one minute until the soil and water were a homogeneous mixture. The pH probe from an Orion Multi-Purpose pH Meter Model 250A was rinsed with distilled water and submerged into the soil paste and continuously stirred until the pH measurement became stable.

Total nitrogen levels were similarly analyzed from the soil samples with a LECO CHN 2000 analyzer. However, no correction factor was needed since total percent nitrogen did not need to be converted. Total percent carbon was analyzed with a LECO CHN 2000 analyzer (Littlefield et al., 2013). Once this Total C was calculated, it was converted to SOC (soil organic carbon) depending on whether the carbon corresponded to a forest or mine site. For forest sites, Total C was multiplied by a correction factor of 0.58, regardless of the age of the site. To convert Total C in mine sites to SOC, the correction factor was found from solving for x in the following equation: $y=0.1285 \ln(x) + 0.0277$, where x is the age of the mine site (in years) and y is the correction factor. Once the correction factor was found, it was multiplied by the original Total C of the mine site. For mine sites that had an age of 0, 1 was used instead (since ln(0) does not work) and so a newly reclaimed site to have an age of 1 was assumed in developing the relationship.

We used a colorimetric technique to measure soil phosphate. After allowing the mixture of 10 g of soil, 10 mL of distilled water, and 1g of dissolved ammonium molybdate and ammonium metavanadate to stand for five minutes after having been well shaken for one minute, the test tubes were read using a Hach DR-890 Colorimeter to measure in milligrams per liter.

In order to measure electrical conductivity (μS), an additional 20 mL of deionized water was added to the pH soil paste to make a 3:1 water:soil ratio in the tubes. The tubes were capped and shaken until the soil chunks and the water formed a smooth mixture. The entire tube was poured into a small cup so that the tip of a Hanna Instrument Conductivity probe could be submerged into the liquid. The conductivity probe gave a reading almost instantaneously, and the EC (in μS) was recorded for each plot.

Two methods were used as indicators of soil compaction, dry bulk density and a cone penetrometer. One soil core sample was taken from each 20 m x 20 m plot (i.e., two per site) using either a 136.7 cm^3 (height = 7.400 cm, radius = 2.423 cm) aluminum or 102.13 cm^3 (height = 5.500 cm, radius = 2.525 cm) brass cylinder. Plot sample placement was randomized yet constrained by conditions which limited soil extraction, including presence of rocks in the soil and surface water. The core cylinders were hammered into the ground perpendicular to the soil profile until the interior of the cylinder was filled. We excavated the cores by digging around the cylinder with a spade until the cylinder could be removed without losing any soil. Plastic lids were secured to both ends of the cylinders to seal the contents. In the lab, all soil was removed from the cylinders, wrapped in tin foil, weighed for wet mass, then placed into an oven at 200 °F for at least 20 hr and then weighed again to determine dry mass. Dry bulk density (in g/cm^3) was calculated with the following equation:

$$d = m/v$$

where m was the dry mass of the soil sample (g), v was the volume of the core cylinder (cm^3). The two bulk density values per site age were then averaged together.

Five subsamples within each plot were chosen to measure soil penetration with an Agratronix Soil Compaction Tester. The sampling points were selected with a stratified random design with the four corners and center of the plot as strata. One sampling point within each stratum was selected at random but occasionally impediments such as rocks forced us to nonrandomly select sampling points. At each sampling point we oriented the penetrometer perpendicular to the soil surface and applied constantly increasing pressure to the handles until the tip of the penetrometer was 10 cm below the soil surface. We then recorded the pressure (psi) reading displayed on the gauge atop the penetrometer. The replicates used for statistical analyses were calculated by averaging the five penetrometer readings for each plot and then averaging again across both plots.

Soil moisture levels were obtained using two methods. The first method used an Echo Ec10 Soil Moisture Probe and an Ech20 Check Echo Sensor Reader to measure the volumetric water content in the soil, which represents the fraction of the total volume of the soil that contains water. The probes were randomly placed, three in each plot, totally six moisture readings per site. At each sampling point a two inch wide steel putty knife was used to make a slit in the soil deep enough so that the moisture probe could be completely enveloped by the soil. Each probe was left in the soil for approximately ten minutes before plugging it into the sensor reader. The sensor reader was turned on and two readings were taken. The first reading was dismissed as a way to account for potential error in the device as it was just turned on. The second measurement was recorded and the soil moisture probe was removed from the ground. The second method measured soil moisture as a percent mass of water using the data from the soil core samples using the following equation:

$$w = M_1/M_2 x\ 100$$

where M_1 is the mass of water, calculated by subtracting the oven dry weight of the soil from the initial mass, and M_2 is the total mass of the soil.

To quantify tree growth in reforested areas we measured tree diameter and height of every tree that was within 1m of each of the 20 m transect lines (see Fig. 2). All trees were identified as either oak, poplar, or other in order to make comparisons of tree growth rates for all trees as well as two of the most common tree types that are planted on mine sites. Identification was done through bark and bud characteristics since our study was conducted in early spring before leaves were present. Tree diameter was measured with one of three instruments, calipers, forceps, or diameter at breast height (DBH) tape, depending on the size of each tree: The calipers with a precision of 1/10 cm were used for stems with diameter <2 cm. The forceps, with a precision of 1 cm, were used on stems that were <10 cm. The DBH tape, with a precision of 1/10 cm was used for trees >10 cm in diameter.

Tree height was also measured using three different instruments that correspond to the tree size: meter stick, telescoping tree measuring rod, and a clinometer. The meter stick was used for trees that were < 2 m. These relatively small trees were manually straightened and height was measured with a precision of 1/10 cm. The telescoping rod was used to measure trees 5 - 32 ft tall . Rods were placed at the base of trees and extended up until the highest point of the tree was reached by the tip of the rod; then height was recorded to the closest inch. A clinometer was used to measure trees that were > 32 ft tall with a precision of 1 ft.

We conducted a series ANCOVAmodels to test whether each soil property and tree growth differed for the main effect of site type (mine vs. forest), changed with the covariate (time), and if there was an interaction between the main effect and covariate.. In cases where there was a significant interaction (i.e., violating an assumption of ANCOVA) we conducted separate linear regressions of the effect of time on the response variable for each level of the main effect. For response variables where there was no significant site*time interaction we removed the interaction from the full ANCOVA model and examined the main effects.

Results:

Nearly all of the physiochemical soil property variables we measured were similar between mine and forest sites and showed no discernable trend over time. The ANVOVA models for soil

Nitrogen, Phosphorus, compaction (bulk density and penetration), and pH had no significant interactive effects of site (forest vs. mine) and time ($p > 0.05$). Moreover, when the interaction term was removed from the model, there were no statistically significant main effects ($p > 0.05$). The full ANCOVA model for soil moisture had a significant site-by-time interaction ($p = 0.04$), however, separate regression models of time vs. soil moisture for each site type did not indicate significant changes in soil moisture over time ($p > 0.05$). Furthermore, there was no significant difference in soil moisture between forest and mine sites, therefore our data suggest no patterns in soil moisture over time or between site types.

Two of the soil parameters, electrical conductivity and organic Carbon did exhibit statistically significant differences between mine and forest sites. The full ANCOVA models for both response variables indicated no significant interaction between site and time ($p = 0.71$) so it was removed from the models so main effects could be tested. Although there was no significant effect of time on electrical conductivity or organic carbon ($p > 0.11$), mine site soil EC values (112.5 μS ± 3.2 μS) were approximately 21 μS greater than forested soils (91.3 μS ± 4.3 μS) (Fig. 4; $p = 0.0035$) and their organic Carbon content (1.9% ± 0.18%) was four times lower than at forested sites (8.42% ± 0.60%) (Fig. 5; $p = 0.04$).

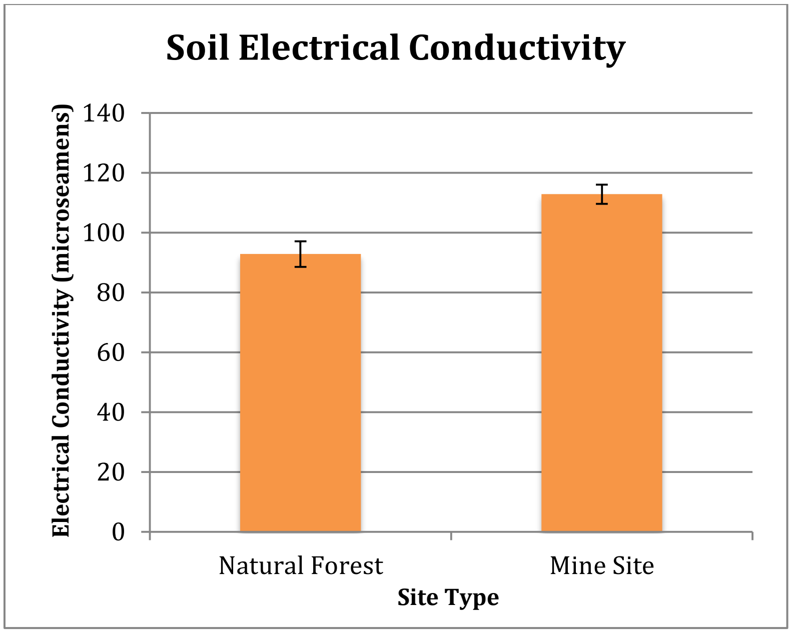


Figure 4: Differences in mean (± SE) soil conductivity between mine sites and natural forest sites.

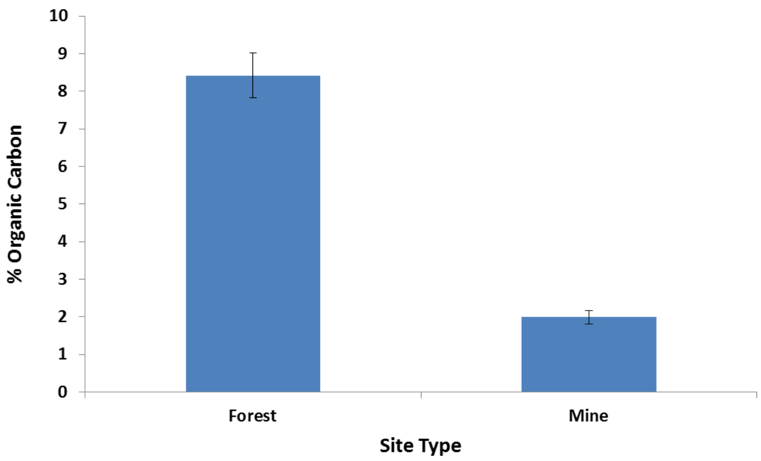


Figure 5: Differences in mean (± SE) soil organic Carbon content between mine and natural forest sites.

Lastly, we examined the main and interactive effects of site and time on the growth (height and DBH) of all trees, oaks, and poplars. When growth, in height and DBH, was pooled across all trees there was a significant interaction ($p = 0.02$) between time and site suggesting that trees grew at different rates on mine and forest sites. We therefore developed separate linear regression models of tree growth for each type of site. According to the regression models, the significant interaction was due to tree height and DBH increasing at a faster rate on reforested mine sites compared to clear cut forests ($p < 0.05$) during the first 20 years of growth (Fig. 6).

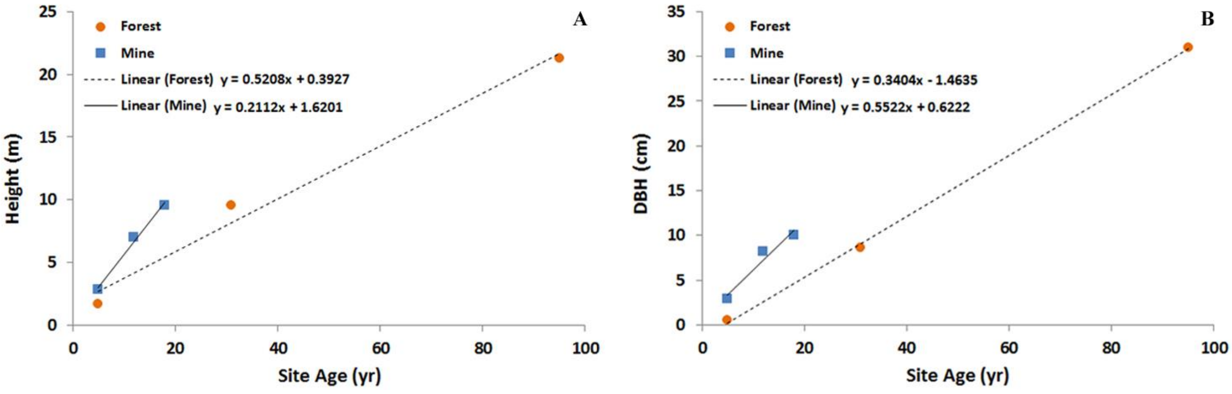


Figure 6: Change in tree height (A) and DBH (B) for all trees from clear cut forests (orange circles) and reclaimed mines (blue squares).

In order to determine if the differences in tree growth between the mine and forested sites was true of all species or due to a particular tree species we examined trends in tree height and DBH for oaks and poplars separately. For tree height, the ANCOVA models for oaks and poplars indicated a significant interactive effect ($p < 0.05$) of site and time therefore we developed linear regression models of time vs height for oaks and poplars on each type of site. Both oak and poplar height significantly increased over time on both mine and forest sites ($p < 0.05$). The slopes of the mine site regression lines, however were two to almost four times greater on mine sites compared to forest sites (Fig. 7 A & C). Therefore, both oaks and poplars increased in height at a faster rate on mine compared to forest sites. Although a similar pattern of greater oak and poplar growth at mine sites existed for the DBH metric (Fig. 7) there was a significant main effect of time but no significant interaction or site main effect ($p > 0.05$). Therefore, oak and poplar DBH increased over time equally between mine and forest sites.

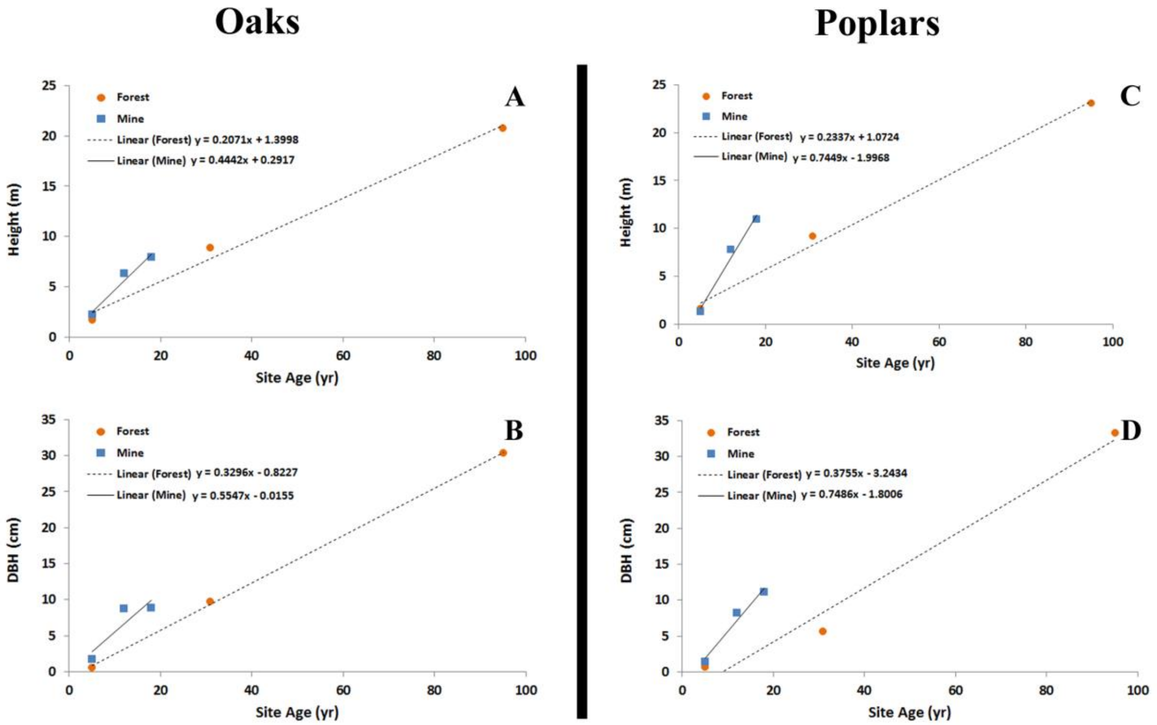


Figure 7: Change in tree height and DBH for oaks (A & B) and poplars (C & D) from clear cut forests (orange circles) and reclaimed mines (blue squares).

Discussion:

The majority of the physical and chemical soil properties we measured (moisture, pH, compaction, Nitrogen, and Phosphorus) did not differ between reclaimed mine lands and naturally regenerating clear-cut forests nor did they change much with time. The lack of any patterns could be due to several reasons. First, our sample size was small. We only had four restoration ages per site type and a single replicate for each site type's restoration age. Although we attempted to standardize for confounding factors like mine reclamation approach, slope aspect, season of sampling, geographic region, etc. the geology and hydrology of this region can vary greatly on small spatial scales thereby adding random error to our results. Therefore, we may have had low statistical power to detect trends over time or differences between sites. Second, the range of restoration ages we used may not have been sufficient to capture important changes in soil structure and chemistry. For example, for both mine and forest sites our age-0 sites were not recently clear-cut or reclaimed but rather have been actively managed for a decade or more to maintain grassy ecosystems. Therefore, our age-0 plots were not truly representative of recently disturbed conditions. Also, the youngest restoration age for both site types was five years old, which for some soil characteristics can be sufficient time to recover to normal levels (Sena et al. 2014). Moreover, our maximum mine site age was 18 years while our oldest forest site was nearly 100 years so we may not have had sufficient temporal contrast in our mine sites. The final possibility for why we were not able to detect significant patterns in our soil variables was the heavy precipitation the region experience around the time of our field data collection. Less than a week prior to our site visits, eastern Kentucky experienced over a foot of snow. Moreover, during our week-long sampling period the study sites were inundated with over two inches of rain. Therefore, soils at all of our sites were likely saturated and our data may not have provided a true representation of soil moisture, chemistry, and compaction.

The two exceptions where we observed patterns in soil characteristics were the higher soil EC and lower organic Carbon in our mine sites relative to forest sites. Although EC was ~ 20% lower on forest sites compared to mine sites, the range of mine site EC values we recorded (100 – 140 μS) are well within the range of what is considered normal for Appalachia watersheds (13 – 253 μS) and are well below the typical specific conductance values (502 – 2543 μS) recorded for valley fill impacted streams (Lindberg et al. 2011). Therefore, although the elevated EC at our mine sites may be statistically significant it probably does not reflect any meaningful difference in soil water quality. The lack of a difference in EC is not all that surprising given that specific conductance in streams drops rapidly within the first two years after reclamation and can return to normal levels in as little as five to eight years (Sena et al. 2014). Since our youngest reclaimed mine site was five years old, it is likely that enough time had elapsed for soil pore water to return to EC levels comparable to natural watersheds.

Therefore, the only soil characteristic to show any genuine pattern was organic Carbon. Although the four-fold greater SOC in our forest sites compared to mine sites is consistent with patterns observed in another similar study by Littlefield et al. (2013), our SOC values were larger than they reported. For example, their 4-, 12-, and 20-yr old clear-cut forest sites had SOC values (2.3% - 2.6%) were closer to SOC at our mine sites (1.99% ± 0.17%). Moreover, their 1-, 3-, and 8-yr old mine site SOC values (0.1% - 0.8%) were an order of magnitude less than our mine sites. It is not entirely clear why our values would differ so much from their study.

Although we originally hypothesized that tree growth would be faster on forest sites because mine spoil is generally more compact, less nutrient rich, and has more variable soil moisture and chemistry than clear cut forests nearly all of the soil characteristics we measured, with the exception of organic Carbon, were no different between our mine and forest sites. Therefore, our soil results suggest that an alternative hypothesis of equal tree growth between mine and forest sites is likely as well assuming soil properties are an important factor controlling tree growth. Growth for all tree species, however, was significantly higher on mine sites than in the clear cut natural forests in terms of height and diameter. Moreover, this difference does not appear to be driven by one species of tree (e.g., oaks or poplars) that may thrive better in mine spoil soils because tree growth was faster on mine sites for the oak, poplar, and other species categories. There are two implications to these findings. First, it suggests that some environmental variable or variables, other than the soil characteristics we measured, may be more important for tree growth and that it may be at more optimal levels on mine sites. Second, it indicates that in terms of soil development and tree growth, reclaiming mine lands using the FRA guidelines can be a successful way to reforest lands in Appalachia.

References:

About OSMRE. (2014, October 28). Retrieved May 3, 2015.

Angel, P. N., Graves, D. H., Barton, C., Warner, R. C., Conrad, P. W., Sweigard, R. J., & Agouridis, C. (2006, March). Surface mine reforestation research: Evaluation of tree response to low compaction reclamation techniques. In *Proceedings, American Society of Mining and Reclamation* (pp. 45-58).

Bendfeldt, E. S., Burger, J. A., & Daniels, W. L. (2001). Quality of amended mine soils after sixteen years. *Soil Science Society of America Journal*, *65*(6), 1736-1744.

Brenner, F. J., Werner, M., & Pike, J. (1984). Ecosystem development and natural succession in surface coal mine reclamation. *Minerals and the Environment*, *6*(1), 10-22.

Burger, J., Graves, D., Angel, P., Davis, V., & Zipper, C. (2005). The forestry reclamation approach. *Forest Reclamation Advisory*, *2*, 1-4.

Burt, T. P., & Butcher, D. P. (1985). Topographic controls of soil moisture distributions. *Journal of Soil Science*, *36*(3), 469-486.

Christ, M. J., Peterjohn, W. T., Cumming, J. R., & Adams, M. B. (2002). Nitrification potentials and landscape, soil and vegetation characteristics in two Central Appalachian watersheds differing in NO 3− export. *Forest Ecology and Management*, *159*(3), 145-158.

Climate in Hazard, Kentucky (Climate in Hazard, Kentucky) http://www.bestplaces.net/climate/city/kentucky/hazard

Cotton, C., Barton, C., Lhotka, J., Angel, P. N., & Graves, D. (2012). Evaluating reforestation success on a surface mine in eastern Kentucky. *National proceedings: forest and conservation nursery associations-2011. Rocky Mountain Research Station, Fort Collins, Colorado*.

County, G. (1989). Incidence of chestnut blight and survival of American chestnut in forest clearcut and neighboring understory sites. *Plant Disease*, 123.

Davis, D. E. (2006). Historical significance of American chestnut to appalachian culture and ecology. *Restoration of American Chestnut, The North Carolina Arboretum*.

Elliott, K. J., & Knoepp, J. D. (2005). The effects of three regeneration harvest methods on plant diversity and soil characteristics in the southern Appalachians. *Forest Ecology and Management*, *211*(3), 296-317.

Emerson, P., Skousen, J., & Ziemkiewicz, P. (2009). Survival and growth of hardwoods in brown versus gray sandstone on a surface mine in West Virginia. *Journal of environmental quality*, *38*(5), 1821-1829.

Fields-Johnson, C., Burger, J., Evans, D., & Zipper, C. (n.d.). Ripping improves tree survival and growth on unused reclaimed mined lands. *Environmental Management, 53*(6), 1059-1065.

Giai, C., & Boerner, R. E. J. (2007). Effects of ecological restoration on microbial activity, microbial functional diversity, and soil organic matter in mixed-oak forests of southern Ohio, USA. *Applied Soil Ecology*, *35*(2), 281-290.

Haering, K. C., Daniels, W. L., & Galbraith, J. M. (2004). Appalachian mine soil morphology and properties. *Soil Science Society of America Journal*, *68*(4), 1315-1325.

Holl, K. D. (2002). Long-term vegetation recovery on reclaimed coal surface mines in the eastern USA. *Journal of Applied Ecology*, *39*(6), 960-970.

Jacobs, D. F. (2007). Toward development of silvical strategies for forest restoration of American chestnut (Castanea dentata) using blight-resistant hybrids. *Biological Conservation*, *137*(4), 497-506.

Jobbágy, E. G., & Jackson, R. B. (2000). The vertical distribution of soil organic carbon and its relation to climate and vegetation. *Ecological applications*, *10*(2), 423-436.

Li, J., Zhou, X., Yan, J., Li, H., & He, J. (2015). Effects of regenerating vegetation on soil enzyme activity and microbial structure in reclaimed soils on a surface coal mine site. *Applied Soil Ecology*, *87*, 56-62.

Lindberg, T.T., E.S. Bernhardt, R. Bier, A.M. Helton, R.B. Merola, A. Vengosh, and R.T. Di Giulio. (2011). Cumulative impacts of mountaintop minin on an Appalachian watershed. Proceedings of the National Academy of Sciences 108(52): 20929-20934

Ling, P. 2005. A review of soil moisture sensors. Vol. 12, Issue 3. Ohio Floriculture Online. The Ohio State University Extension. Columbus, OH.

Littlefield, T., Barton, C., Arthur, M., & Coyne, M. (2013). Factors controlling carbon distribution on reforested minelands and regenerating clearcuts in Appalachia, USA. *Science of The Total Environment*, *465*, 240-247.

Mummey, D. L., Stahl, P. D., & Buyer, J. S. (2002). Microbial biomarkers as an indicator of ecosystem recovery following surface mine reclamation. *Applied Soil Ecology*, *21*(3), 251-259.

Pastor, J., & Post, W. M. (1986). Influence of climate, soil moisture, and succession on forest carbon and nitrogen cycles. *Biogeochemistry*, *2*(1), 3-27.

Phillippi, M. A., & Boebinger, A. (1986). A vegetational analysis of three small watersheds in Robinson Forest, Eastern Kentucky. *Castanea*, 11-30.

Sena, K., C. Barton, P. Angel, P., C. Agouridis, and R. Warner. (2014). Influence of spoil type on chemistry and hydrology of interflow on a surface coal mine in the Eastern US coalfield. Water Air and Soil Pollution 225(1): 2171.

Skujins, J., & Richardson, B. Z. (1985). Humic matter enrichment in reclaimed soils under semiarid conditions. *Geomicrobiology Journal*, *4*(3), 299-311.

Shukla, M. K., Lal, R., Owens, L. B., & Unkefer, P. (2003). Land use and management impacts on structure and infiltration characteristics of soils in the North Appalachian region of Ohio. *Soil Science*, *168*(3), 167-177.

Thomas, K. A., Sencindiver, J. C., Skousen, J. G., & Gorman, J. M. (2000). Soil horizon development on a mountaintop surface mine in southern West Virginia.*Green Lands*, *30*(3), 41-52.

Yeakley, J. A., Swank, W. T., Swift, L. W., Hornberger, G. M., & Shugart, H. H. (1930). Soil moisture gradients and controls on a southern Appalachian hillslope from drought through recharge. *Hydrology and Earth System Sciences*,*2*(1), 41-49.

Zipper, C. E., Burger, J. A., Skousen, J. G., Angel, P. N., Barton, C. D., Davis, V., & Franklin, J. A. (2011). Restoring forests and associated ecosystem services on Appalachian coal surface mines. *Environmental Management*, *47*(5), 751-765.