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How do reclamation conditions affect the invasion success of the exotic autumn olive?

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Introduction:

Post-mining landscapes are currently reclaimed using the Forestry Reclamation Approach (FRA) developed at Virginia Tech that seeks to achieve high hardwood tree canopy cover following the establishment of "tree-compatible groundcover". FRA has been successful in advancing development of ecosystem structure (e.g., ground cover, species diversity, stem density). However, as Dr. Burger and colleagues pointed out in 2009, FRA results in more bare ground, which "allows more invasion by plant species from nearby areas." They point out this is often from adjacent native species from natural dispersal or by animals. However, the gaps left by FRA leave much of the ground open to invasion by exotic plants as well, that may have negative impacts to desirable vegetation. Exotic invasive plants are known to have negative impacts to ecosystem structure and function in a wide range of systems. However, the effect of these exotic plants can be especially problematic on reclaimed mine sites due to the harsh growing environment. One of the most common exotic invaders of the Powell River Project is autumn olive, and is problematic for mine operators during bond release.

Autumn olive (*Elaeagnus umbellata*) is one of the most common species on former coalmines in the Appalachian region (Zipper *et al.* 2011). It is a large shrub native to Pakistan, China, and Eastern Asia, and was brought to the United States in 1830 as an ornamental species (Dirr 1983). Around the 1960s, *E. umbellata* was planted for erosion control, wildlife conservation, and as a nurse species for tree plantations (Fowler & Fowler 1987; Lemke *et al.* 2013). As a result, *E. umbellata* was commonly planted on reclaimed mines post-SMCRA (Zipper *et al.* 2011). However, it has since become reviled as interfering with FRA reclamation and preventing bond release.

E. umbellata can produce up to 24,000 seeds per mature plant annually (Ahmad, Sabir & Zubair 2006) and is a popular food source among wildlife in its native range, with drupes persisting on the branches into the winter and providing nourishment for birds and mammals when other food sources are not abundant (Fowler & Fowler 1987; Kohri, Kamada & Nakagoshi 2011). Almost 99% of the *E. umbellata* seeds can germinate six days after the fruits are consumed and passed through a native crow species (*Corvus corone*) in Japan (Kohri *et al.* 2002). *E. umbellata* also has a rapid growth rate and a broad, dense crown (Evans *et al.* 2013). Once *E. umbellata* is established, it can develop intense shade, which suppresses native species, and hinder the dispersal and establishment of desirable woody species (Zipper *et al.* 2011).

E. umbellata also fixes atmospheric nitrogen through an actinomycete symbiosis in root nodules (Ahmad, Sabir & Zubair 2006), which enables it to establish as a pioneer species on degraded landscapes. Due to their competitive advantage in nutrient deficient locations (Walker & Syers 1976; Vitousek & White 1981), nitrogen fixing species are often the dominant species during primary succession that occur following large disturbances (Stevens & Walker 1970; Gorham, Vitousek & Reiners 1979; Reiners 1981). *E. umbellata* is no exception, as it readily colonizes reclamation sites and can quickly become dominant.

Once *E. umbellata* is present in an ecosystem, its potential to impact other plant species and ecosystem processes, as well as to fix nitrogen (Schlesinger & Williams 1984), gives it the potential to alter the long-term development of forests (Moore *et al.* 2013). For example, in a restoration experiment conducted by Evans et al. (2013), volunteer species represented 65% of the total individual plants present in the fourth growing season, with autumn olive covering 27% of the of the total experimental area and producing much greater volume than native tree species. Unaided ecological succession is usually not adequate to restore native vegetation if invasive species are present and persisting on reclaimed mine sites. Therefore, it is believed that if invasive species such as autumn olive are not managed, successful reclamation will be hindered. Since the time autumn olive was intentionally planted on mine sites in the 1960s, it has thrived on these degraded sites and has become a major invader on many reclaimed mine sites (Lemke *et al.* 2013). As is the case with many intentionally introduced species, autumn olive has gone from degraded landscape benefactor to pariah.

Autumn olive is widespread at the Powell River Project, and throughout the coal-mining region of Appalachia. Autumn olive interferes with bond release by inhibiting success of post-mining land uses by invading both pastures and hardwood plantings. Potentially, the most cost-effective management of autumn olive would be to prevent its establishment and success in the first place – "an ounce of prevention".

Several substrate types and vegetation mixes are used in reclamation at the Powell River Project that may vary in their susceptibility to autumn olive invasion. It would be advantageous to mine operators to identify the best combination of substrate material and vegetation to achieve post-mining land use goals, as well as preventing (or slowing) autumn olive invasion.

In many reclaimed sites autumn olive has already become a major invader, and dominates much of the land area, often outcompeting desirable tree species. Thus, operators are faced with removing autumn olive to achieve the post mining land use to get bond release. Since autumn olive fixes nitrogen, there may be higher plant available nitrogen in locations where autumn olive was versus adjacent areas with autumn olive. It would be valuable to understand if single year mechanical removal is sufficient ot both control autumn olive and establish productive hardwoods.

Objectives:

To address whether autumn olive establishes better or grows more quickly under some reclamation conditions than others, as well the effect of autumn olive management on hardwood establishment, we will utilize several locations at the Powell River Project that differ in reclamation conditions. The objectives of this proposal are to:

1. Characterize the effect of substrate (weathered sandstone vs. unweathered mudstone) on autumn olive survival and performance.
2. Characterize the effect of reclamation vegetation cover on autumn olive survival and performance.
3. Determine how autumn olive management affects hardwood establishment.

Methods and Procedures:

Objectives 1 and 2:

To meet our objectives, we conducted two separate, but complementary studies at the Powell River Project. To look at the effect of substrate on autumn olive, we identified a site with one half of the mountain face laid with a brown, weathered sandstone substrate and the other half laid with a gray, unweathered sandstone substrate. The weathered substrate had a pH of 5.6 and originated from a stratigraphic location closer to the surface and directly beneath the original topsoil, thus it was more weathered. The unweathered substrate had a pH of 7.2, and was less weathered due to it's origination from lower in the rock strata further beneath the surface. Both sides were seeded in 2011 by the mining firm with the same conventional species mix containing the following: perennial ryegrass (*Lolium perenne*); birdsfoot trefoil (*Lotus corniculatus*); ladino clover (*Trifolium repens*); weeping lovegrass (*Eragrostis curyula*); rye grain (*Secale cereal*); orchardgrass (*Dactylis glomerata*); Korean lespedeza (*Kummerowia stipulacea*); and redtop (*Agrostis gigantean*).

To look at the effect of plant community composition that has established post-initial seeding on autumn olive recruitment and performance, we identified a site with one half of the mountain face seeded with the conventional vegetation mix, and the other half seeded with the tree-compatible vegetation mix in 2008 by the mining firm. The underlying substrate is a mostly unweathered sandstone and mudstone mix with a pH 7.4. Both mixes contained perennial ryegrass (*Lolium perenne*), birdsfoot trefoil (*Lotus corniculatus*), ladino clover (*Trifolium repens*), and weeping lovegrass (*Eragrostis curyula*). The tree compatible mix also contained annual ryegrass (*Lolium multiflorum*) and timothy (*Phleum pretense*), whereas the conventional mix contained rye grain (*Secale cereal*), orchardgrass (*Dactylis glomerata*), Korean lespedeza (*Kummerowia stipulacea*), and redtop (*Agrostis gigantean*). The following trees were planted on both sites: white ash (*Fraxinus americana*), white oak (*Quercus alba*), sugar maple (*Acer saccharum*), black cherry (*Prunus serotina*), red oak (*Q. rubra*), chestnut oak (*Q. prinus*), black oak (*Q. velutina*), yellow poplar (*Liriodendron tulipifera*), gray dogwood (*Cornus racemosa*), red mulberry (*Morus rubra*), redbud (*Cercis canadensis*), white pine (*Pinus strobus*), and shagbark hickory (*Carya ovata*).

In both the substrate and vegetation sites, we also wanted to examine the effects of resident plant composition that has formed post-seeding on autumn olive establishment and growth. We used the following four plant community treatments in both locations established in 10 randomly located 2x1m plots:

1) full resident community;
2) grasses only;
3) broadleaves only;
4) no plant community - bare ground;

The bare ground, grass, and broadleaf only plots were initially treated with herbicides, and then managed by hand clipping. The overall design was a split-plot design with the main plot being the plant community, and one side of the plots were planted with 42 autumn olive seeds in the spring of 2014, while the other side was planted with 3 one-year-old bare root autumn olive transplants in early spring 2015.

Plots were monitored monthly for germination and survival. We also recorded autumn olive height and basal diameter from May to October of 2014 and 2015. Basal diameter is also being recorded due to the fact that autumn olive puts out many branches, starting at a young age, and having both measurements could also account for multiple types of growth. Percent cover of autumn olive and all other species was taken throughout the spring and summer of 2014 and 2015. At the conclusion of the project, the plots will be sprayed with herbicide to eradicate all autumn olive and will be monitored and spot treated for at least a year.

Results:

For both experiments, none of the 6,800 autumn olive seeds germinated in any of the plots in 2014 or 2015. Therefore, we are only reporting results of the establishment and performance of the autumn olive transplants from 2015.

Growth in different substrates

There were no differences in autumn olive survival among substrate types or community plots ($p>0.5$). Autumn olive grew twice as tall ($p<0.0001$, Figure 1) with double the growth in basal diameter ($p<0.0001$, Figure 2) in the weathered substrate compared to the unweathered substrate.

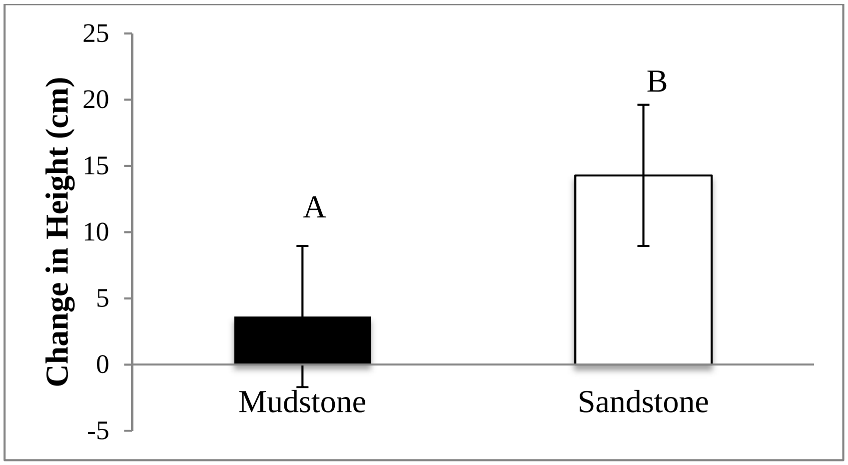

Figure 1. Mean change in height of autumn olive by substrate type with standard error.

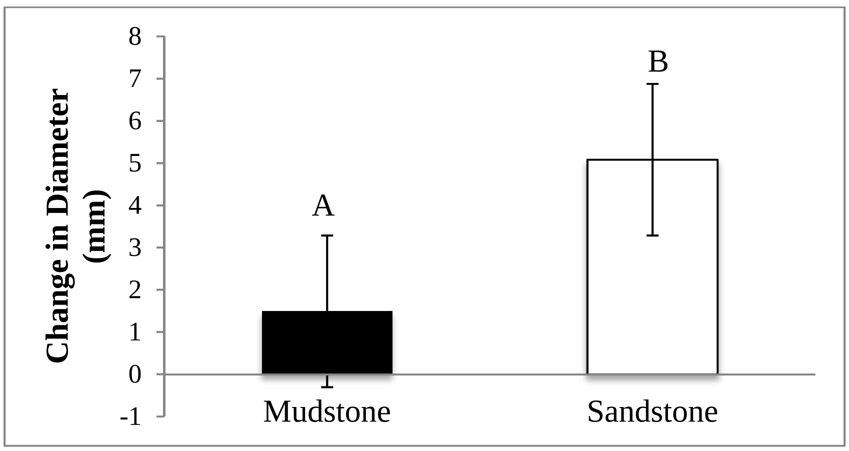

Figure 2. Mean change in basal diameter of autumn olive by substrate type with standard error.

Autumn olive also grew almost four times taller ($p=0.00017$, Figure 3) and had almost double the basal diameter growth ($p=0.0030$, Figure 4) in the bare ground community plots than the full resident community plots and forbs only community plots.

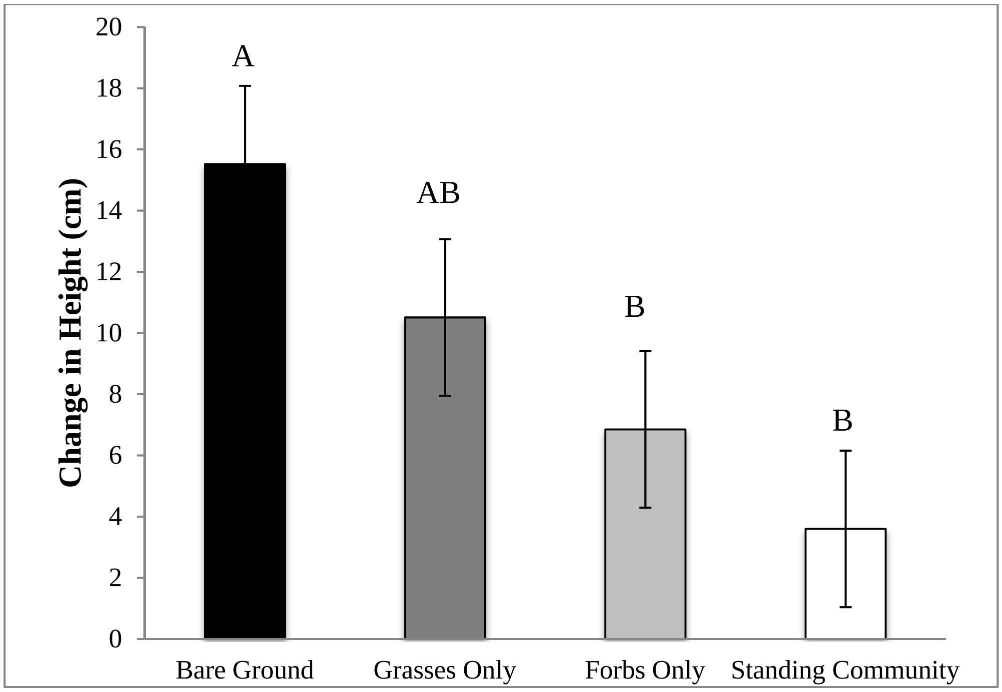

Figure 3. Mean change in height of autumn olive by community plot in substrate sites with standard error.

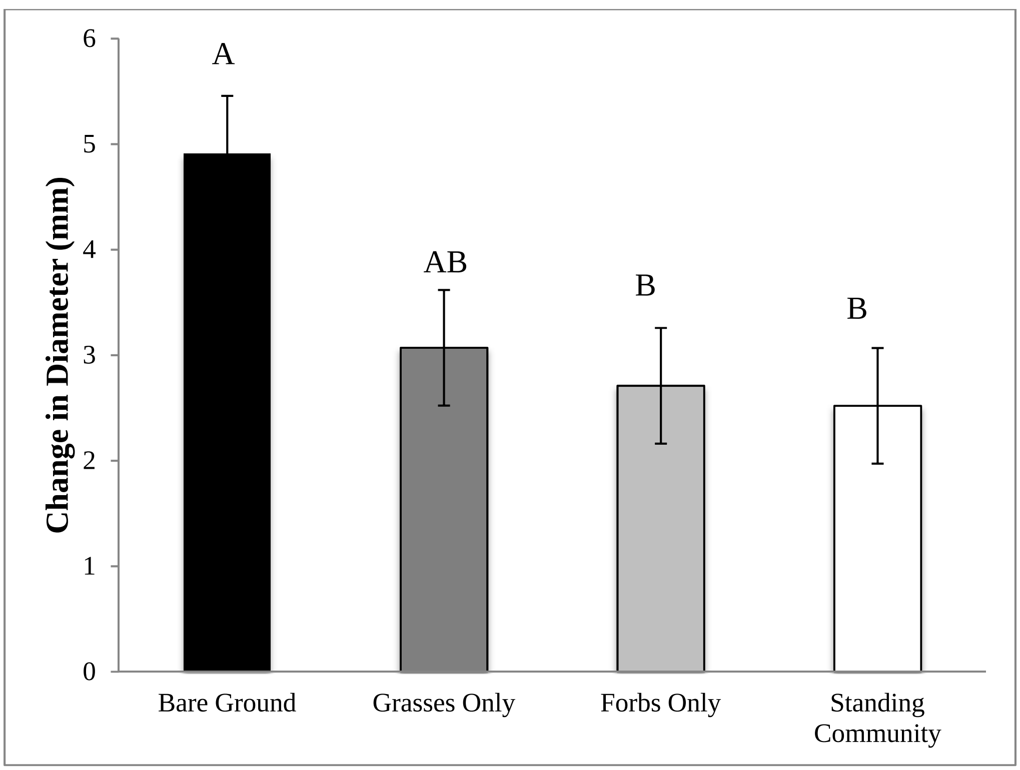

Figure 4. Mean change in basal diameter of autumn olive by community plot in substrate sites with standard error.

Overall, autumn olive growth was much greater in the more highly weathered sandstone substrate, even though we saw no difference in the initial survival between substrate types. The greater growth in weathered sandstone is not surprising, considering the overall better growing conditions of the weathered sandstone versus the unweathered sandstone. Unweathered gray mine spoils, though they will eventually weather into soils, are generally not suitable for restoring forests. For example, Zipper et al. (2013) reviewed comparison studies looking at survival and growth on weathered and non-weathered materials, and they found that planted tree survival was not different between weathered and unweathered minespoil, but tree growth was usually significantly greater on weathered materials (Torbert, Burger & Daniels 1990; Angel *et al.* 2005; Emerson, Skousen & Ziemkiewicz 2009; Miller *et al.* 2012). Early tree growth is commonly suppressed in unweathered minespoils (Zipper *et al.* 2011). The more organic materials in the substrate, the greater the forest restoration potential. However, use of unweathered materials may be unavoidable depending upon availability from site to site (Skousen *et al.* 2011). Unweathered minespoils are available in much greater quantities on modern mines than weathered minespoils or native soils (Zipper *et al.* 2011).

Among the plant community types, across both substrates, autumn olive grew taller and larger in bare ground plots, without competition than in the forb only or standing community plots. Bare ground creates the potential for the autumn olive transplants to exploit the limited available resources instead of having to compete with other fast growing forbs or the combination of forbs and grasses that are typically present four years following seeding of a site. This site was seeded in 2011, thus the vegetation was only 3 years old when we began and very small throughout the entire experiment. This could also explain why we didn't see meaningful differences in autumn olive growth between the three community plots that still had vegetation (grasses, forbs, or standing community). No matter what vegetation type was present, the percent cover of plots (excluding bare ground plots) was very similar, especially at the sandstone site (sandstone average plant cover: 39±14%; mudstone average plant cover: 67±11%).

Growth in different vegetation mixes

There were no differences in autumn olive survival among vegetation mixes or community plots ($p>0.5$). Autumn olive grew approximately 10 cm taller ($p=0.0194$, Figure 5) and had almost double basal diameter growth ($p=0.0244$, Figure 6) when planted into the conventional vegetation mix vs. the tree compatible vegetation mix.

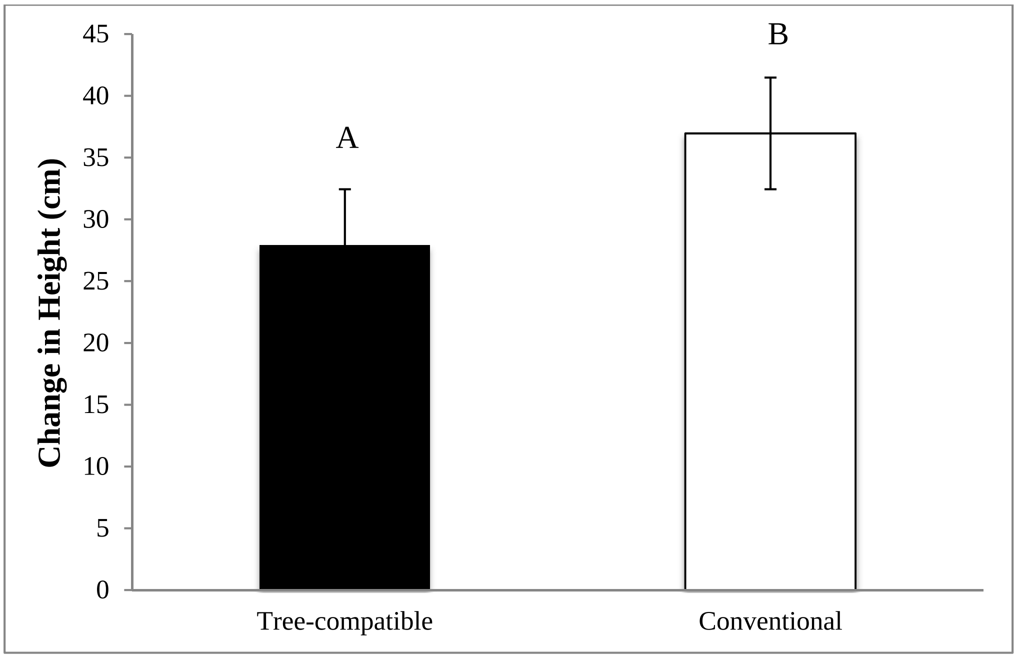

Figure 5. Mean change in height of autumn olive by vegetation mix with standard error.

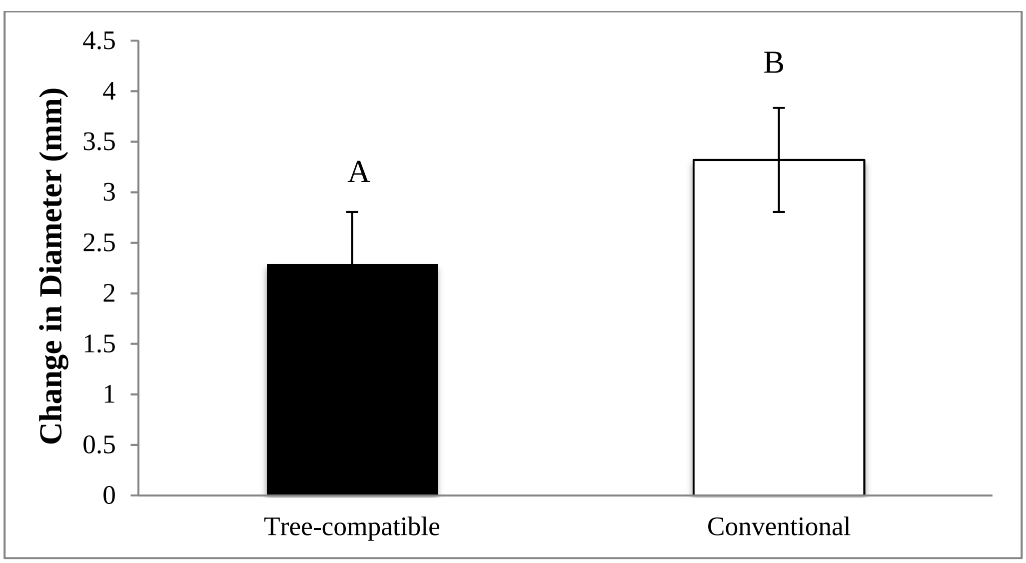

Figure 6. Mean change in basal diameter of autumn olive by vegetation mix with standard error.

There were 38 plant species in our plots in the tree-compatible site, whereas there were 27 plant species in our plots in the conventional site. Of those plant species, there were 21 common species between both sites, with the 17 unique species present at the tree-compatible site and 6 unique plant species at the conventional site. There were no significant differences in autumn olive transplant's growth (height or basal diameter) among the four plant community treatments (p=0.1026; p=0.2262), nor were there any significant growth differences (height or basal diameter) in the interaction between the community treatment plots and vegetation mixes (p=0.0983; p=0.5372). Height growth and basal diameter growth were significantly correlated (p=0.029).

Contrary to our expectation, the autumn olive transplants grew significantly larger in the conventional mix versus the tree-compatible mix. This result is surprising considering the conventional mix was used pre-FRA, and focused on using species that were more aggressive colonizers to prevent soil erosion. The conventional mix incorporated species such as the very competitive Korean lespedeza, unlike the tree-compatible mixture which incorporates species that would be intentionally less competitive to allow for native colonization of desired, forest-compatible species (Fields-Johnson *et al.* 2012). However, this site was set up in 2008 and had well-established plant communities, with species that were included in the initial mixes as well as volunteers. When looking at just the species richness of each site, the tree-compatible site had 38 species total, compared to the conventional site, which had 27 total species. There were 21 common species between both sites, but the variation in species assemblage at the sites could speak to the difference in autumn olive growth, with the larger number of unique species in the tree-compatible site hindering the success of autumn olive in some way. Again, we are unable to comment on the competitive ability autumn olive could have if it had been planted or colonized the same area during the initial reclamation seeding.

Restoration approaches of seeding herbaceous species have not always been successful in creating self-sustaining ecosystems (Gonzalez-Alday et al., 2009). Nutrient availability also affects the composition of the success of the plant communities (Evans *et al.* 2013). In the Appalachians, soil organic nitrogen pools and cycles have been identified as essential processes for ecosystem recovery (Zipper *et al.* 2013). Thus, nitrogen-fixing plants, such as autumn olive, often make up large components of plant communities on reclaimed mine sites, which suggests that nitrogen available to plants is a common influence on the plant community (Zipper *et al.* 2011). In order to adequately inform management decisions, there needs to be a better understanding of the different aspects that promote successional processes after the large land disturbances created by surface mining (Alday, 2011). The Forest Reclamation Act is a step in the direction of aiding forest restoration on mine sites, especially in the Appalachian region of the United States.

Objective 3:

We conducted an experiment to record hardwood tree seedling growth on reclaimed land in four different autumn olive control treatments at the Powell River Project. We identified a reclamation site that was heavily colonized by mature autumn olive, but also had adjacent large areas where there was no history of autumn olive. We set up the following four treatments in the fall of 2014 in a randomized complete block design with 8 total blocks:

1) autumn olive present;
2) mechanical control of autumn olive;
3) mechanical control of autumn olive followed by cut-stump herbicide application;
4) autumn olive never present,

To simulate how autumn olive would be managed on a large scale, we cut autumn olive with a chainsaw at 10-15cm above the soil surface for treatments 2 and 3. For treatment 3, we also applied the herbicide Garlon 4 Ultra (active ingredient triclopyr) at 50% v/v in basal oil. Each plot size was approximately 3 x 3m depending on the size of the autumn olive, but in each case 2-4 mature individuals were cut for treatments 2 and 3.

Reclamation specialists typically hand transplant bare rootstock seedlings in late winter. Therefore, we used bareroot seedlings of pin oak (*Quercus palustris*), red maple (*Acer rubrum*), and black cherry (*Prunus seritona*), which were chosen for their local use and rapid growth rate on reclaimed mine sites (Davis *et al.* 2012). Three individuals of each species were randomly planted into each treatment at each block in mid-March 2015. Within each plot we monitored hardwood survival, hardwood height and basal diameter, and autumn olive regrowth (for treatments 2 and 3) from February to October 2015.

Results:

Survival

Survival was high (>80%), and did not differ among the three native tree species (p=0.1685) or the interaction between species and treatments (p=0.3155), but survival did vary among the treatments (p=0.0392). Hardwood tree seedlings had the highest survival in the autumn olive cut/spray management plots (p=0.0392, Figure 7).

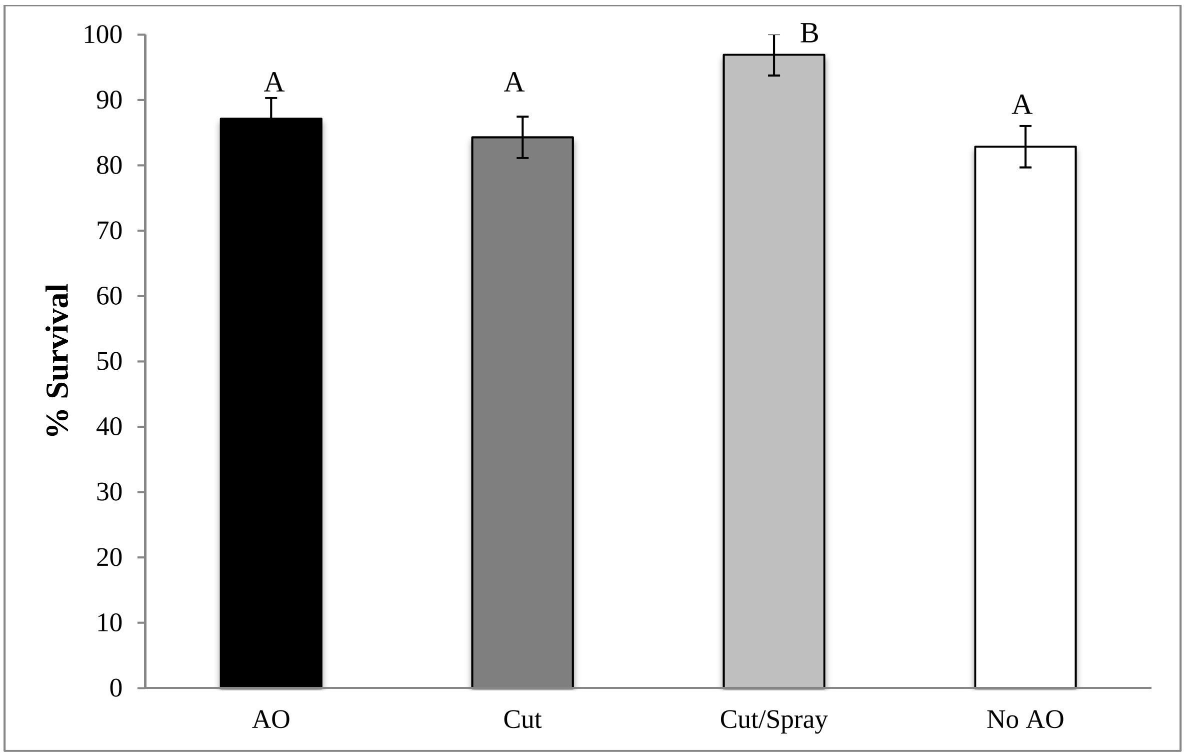

Figure 7. Percent survival of hardwood tree seedlings by management plots with standard error.

Overall, native tree survival was high, and the presence or absence of autumn olive had little effect on tree survival or growth. Despite higher plant available nitrate levels when autumn olive is present, in this study the trees did not appear to be affected by increased nutrient availability. The lack of overall differences most likely reflects the short duration of the study, and we would expect differences, if they did exist, to manifest with more time as tree growth is relatively slow.

While hardwood seedling survival was highest in the autumn olive management plots where autumn olive had been cut and sprayed, there were no differences in seedling growth among the autumn olive management plots at the end of the growing season. This was somewhat surprising, considering the almost double amount of nitrate (NO_3^-) available in the management plots with standing autumn olive compared to the plots without autumn olive present.

Hardwood Growth

Autumn olive management produced no significant differences in tree seedling height or basal diameter growth (p=0.1788; p=0.4393), nor were there significant differences in the interactions between autumn olive management and species height growth or basal diameter growth (p=0.5054; p=0.4807). However, during peak growing season (August), there was a significant difference between autumn olive management treatments, with the seedlings in autumn olive plots on average growing more (40 cm) than seedlings in the plots without autumn olive present (34 cm) (p=0.0187, Figure 8).

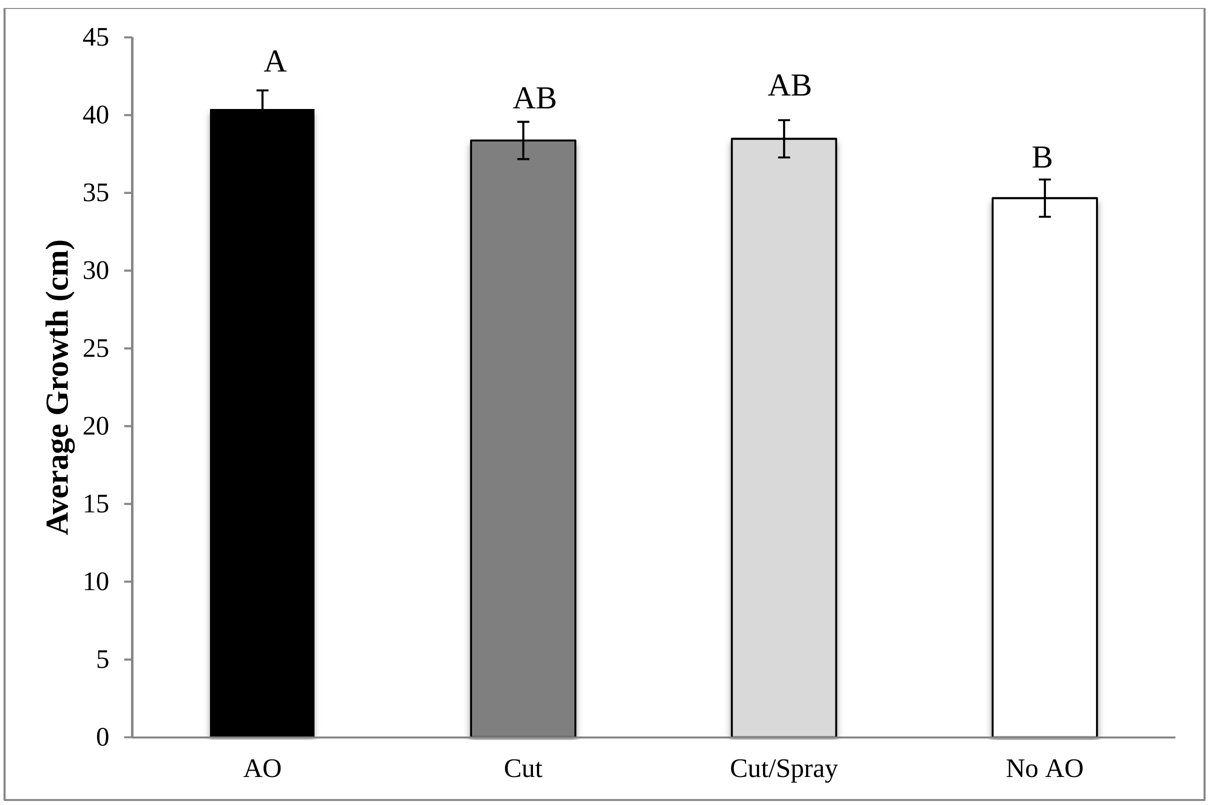

Figure 8. Mean change in height of planted tree seedlings by treatment with standard error.

Across all treatments and tree species, new growth was the same, 4.4 cm ($p=0.3460$). Pin oak seedlings had almost four times as much basal diameter growth across all treatments than did red maple seedlings, and almost double the amount of basal diameter growth than cherry seedlings ($p<0.0001$, Figure 9).

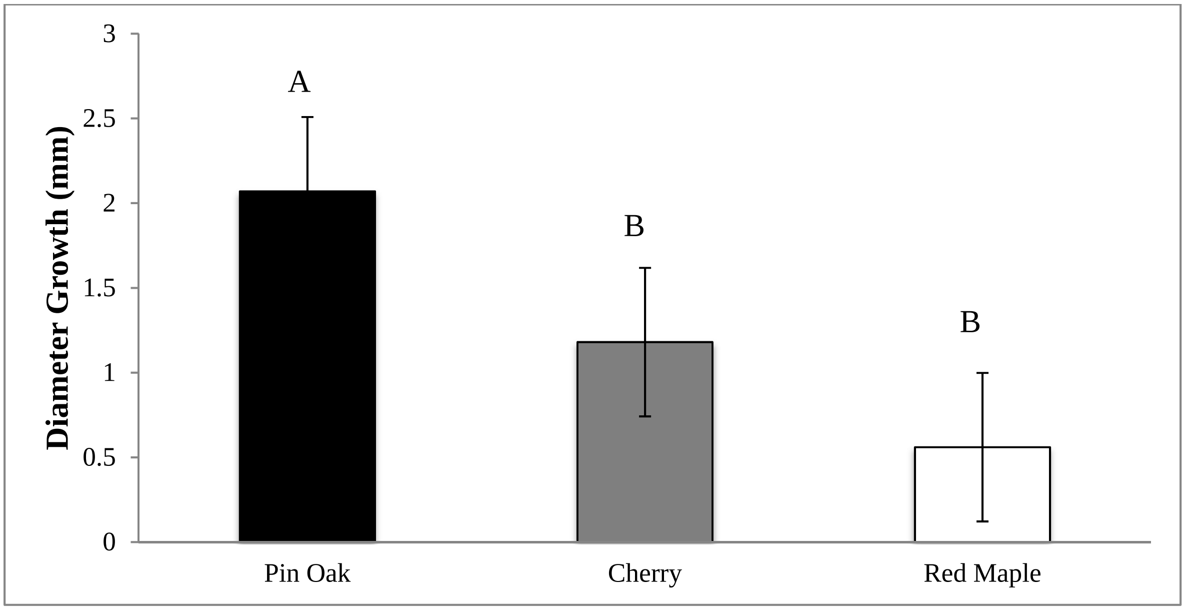

Figure 3. Mean change in basal diameter of tree seedlings by species with standard error.

Autumn olive creates root nodules that have a symbiosis with actinomycetes (*Frankia* spp.) in the soil, giving them the ability to fix and utilize atmospheric nitrogen (Paschke, Dawson & David 1989; Kim, Cardenas & Chennupati 1993). This symbiosis, combined with rapid growth rates and endozoochory have allowed autumn olive to thrive on degraded lands. In fact, there is evidence that underneath autumn olive, there are higher nitrification rates, and nitrate leaching underneath autumn olive is comparable to a fertilized agricultural field (Baer *et al.* 2006). Therefore, we expected the tree seedlings to grow better in plots with autumn olive, managed or unmanaged, than in the plots where there is no autumn olive present due to the increased concentration of plant available nitrogen. Instead, we observed no influence of the varying amounts of NO_3^-concentration on tree seedling growth at the end of the growing season (October) among autumn olive management plots. While nitrogen availability did not appear to affect tree growth, our study may have been too brief to observe differences among relatively slow growing trees, or competition from other species could be mediating the impact of nitrogen. In the first year, the tree seedlings are spending resources establishing a root system, which may not be fully developed enough to exploit differences in plant available nutrients.

Across all treatments, the pin oaks had more growth in basal diameter than the black cherry or red maple over the course of the first growing season. Anecdotally, we noticed poor drainage and standing water at some of our experimental blocks after rainfall. Even though red maple, black cherry, and pin oak are all woody species with rapid growth rates and ability to tolerate varying pH levels (Davis *et al.* 2012), pin oaks are better suited for wet sites than red maples and black cherries (Davis *et al.* 2012). Though we did not take data pertaining to the standing water we observed in some areas, this could help to explain the larger basal diameter growth of pin oaks than the other two species.

Once autumn olive becomes established in an area, eradication requires tremendous effort and expense. In fact, for most invasive species, eradication, or the complete elimination of the species in the area, grows proportionally more difficult with the size of the invasion (Rejmánek & Pitcairn 2002). The difficulties of autumn olive eradication stem from prolific seed production, dispersal via wildlife, and the ability to re-sprout after cutting or damage (Kohri *et al.* 2002), resulting in aggressive colonization which hinders native woody species dispersal on reclaimed mine areas (Zipper *et al.* 2011). Often, a single mechanical removal is used to control dense groves of autumn olive on abandoned mines that are hindering the establishment and growth of hardwood tree species (Byrd *et al.* 2012). However, mature autumn olive is known to aggressively resprout when cut (Campbell, Dawson & Gregory 1989), thus requiring an additional chemical component.

Autumn olive also has the potential to impact ecosystem processes, through nitrogen fixation and alteration of nutrient cycling (Schlesinger & Williams 1984), giving it the potential to impact the long-term development of forests (Moore *et al.* 2013). Successful management of autumn olive with all techniques requires continual management (Byrd *et al.* 2012). Despite the known effects of autumn olive, our results have not shown autumn olive to be detrimental to the success of tree seedlings, at least in the first year. However, it is important to maintain this experiment to continue following the effects autumn olive management (or lack thereof) may have on hardwood tree seedlings as they mature, further our understanding of forest succession on reclaimed mine sites.

Benefits:

The benefits of this study are directly in line with the overall mission of the Powell River Project, which seeks to enhance reclamation of coal-mined lands. Exotic plants are common in reclamation sites across the Appalachian coalfields, and this project seeks to understand the causes and consequences of autumn olive invasion on reclamation. We only have one year of data, so we aren't able to give concrete management suggestions, but overall, this project seeks to address challenges to successful reclamation, which has direct implications for regulatory compliance, bond release, and ecosystem services to local communities.

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