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Plant community development following restoration treatments on a legacy reclaimed mine site

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ABSTRACT

Large-scale soil disturbances due to surface mining for coal have removed nearly one million hectares of native forests in the eastern deciduous forests of North America. Reclamation methods have induced long-term changes in soil properties by continual mechanical grading and heavy seeding of herbaceous plant species. Years after initial reclamation, many sites remain unproductive landscapes comprised of a few non-native, invasive plant species. Recently, various methods that employ deep-soil ripping have been used to alleviate soil compaction on these sites to prepare the substrate for tree planting. The objective of this study was to compare how herbaceous plant communities reassemble throughout the first five years of vegetation recovery after deep-soil ripping (1 m), traditional plow and disking (30 cm), and the combination of the two soil treatments. Vegetation cover increased over five years ($P < 0.0001$) and varied among soil treatments ($P = 0.007$). There was a significant treatment effect on native species abundance ($P = 0.01$), while native and naturalized vegetation cover varied with time ($P < 0.001$). Deep-soil ripping, in the absence of plow/disking, generally had the least vegetative cover but promoted an even distribution of native, naturalized, and invasive vegetation. Non-native reclamation species regenerate very quickly in plow and disked plots, and their composition was similar to the control plots. Shannon and Simpson diversity did not differ among the treatments, but it was negatively impacted by the presence of tall fescue (*Festuca arundinacea*) and Chinese lespedeza (*Lespedeza cuneata*; $P < 0.001$), two common non-native species used in traditional mine-land reclamation practices. Continual monitoring of the temporal dynamics of novel, non-native systems following site reclamation will help select methods required to restore native plant communities.

1. Introduction

Large-scale soil disturbances due to surface mining for coal have removed nearly one million hectares of native deciduous forests in eastern North America (USGS, 2011), resulting in long-term changes in soil chemistry, altered water and nutrient cycles, and significant topographical transformations to the original landscape (Saylor, 2008; Wickham et al., 2007). Following the passage of the federal Surface Mining Control and Reclamation Act (SMCRA) in 1977, over 7000 km^2 of historic forest area in the Appalachian region of the U.S. have been mined and reclaimed to non-native grassland (Franklin et al., 2012). Under SMCRA, efforts to mitigate environmental impacts in the United States required stockpiled topsoil to be graded back to contour using heavy equipment and non-native cover crops to be seeded on compacted soils (Plass, 2000; Zipper et al., 2011). Commonly used cover crop species include tall fescue (*Festuca arundinacea*), Chinese lespedeza (*Lespedeza cuneata*), birdsfoot trefoil (*Lotus corniculatus*), sweet clover (*Melilotus officinalis*), and Kentucky bluegrass (*Poa pratensis*), all of which were selected for their high seed purchase availability and fast establishment on coal mine reclamation soils (Bussler et al., 1984; Torbert and Burger, 2000).

The soil compaction methods and aggressive herbaceous groundcover used at these sites are not conducive to forest tree recovery, as evident from the lack of natural recruitment of native herbaceous plants and trees and low survival of directed tree

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plantings (Cavender et al., 2014; Franklin et al., 2012; Groninger et al., 2006; Zipper et al., 2011). Many sites remain relatively unproductive landscapes composed of a few invasive, non-native plant species for years after initial reclamation (Bunnell et al., 2004; Cavender et al., 2014; Stacy et al., 2005). These constructed non-native grasslands appear to slow the recruitment of native pioneer species resulting in a 'legacy' of arrested succession in otherwise forested landscapes (Davis et al., 2005; Pritekel et al., 2006). Consequences include large-scale forest fragmentation and decreases in biodiversity, native habitat, and biomass production (Evans et al., 2013; Krieger, 2001). These outcomes indicate that current practices of passive management at these sites will result in the continued loss of native habitat by delayed recovery of native forest plants.

As restoration goals shift from reclaiming ecosystem processes to restoring ecosystem structure and native habitat, more aggressive management of non-native, invasive plant communities may be necessary to artificially establish native trees and promote the recruitment of native volunteer species on legacy mine sites reclaimed using SMCRA (Evans et al., 2013; Zipper et al., 2011). The grassland-reclamation methods utilized under SMCRA typically result in bulk densities above the threshold for woody root penetration (means 1.64–1.84 g cm^{-3}, Bauman et al., 2013; Gilland and McCarthy, 2014; Heilman, 1981). Methods that employ deep-soil ripping to alleviate compaction that originated during reclamation have been used to establish trees on sites where soil chemistry would be favorable to tree establishment (Fields-Johnson et al., 2008; McCarthy et al., 2008; Skousen et al., 2009; Zipper et al., 2011). Deep-soil ripping (1–2 m) has been reported to effectively fracture hardpans common to mining operations (Löf et al., 2012), increase water capture and soil aeration (Cleveland and Kjelgren, 1994), decrease bulk density (Gwaze et al., 2007), and encourage beneficial microbial interactions (Bauman et al., 2013). Studies have also reported soil disturbance to be important for the establishment of seeded native cover crops (Skousen and Venable, 2008) and directed tree plantings (Bauman et al., 2014; Fields-Johnson et al., 2014; Skousen et al., 2009).

Individual herbaceous species differ in their competitive abilities, and it is not clear how mechanical surface treatments influence vegetation reassembly on reclaimed grasslands. Soil disturbance is documented to be a precursor for invasion by non-native plant species (Chalmers et al., 2005; Engelberg et al., 2014), but may also facilitate natural succession by allowing the recruitment of native woody pioneer species. The successional trajectory of these sites will partially depend on the competitive interactions between these native recruits and the non-native reclamation species that could quickly re-establish from propagules (seed/bud banks, roots, rhizomes) present in the soil or by dispersal from source populations on adjacent legacy sites. The objective of this study is to compare how herbaceous plant communities reassemble throughout the first five years of vegetation recovery after mechanical site-preparation treatments were used. We report on vegetation composition after deep-soil ripping (1 m), traditional plow and disking (30 cm); and the combination of the two soil treatments was used to prepare a reclaimed grassland for hardwood tree planting (Bauman et al., 2014). We hypothesize that the mechanical treatments used will promote differential changes in reclamation vegetation through time. We predict differences in community composition among treatments based on the severity of soil disturbance (deep ripping fractures the soil profile, but plow/disking tills and spreads soil as well as plant propagules). We also hypothesize continual inhibition of native species recovery in undisturbed (control) plots and predict a decrease in species richness and diversity in these plots through time as well as in comparison to the disturbed treatment plots.

2. Research methods

2.1. Study site

The field site used for this study is located in the Tri-Valley Wildlife Management Area (TVWMA), Muskingum County, central Ohio, USA (40° 6′ 44″ N, −81° 58′ 23″ W). This coal surface mine site was excavated in the 1970s and reclaimed under SMCRA in 1978, which enforced the placement of topsoil, graded contours, and the establishment of a productive vegetation cover. Topsoil used was part of the original soil that had been excavated using truck and shovel, stockpiled prior to surface mine operations, reapplied using end dumping over rock overburden and coal mine spoil to an approximate depth of 45 cm, and graded to original contour. Reclamation records from the county indicate the use of seed mixes that included birdsfoot-trefoil (*L. corniculatus*), tall fescue (*F. arundinacea*), orchard grass (*Dactylis glomerata*), alfalfa (*Medicago sativa*), red clover (*Trifolium pratense*), rye grass (*Lolium perenne*), timothy (*Phleum pratense*), Kentucky blue grass (*Poa pratensis*), and Chinese lespedeza (*Lespedeza cuneata*).

Small pockets of forest comprised primarily of *Quercus*, *Pinus*, and *Acer* species were left undisturbed at the time these lands were mined (McCarthy et al., 2008). Fragmented forest patches are located 70 m to the north, 140 m to the east, >200 m to the south, and 110 m to the west of the treatment plots. This area received an average of 99 cm precipitation annually with temperatures averaging 22 °C during the first two growing seasons (17, 28, and 11 °C in spring, summer and fall, respectively; National Climatic Data Center).

Test plots were designed as a randomized split plot design, with a total of three replicated blocks, each containing the control and three soil treatments. Each block was measured (117 m × 40 m) and mowed with a bush hog prior to treatment installation and chestnut planting. As described in Bauman et al. (2014), the following treatment plots were established: (1) a control left undisturbed (C), (2) a plot cross-ripped 2.5 m × 2.5 m on center at a depth of approximately 1 meter created by a D-6 dozer with a 1.0 m steel ripper bar attachment (R), (3) a plowed and disked plot installed by a conventional tractor to a depth of approximately 30 cm (PD), and (4) a ripped + plowed and disked plot (RPD). Six weeks after soil treatments were installed, a total of 1200 one-year-old chestnut seedlings were planted in the treatment plots (12 plots, approximately 100 seedlings per plot) as bare rootstock in March of 2007 at a spacing of 2.15 m × 2.15 m. Seed stock were pure American chestnut (*Castanea dentata* Marsh. Borkh.) and two hybrid (*C. dentata* × *C. mollissima*) breeding generations (BC_1F_3 and BC_2F_3) collected from The American Chestnut Foundation open-pollinated orchards at Meadowview, VA, U.S.A.

At the time of treatment installation, topsoil pH ranged from 5.4 to 5.7. Soil texture averaged 61% sand, 23% silt, and 16% clay. Organic matter and cation exchange capacity (CEC) averages were 1.3% and 7.5 CEC, respectively. Values for soil nutrients were similar among blocks and therefore, averaged together: aluminum, 3.5 ppm; calcium, 720 ppm; potassium, 78 ppm; magnesium, 182 ppm; manganese, 3.75 ppm; nitrogen, <2 ppm; and phosphorus, 8 ppm. Differences were detected in average bulk densities (mg m^{-3}) in the top 18 cm of soil: RPD 1.59, R 1.48, PD 1.47, and control plots 1.64 (Bauman et al., 2014).

2.2. Data collection

Vegetation surveys were conducted in July of 2008, 2010, and 2012. Four 1 m × 1 m quadrats were randomly placed in each of the 12 treatment plots (n = 48). Cover values were determined for each species based on a 1-m^2 scale using the following cover class estimations: 1 = trace (<1%), 2 = 0–1%, 3 = 1–2%, 4 = 2–5%, 5 = 5–10%,