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Establishment of earthworms on reclaimed lignite mine soils in east Texas

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ABSTRACT

Little is known about earthworm establishment after surface mining of lignite coal in continental climates such as the south central region of the United States. This study examined the abundance and species composition of earthworms in afforested lignite coal mine soils in east Texas. In a $3 \times 3 \times 2$ factorial design, earthworms were sampled under two methods of land reclamation, haul-back ($n = 30$) and mixed overburden ($n = 30$). The study was conducted on a chronosequence of 2–28 years since afforestation under pine plantations and mixed pine and hardwood stands. The fieldwork was conducted from January 2012 through March 2014 using hand-sorting field methods. Forest cover type was significant at the mixed overburden sites ($p = 0.0128$); mixed pine and hardwood forest soils (13.7 ± 25.46 ind. m^{-2}) contained 43% more earthworms than pine plantation soils (7.6 ± 17.06 ind. m^{-2}). The number of earthworm individuals was significantly lower in 2–8 year-old stands than in 12–18 and 22–28 year old stands ($p < 0.0001$) at both haul-back and mixed overburden sites. Regression analysis found percentage of silt to positively influence earthworm abundance. Analysis of the species composition at both Beckville and Oak Hill mines revealed that 83% of earthworms were native earthworms species (from the genera *Diplocardia* and *Bimastos*) and 17% were exotic species (*Aporrectodea trapezoides*, *Microscolex dubius*, *Lumbricus rubellus* and *Octolasion tytaeum*).

1. Introduction

Lignite coal mining in Texas, and the United States, is an important part of the economy and a reliable local source of fuel for electric power (Clower and Reyes, 2013). The process of lignite coal mining involves removing the surface material (overburden) overlaying the lignite seams, then stock piling the soil before it is used to reclaim the mine land or, if possible, immediately placing it in an already excavated area. During this process soil fauna, including earthworms, are lost due to harsh conditions and loss of habitat (Eijsackers, 2010). Recovery of the belowground ecosystem and restoration of soil health are essential to the success of land reclamation (Bradshaw and Hüttl, 2001; Muys and Granval, 1997; Stewart et al., 1988). However, important components of the ecosystem are often overlooked as measures of land reclamation success (Boyer and Wratten, 2010). Earthworms, keystone species in the belowground ecosystem (Muys and Granval, 1997), are recognized for providing several ecosystem services that are likely to accelerate soil restoration (Boyer and Wratten, 2010). Earthworms are known to incorporate organic matter into the mineral soil (Frouz et al., 2013) as well as mineralize organic matter to increase plant available nutrients (Brady and Weil, 2008). Soil physical properties such as soil structure (Eijsackers, 2010; Stewart et al., 1988) and stable aggregate production (Damoff, 2008; Marinissen, 1994) are also improved from the actions of earthworms.

Soils disturbed and moved after surface mining operations are particularly unfavorable for earthworms because of the lack of structure (Stewart et al., 1988), potential compaction, low to no organic matter content, unfavorable moisture conditions, and low soil pH (Eijsackers, 2010). Thin to no litter layer allows for great fluctuations in soil temperature and the impact of UV radiation is great due to the lack of vegetative layer (Eijsackers, 2010). The success of earthworms during the early stages of reclamation will depend on the ability of the species to tolerate great fluctuations in temperature and moisture levels. Soil amelioration such as liming, fertilization, and the planting of grasses and forbs to promote soil stabilization (Lee, 1985) helps to improve soil properties and encourage reestablishment of soil fauna (Curry, 1994).

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Earthworm colonization onto reclaimed mine lands is further complicated by the difficulties of migration. Some earthworms species have been shown to actively migrate less than 10 m per year (Dunger et al., 2001) and therefore must rely on passive transport onto these severely disturbed soils (Dunger et al., 2001). One source that facilitates the initial invasion of species in reclaimed areas may be soil that remains attached to the roots of those plants used for afforestation (Topp et al., 2001). Birds and mammals may also carry earthworm cocoons attached to their feet while humans may transfer cocoons on tractor or truck wheels (Marinissen and Van den Bosch, 1992). Earthworm cocoons may also be transported by overland flow during heavy massive rains, especially downhill (Atlavinyte and Paryarskaita, 1962), or by intermittent streams and ditches (Schwert, 1980).

Past studies on reclaimed mined soils in the Lusatian lignite mining district in Eastern Germany found that earthworms returned to reclaimed soils as soon as three years after land reclamation under deciduous forests (Dunger and Voitgtländer, 2005; Topp et al., 2001) and as late as 10 years under pine forests (Dunger and Voitgtländer, 2005). Earthworm densities also increased with time since reclamation (Dunger and Voitgtländer, 2005; Hüttl and Weber, 2001; Wanner and Dunger, 2002) and, under optimal conditions, species richness and abundance similar to those of unmined lands were found within 20–25 years after land rehabilitation (Hüttl and Weber, 2001). In England, Armstrong and Bragg (1984) found total earthworm populations similar to undisturbed adjacent control areas within 10 to 20 years after surface soil replacement.

In the United States, Frouz et al. (2013) found no difference between earthworm communities on 10–20 year old reclaimed sites and their equivalent climax communities in Tennessee, Indiana, and Illinois. In this study, earthworms of the family Lumbricidae were found to dominate in the reclaimed sites, while Acanthodrilidae (especially *Diplocardia*) dominated in climax communities.

Despite research that supports the importance of restoring the belowground ecosystem after surface mining, (Boyer and Wratten, 2010; Scullion and Malik, 2000; Snyder and Hendrix, 2008), there is a paucity of research on the recovery of earthworms after open cast coal mining and subsequent land reclamation in continental climates such as the south central region of the United States. The lignite mines in east Texas present a unique opportunity to study the reestablishment of earthworms on these severely disturbed soils in a region with hot, humid summers and mild winters. Two mines in east Texas were chosen as study sites where chronosequences were examineed under mixed pine and hardwood and pine plantation cover types. Each chronosequence consisted of three age since reclamation categories; a young post-mining site 2–8 years after afforestation, a mid-aged post-mining site 12–18 years after restoration, and an old post-mining site 22–28 years after restoration.

The chronosequence approach is useful as it replaces time for locations where results should indicate the presence or lack of a linear trajectory of increasing earthworm abundance through time (Walker et al., 2010). However, the results of the chronosequence approach may be somewhat confounded by the influence of landscape variability (del Moral, 2007). The results of this study are therefore interpreted with much care, as chronosequence studies are generally characterized by the problem of trying to compare conditions that are in fact not fully comparable (Hüttl and Weber, 2001).

2. Methods

2.1. Site description

The Beckville (Latitude: 32.33°N, Longitude: −94.73°W) and Oak Hill (Latitude: 32.22°N, Longitude: −94.73°W) lignite mines are located in the Southern Mixed Forest Province (Bailey, 1995) in the northern portion of east Texas. This area include a region commonly referred to as the Piney Woods ecoregion of east Texas where annual rainfall ranges from 1016 to 1270 mm (40–50 in.) and mean annual temperature ranges from 17 to 20 °C (63–68 °F) (NRCS, 2015). Both reclaimed mine areas were established from overburden material (formed from clayey, shale and sandstone marine deposits, as well as and loam residuum) and are classified as Hapludults (NRCS, 2015). The overburden can be as shallow as 3 m (10 ft) below the soil surface to a depth of 61 m (200 ft), depending on the depth of the lignite seam. However, the majority of the overburden material was 15 to 18 m (50–60 ft) deep (Grimes, 2015).

The Beckville lignite mine uses the reclamation method called mixed-overburden. Here, the overburden material is placed into an existing excavated lignite pit according to the volume of removed previously removed material and the size of the pit. The surface soil at Beckville is rarely if ever stockpiled. The new soil surface is then contoured approximating the original relief preceding vegetation restoration. The oxidized and reduced overburden are mixed in the process. Lime is added as a maintenance tool if pH levels fall below 5.5 (Grimes, 2015).

The Oak Hill lignite mine practices a method of reclamation called haul-back. Here, the reduced overburden material contains pyrite (FeS_2) that if exposed to oxygen has the potential to create highly acidic and toxic acid seeps that may prevent the establishment of vegetation for many years (Hüttl and Weber, 2001). The surface layers of oxidized material (approximately 1.2 m deep) are separated from the underlying unoxidized material during excavation. The oxidized surface overburden is then placed on top of the previously replaced unoxidized material to a minimum depth of 1.2 m. The oxidized overburden is occasionally stock piled if necessary (Lamb, 2015).

Many unmined sites in are around the Beckville and Oak Hill mines were difficult to access because of their location on private property, or the density of the understory made soil excavation difficult. Therefore, previous research conducted in east Texas on unmined mixed pine and hardwood communities (Damoff, 2008) and pine plantations (Wilson, 2001) served as reference sites (RS) for earthworm community characteristics. The vegetative overstory at Damoff (2008) sites included *Pinus taeda*, *P. echinata* mixed with oak species (*Quercus falcata* and *Q. stellata*). The soils were predominately Alfisols and Entisols. Wilson (2001) studied earthworm abundance under pine plantations (*P. taeda*) planted on 1.8 m × 3.0 m spacing. The soils were a combination of Ultisols and Entisols (NRCS, 2015). Table 1 compares some pre-mining soil properties with the unmined reference sites.

After return of the overburden material, the reclamation process at both mines included an initial planting of winter wheat (*Triticum aestivum*) in the fall months (October through November) for stabilization. If additional stabilization was necessary, millet (*Setaria italica*), a spring annual, was planted the following spring. The following fall, winter wheat was drilled into the soil and fertilized. January through March tree seedlings were planted. At pine plantation sites, second and third generation improved loblolly seedlings (*Pinus taeda*) were planted at 625 trees ha^{-1}. At the mixed pine and hardwood sites, each site was planted with 15–30% loblolly pine and 70–85% native oaks (*Quercus* sp.). The remaining 20% of the native hardwoods were minor species such as *Fraxinus americana*, *Liquidambar styraciflua*, *Prunus serotina*, and others (Grimes, 2015).

2.2. Experimental design

The Beckville mine was sampled from February 2012 through March 2013. The Oak Hill mine was sampled from April