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Research paper

Belowground eco-restoration of a suburban waste-storage landscape: Earthworm dynamics in grassland and in a succession of woody vegetation covers☆

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HIGHLIGHTS

- Earthworms were most abundant and diverse in summer.
- Evaluate success of belowground eco-restoration in spring/summer season.
- Age of vegetation more critical than type for belowground eco-restoration.
- Belowground eco-restoration most effective in woody/herbaceous mixtures.
- Woody/herbaceous mixtures also have hydrologic and aesthetic benefits.

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ABSTRACT

Restoration of belowground ecology is seldom a priority in designing revegetation strategies for disturbed landscapes. We determined earthworm abundance and diversity in a 16-year old grass sward (grassland), a 6-year old (Plantation-04) and a 4-year old (Plantation-06) plantation, both of mixed woody species, on a reclaimed waste disposal site, and in nearby remnant woodland, in suburban Sydney, Australia. While no catches were made in autumn, more earthworms were found in spring ($21 \pm 8.6\,m^{-2}$) than in winter ($10.2 \pm 5.9\,m^{-2}$) or summer ($14.4 \pm 5.5\,m^{-2}$). Earthworm abundance in spring was in the order grassland ≈ Plantation-04 ($35.2\,m^{-2}$) > woodland ($12.8\,m^{-2}$) > Plantation-06 ($0.8\,m^{-2}$). None of the revegetated covers had restored earthworm diversity to levels found in the woodland. Exotic species, mostly *Microscolex dubius*, dominated in the four vegetation covers at any time; the only two native species (*Heteroporodrilus* sp. and *Megascoleceides* sp.) found were in the woodland. We also assessed how quality of the evolving soils from the three revegetated covers, compared with that from the woodland, impacted viability of common exotic earthworm species. Both weight gain and cocoon production by the exotic earthworms were higher in the soil from Plantation-04 than in soils from the other vegetation covers, including the woodland; the two variables were positively correlated with the pH and mineral nutrient content (as indicated by electrical conductivity that was in turn correlated with clay content) of the soil. Age of vegetation rather than its composition explained differences in the level of earthworm recovery observed.

1. Introduction

There is an over-reliance on aboveground vegetation processes, including plant growth, in assessing efficacy of revegetation strategies for landscapes used for waste disposal or mining. This is because restoration of ecohydrologic process to minimize the risk of chemical and particulate pollution of the atmospheric and water resources often takes priority over other considerations. Restoration of soil ecosystem tends to receive little attention, despite its

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central role in maintaining soil health that ultimately underpins success of the planted vegetation and its dependent processes (Bradshaw, 1984). Both the chemical and physical properties of the recovered soil, along with its reprocessing and use in seedbed preparation, all impact on the survival and viability of the macrofauna, and on that of the plant species.

The need to conserve local biodiversity and aesthetics has increased the use of native plant species for ecological restoration (Grant, Campbell, & Charnock, 2002; Weir, Fulton, & Menzies, 2006). Woody species are therefore the appropriate choice for environments along the coastal fringes of southeastern Australia, where woodland is the dominant natural vegetation. However, relatively high cost and the long lead-time to achieve effective vegetation cover with woody species, make the use of herbaceous species, grasses in particular, attractive in some instances (Richardson, Burn, & Craig, 1987). Differences in species composition of vegetation covers can alter the evolving belowground ecosystems on rehabilitated landscapes. For instance restoration of physical properties, such as porosity and permeability, may take longer under grassland than woodland (Richardson et al., 1987; Yunusa et al., 2012), and will have significant influence on the developing soil biota such as earthworm communities (Chan and Barchia, 2007) or ants (Gollan, Lobry de Bruyn, Reid, Smith, & Wilkie, 2010).

Earthworms are effective indicators of soil health because of their sensitivity to both immutable and anthropogenic stresses in the soil, and are widely used to assess the ecological consequences of disturbance arising from changes in land use (Boyer and Wratten, 2010; Chan and Heenan, 2006; Hendrix et al., 2006; Smith et al., 2008). For instance, Smith et al. (2008) found a strong tendency towards increasing earthworm populations (abundance) in minimally disturbed landscapes, with earthworms being most abundant in an old growth forest. In addition to changes in abundance, land disturbance also induces strong alterations in the distribution of earthworm species. Land disturbance often results in the displacement of native earthworm species by exotic species (Chan and Heenan, 2006) such as the European *Aporrectodea* species that tend to easily displace pre-existing native species on disturbed lands (Scullion, Ramshaw, & Mohammed, 1988; Smith et al., 2008). It is probable that reconstituted soils may become inhospitable to native species, and in Australia exotic species are known to thrive better than native species in soils contaminated with heavymetals (Yunusa, Braun, & Lawrie, 2009) by minimizing ingestion of potentially harmful trace metals (Muir et al., 2007). The rarity of native species in disturbed lands could, however, be simply a function of time needed to recolonize the now changed habitat and readjust to the now changed edaphic environment, a processes that may take decades (Boyer and Wratten, 2010; Bradshaw, 2000).

In this study we used earthworm abundance, as surrogate of the whole soil biota, to assess the degree to which three vegetation covers consisting of a 16-year old grassland sward and a four- and a six-year old woody vegetation covers had restored earthworm communities on a reclaimed waste disposal site, when compared with an old growth woodland. We undertook field surveys to characterize seasonal changes in the abundance and diversity of earthworms in the four vegetation covers, and laboratory experiments to test how the soils from the four vegetation covers impacted viability of two common exotic earthworm species.

2. Materials and methods

This study was conducted at the Waste Management Centre at Castlereagh (33°39′41″S, 150°46′57″E or Google Locator −33.658781,150.780973) approximately 65 km north-west of central Sydney. The site covers an area of 357 hectares and the original soil at the site is classified as Chromosol, which is equivalent to Haplic Xerosol (FAO, 1974). This soil has a duplex profile consisting of 0.7 m loamy sand topsoil over impermeable heavy clay referred to as Londonderry Clay overlaying conglomerate sandstone and shales of the Triassic Wianamatta Group (Itakura, Airey, & Dobrolot, 2005). Storage cells consisting of trenches (20 m × 5 m, and 5 m deep) constructed into the clay subsoil, and spaced 2 m apart resulting in approximately 65 cells/ha. Once filled with wastes, the cells were capped using the excavated soil that was returned in reverse order of their removal. The cap forms a profile of 2 m over the cells. The reconstructed soil was then planted with either grasses or mixtures of woody and herbaceous species. For this project, we selected three vegetation covers along with nearby remnant woodland, described below:

Grass pasture: This was established in 1994 with a mixture of *Cynodon dactylon* (couch grassland), *Axonopus affinis* (carpet grassland), *Paspalum dilatatum* (paspalum), *Pennisetum clandestinum* and *Trifolium repens* (white clover). Prior to sowing, the soil was fertilized with 300 kg/ha or 30 mg/m^2 of compound fertiliser containing mainly nitrogen, phosphorus and potassium (24:6:12). The grassland was about 16 years old at the start of this study, and it represented a relatively quick and cheap rehabilitation strategy.

Plantation-04: This was established in autumn (April–May) 2004 using a mixture of native trees and shrubs planted in 5 m rows. The tree species used were *Eucalyptus* spp., *Angophora* spp., *Casuarina glauca*, *Melaleuca linariifolia* and *Syncarpia glommulifera* and were interplanted with rows of shrubs made up of species of *Acacia*, *Callistemon*, *Grevillea*, *Hakea*, *Kunzea* and *Leptospermum*. Mineral fertiliser containing nitrogen, phosphorus and potassium (NPK) was applied at the time of establishment. The vegetation was almost six years old at the start of this study and provided a mixture of woody and herbaceous species as a mimic of native woodlands.

Plantation-06: This was established in 2006 using a mixture of woody species as in Plantation-04, but without shrub species or grassland groundcover. Herbaceous weedy species became established as groundcover. A thin layer (<0.1 m thick) of compost was sprayed over the soil in 2008, and was well incorporated into the topsoil at the time of this study. This cover represented a minimum rehabilitation strategy and was four years old at the start of this study.

Woodland: This is dominated by trees of *Eucalyptus parramentensis* and *Angophora bakeri*, in which the understorey is dominated by shrubs and grasslandes including *Pultinea elliptica* Smith, *Cryptandra amara* Smith and *Melaleuca thymifolia* (Yunusa et al., 2010). There was no record of any major disturbance of this vegetation aside from occasional fires, the last of which was in 1999.

All the four vegetation covers were within a 1.5 km radius of each other and have been described in detail in previous studies (Yunusa et al., 2010, 2012). Basic characteristics of the topsoil under the four vegetation covers are given in Table 1. The woodland is characterized by coarse sandy texture that is mildly acidic and saline with 0.044 dS m^{-1} and except for its higher total carbon content, had lower clay content and cation exchange capacity (CEC), and was less saline and dense, than those under the three revegetated sites all of which contained more trace metals (Table 1).

2.1. Field surveys

Field surveys were conducted on April 21, July 14, September 7 and December 15, 2010 to determine species diversity and abundance of earthworm communities under each of the vegetation covers. On each occasion, 20 quadrats (0.25 m × 0.25 m) were randomly sampled across each of the four vegetation covers. For each quadrat, the soil was collected to a depth of 0.25 m, sieved and the earthworms recovered which were then counted and transferred into bottles containing 70% ethanol. The earthworms were later sorted and identified in the laboratory after Blakemore