Exotic Earthworm Impacts Information

1.0 Introduction

In many ecosystems and in agricultural systems earthworms are highly beneficial to soil processes (Hendrix & Bohlen, 2002). However in forest ecosystems with few or no native earthworms, introduced species can have negative effects. Earthworms are keystone detritivores that can act as “ecosystem engineers” and have the potential to change fundamental soil properties, with cascading effects on ecosystem functioning and biodiversity (Frelich et al., 2006; Eisenhauer et al., 2007; Addison, 2009).

Exotic earthworms are a particular problem in previously earthworm-free temperate and boreal forests of North America dominated by Acer, Quercus, Betula, Pinus and Populus (Frelich et al., 2006).

Earthworms are often classified based on their activity and feeding type, which affects their impacts on the soil (Bouché, 1977 in Addison, 2009). Dendrobaena octaedra and Dendrodrilus rubidus are epigeic species, which inhabit and feed at the soil surface. Epigeics physically disrupt the organic layer of the soil by consuming and mixing the F and H layers, producing a homogenous and granular form of organic forest floor (Addison, 2009). Lumbricus rubellus operates in two categories, 1) epigeic which inhabit and feed at the soil surface and 2) endogeic which live and feed in the mineral horizons below the organic (LFH) layer. Thus it is considered epi-endogeic in its habits, feeding on organic matter in the forest floor, but also mixing the organic material into the upper layer of mineral soil (Addison, 2009). L. terrestris is a deep-burrowing anecic earthworm, which create permanent vertical burrows in the mineral layer. They
come to the surface to feed on litter and pull it down to their burrows, depositing casts of mixed organic and mineral material on the soil surface (Addison, 2009).

Thus earthworms in different functional groups have different impacts on the soil (Frelich et al., 2006; Hale et al., 2008). Often multiple earthworm species inhabit areas of forest, and studies suggest that impacts are greater when earthworms from more than one functional group occur together (Hale et al., 2005; Hale et al., 2008). Earthworm invasions typically occur in waves (e.g. Hendrix & Bohlen, 2002; Eisenhauer et al., 2007), with epigeic (e.g. *D. octaedra*, *D. rubidus*) or epi-endogeic (e.g. *L. rubellus*) species arriving first as they are able to utilise undisturbed forest floors. The first noticeable impacts tend to be physical disruption of the stratified humus layers on the forest floor. Endogeics generally only invade after the organic layer has been modified by epigeic or epi-endogeic species. Anecic species (e.g. *Lumbricus terrestris*) are usually last to arrive (James & Hendrix, 2004 in Addison, 2009).

The purported impacts of invasive earthworms are often varied between publications, and different soil types and soil layers may be affected differently by earthworm invasion. However the main effect of earthworms is to consume litter, and incorporate it into deeper soil layers, thus causing mixing of the A and O soil horizons. This causes extreme reduction of the litter layer and changes in nutrient concentrations and cycling in the soil. Other soil characteristics such as pH, porosity and decomposition rates may also be affected. Physical disruption of plant roots and mycorrhizal associations is also a common impact. These changes to fundamental soil properties have cascading effects on plant communities, microorganisms, micro and mesofauna, birds and mammals (Hale et al., 2008; Addison, 2009).

### 2.0 Ecosystem change

Earthworms consume litter and organic matter, often resulting in extreme reductions of mass and thickness of the litter layer (Wironen & Moore, 2006; Suarez et al., 2006b). Litter disappearance is often positively related to earthworm density, and different combinations of earthworm species affect the rate of litter disappearance. This can be explained by differences in feeding patterns between different functional groups (i.e. epigeic, endogeic, anecic etc) and different age structure of populations (Suarez et al., 2006b).

Loss of the litter layer can make the soil more susceptible to erosion (Hendrix & Bohlen, 2002), increase humification and decomposition rates (Bohlen et al. 2004; Suarez et al., 2006b; Holdsworth et al. 2008), decrease or increase pH (Straube et al., 2009) and change porosity and other physical and hydraulic properties of the soil (Lee, 1985; Edwards & Bohlen 1996 in Wironen & Moore, 2006).
3.0 Modification of nutrient regime

Earthworms also have profound and complex effects on nutrient availability, through the addition of nutrients from urine, mucus and dead tissues; through chemical and physical alterations during gut passage (McLean et al., 2006; Hale et al., 2008); and by affecting the among and distribution of organic matter in the soil by transporting large quantities of carbon (C) from the soil to the lower horizons, causing mixing and homogenisation of the soil layers (i.e. eliminate visible horizonation) (e.g. Wironen & Moore, 2006; Keller et al., 2007, McLean & Parkinson, 1997a; McLean & Parkinson, 2000a). Several studies have demonstrated a reduction in organic matter (O horizon) and an increase in the A horizon in soils with introduced earthworms (Burtelow et al., 1998 in Wironen & Moore, 2006; Hale et al., 2005; Hale et al., 2008; Straube et al., 2009). Earthworms may actually convert mor-moder to mull humus form, with significant effects on microbial biomass and function, nutrient dynamics and seedling establishment (Gundal, 2002; Hale et al., 2005; Addison, 2009).

These changes in the soil affect C and nitrogen (N) soil concentrations, distribution and availability. C and N cycles are greatly affected, with N cycling effects being far more complex and uncertain than for C cycling (Bohlen et al., 2004). Whether earthworm invasion leads to a decrease or an increase in total C and N has been debated, with studies showing variable results (Gundale et al., 2005; Wironen & Moore, 2006; Hale et al., 2008).

The influence of earthworms on soil N depends on the form of nitrogen, the soil horizon, species present, and the availability of C (Costello & Lamberti, 2008). Similarly, the effect of earthworms on soil C may depend on earthworm density, phase of invasion and soil layer sampled (Wironen & Moore, 2006; Eisenhauer et al., 2007; Straube et al., 2009). Worms speed up decomposition, resulting in a loss of C from the upper layers of soil. However they also cause the formation of stable organic matter-mineral complexes in the subsoil that may actually result in an increase in total soil C (Wironen & Moore, 2006). Thus, while it is likely that the initial effects of earthworm invasion (increased decomposition rates, consumption of the litter layer) cause a decrease in total soil C, in the long term total soil C increases as stable organic matter–mineral complexes accumulate (Bohlen et al., 2004c in Wironen & Moore, 2006).

Earthworm invasions also affect phosphorous (P) cycling in the soil. Trees concentrate a large proportion of fine roots in the litter layer, where uptake of P occurs. By consuming the litter layer earthworms can greatly alter P cycling by increasing P fixation by soil minerals and by altering the mineralization of organic P. The effect of earthworms on P cycling is dependent on soil mineralogy, the timeframe of the invasion and the degree of mixing of soil layers. Early stages of invasion may be associated with increases in organic P mineralization, followed by a decrease in available P in later stages of invasion (Bohlen et al., 2004).
4.0 Reduction in native biodiversity

4.1 Plant communities

Earthworm consumption of the litter layer in forests and accompanying changes in nutrient concentrations, soil structure, fine root biomass, microbial and soil fauna communities may affect plant growth (Scheu & Parkinson, 1994; Hale et al., 2008). The loss of the protective leaf litter layer may also expose the soil to harsher microclimates and affect the viability of understory plants and fungal networks (Wironen & Moore, 2006). Earthworms may also directly impact seed regeneration as passage of seeds through their gut and deep burial of seeds may decrease viability (Frelich et al., 2006).

The net effect of this is reduced plant biomass and higher plant mortality which ultimately alter the composition of plant communities (Bohlen et al., 2004; Wironen & Moore, 2006; Eisenhauer et al., 2007). In some cases the forest floor may be entirely eliminated (Addison, 2009).

Earthworm activity has been implicated in reducing rare endemic species such as the goblin fern (Botrychium mormo) raising concerns about the viability of this plant (Frelich & Holdsworth, 2002 in Wironen & Moore, 2006; Gundale, 2002). The spread of earthworms has also been directly linked to reductions in woodland herbs (Hale et al., 2006) and indirectly to declines in sugar maple (Acer saccharum) through alteration of soil mychorrizal colonization and abundance (Lawrence et al., 2003 in Nuzzo et al., 2009).

Exotic earthworms have also been demonstrated to facilitate the invasion of non-native plant invasions in temperate forests of north-eastern North America, possibly through alteration of soil nutrients or disruption of native plant mycorrhizae. Increases in non native species may lead to declines in native plant species, and wider scale changes to entire plant communities in forest understories (Nuzzo et al., 2009).

4.2 Microorganism communities

Effects of earthworms on microbial biomass and respiration appear to be variable, and dependent on earthworm species, soil type and other factors. Gut passage may result in increases or decreases in microbial activity, which is often dependent on the type of earthworm (e.g. anecic or epigeic) (McLean et al., 2006). Aggregates formed by earthworms may increase the stability of soil microclimates, and their mucus secretions may increase the palatability of organic materials for microorganisms (Migge-Kleian et al., 2006). However, reduction of the thickness, heterogeneity and organic matter content of the organic layer by earthworms may reduce the amount of microhabitats and substrates available for microbial exploitation. The deposition of casts enriched in mineral matter in organic soil layers decreases microbial activity (Straube et al.,
2009), and earthworms may compete with microorganisms for resources, leaving less carbon for microorganisms to utilise (Scheu & Parkinson, 1994; McLean et al., 1997b).

These variable impacts mean that some studies have reported increases in microbial biomass (e.g. Eisenhauer et al., 2007; Straube et al., 2009), while some have reported decreases (Scheu & Parkinson, 1994; McLean & Parkinson, 1997a; McLean & Parkinson, 1997b; Li et al., 2002 in Straube et al., 2009). In some studies movement of organic material into mineral layers has resulted in decreases of bacterial activity and biomass in the organic layers and increases in mineral layers (McLean et al., 2006; Keller et al., 2007; Groffman et al., 2004 in Holdsworth et al., 2008).

Several studies have documented a correlation between earthworm abundance and decreases in fungal species density and fungal species diversity and richness, which is likely to be due to physical disruption of hyphae (McLean et al. 2006; McLean & Parkinson, 2000a). Disruption of hyphae may also explain the alteration in soil mycorrhizal colonization of seedlings and abundance observed in earthworm-invaded regions (Welke & Parkinson 2003 in McLean et al., 2006; Lawrence et al., 2003 in Nuzzo et al. 2009). Disruption of mycorrhizae may cause declines in trees such as sugar maple (*Acer saccharum*) (Lawrence et al., 2003 in Nuzzo et al., 2009).

### 4.3 Invertebrate communities

The impact of earthworm invasion on micro and mesofauna is highly variable. Middens and burrows can increase soil heterogeneity and create microhabitats with a larger pore size, high microbial biomass, and microclimates that are attractive to micro and mesofauna, thus having a positive effect on organisms (Migge-Kleian et al., 2006; McLean & Parkinson, 2000b). However such positive effects are often small, transient and restricted to habitats with harsh climates or a long history of earthworm co-occurrence with other soil invertebrates. In the longer-term the activity of exotic earthworms can have strong negative impacts on a range of small and large fauna across multiple trophic levels.

Restructuring of soil layers, the loss of organic horizons, physical disturbance to soil, alteration of understorey vegetation, direct competition for food resources and predation may lead directly or indirectly to declines in the abundance and diversity of soil micro- and mesofauna (McLean & Parkinson, 2000b; Migge-Kleian et al., 2006). Larger earthworms such as *L. terrestris* mix organic material and mineral soil in greater quantities than smaller species such as *D. octaedra* and therefore more strongly compete with microarthropods for food (Migge-Kleian et al., 2006). The impacts on micro and mesofauna may also be variable in different soil layers (McLean & Parkinson, 2000b).
4.4 Vertebrate communities

Earthworms may become an important food source for larger invertebrates and small vertebrates (Migge-Kleian *et al.*, 2006). However many forest floor macroinvertebrates rely on thick organic layers to prevent dehydration, and avoid extreme temperatures and predators; thus they could be negatively affected by loss of the litter layer caused by earthworm invasions. Furthermore, studies have reported declines in ovenbird nesting success (Mattsson, 2001) and reduction in small mammal abundance (i.e. red-backed vole and shrew) in earthworm-invaded forests compared with non-invaded forests in Chippewa National Forest, Minnesota. Woodland salamander abundance and diversity declined in relation to earthworm invasion in Sylvania Wilderness Area, Ottawa National Forest of Michigan (Bergeson, pers. comm. in Migge-Kleian *et al.*, 2006), and in New York and Pennsylvania (Maerz *et al.*, unpublished data in Migge-Kleian *et al.*, 2006), likely due to reduced abundance of small soil fauna and alteration of soil microclimates.

Earthworms may also interact with pollutants in the soil which could affect vertebrate species. Burning of fossil fuels has caused widespread deposition of heavy metals and other pollutants across North American soils. Whether earthworms are more effective than other soil fauna at moving metals into food webs is unknown, but several adaptations of earthworms make them particularly effective at incorporating such pollutants into their tissues (Reinecke *et al.*, 2000 in Migge-Kleian *et al.*, 2006). Thus these heavy metal pollutants could be passed on to vertebrate predators including amphibians and small mammals, with negative effects on their populations (Migge-Kleian *et al.*, 2006).

5.0 Interactions with other invasive species

Epigeic and epi-endogeic species of earthworms may facilitate the establishment of other earthworm species, leading to the establishment of stable populations of endogeic and anecic species, which prevent recovery of the forest floor (Hale *et al.*, 2005). Earthworm invasions often occur in waves, as described earlier. Endogeic species generally only invade after the organic layer has been modified by epigeic or epi-endogeic species while anecic species are usually last to arrive (James & Hendrix, 2004 in Addison, 2009). Anecic species are capable of colonising intact forest floor, they do so at a slower rate than epigeic species (Hale *et al.*, 2005).

The order of different species arrival can be important for the effects on the invaded ecosystem. For example, if epi-endogeic *L. rubellus* is the first earthworm species to arrive, the rapid rate of habitat alteration makes it difficult for vegetation rooted in the forest floor to adapt, and plant mortality may be high. Whereas if anecic *L. terrestris* invades first, this may allow a more
gradual change in the thickness of the forest floor, giving more opportunity for other organisms to adapt (Frelich et al., 2006).

Invasion of a Midwestern woodland by Eurasian earthworms and the exotic shrub *Rhamnus cathartica* were found to facilitate each other. The species are thought to be involved in a mutually reinforcing positive feedback loop, whereby litter breakdown by earthworms creates conditions that promote and sustain invasion by *R. cathartica*, and the shrub conversely alters soil properties in a way that promotes and sustains invasion by earthworms (Heneghan et al., 2006).

Grazers such as North American white-tailed deer (*Odocoileus virginianus*) have severe impacts on plant composition and diversity. These impacts may be increased by earthworms as deer herbivory and earthworm invasion may have a synergistic effect on plant communities. The initial plant mortality resulting from the removal of the forest floor by earthworms increases the deer: plant ratio, so that deer consume a much larger proportion of plants than they would in the absence of earthworms. This can lead to extirpation of plants and to alternate states with lush and sparse plant communities (Frelich et al., 2006; Hale et al., 2006;).

### 6.0 Human nuisance

Some earthworm species may deposit castings on the surface of lawns and golf greens where they are a nuisance (Hendrix & Bohlen, 2002). They may also infest irrigation ditches, making them less able to carry water (Hendrix & Bohlen, 2002).

### 7.0 Transmitting disease

Earthworms may transmit plant or animal pathogens, either as passive carriers or intermediate hosts. Thus earthworm movement may be a mechanism for the introduction of pathogens to new areas (Hendrix & Bohlen, 2002).

### 8.0 Competition

In some cases invading earthworms have replaced native earthworm species (Pop & Pop, 2006). However, Hendrix et al. (2006 in Addison, 2009) lists a large number of studies where native and introduced earthworms appear to coexist.