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Invasion of a deciduous forest by earthworms: Changes in soil chemistry, microflora, microarthropods and vegetation

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Abstract

Ecosystems of northern North America existed without earthworm fauna until European settlers arrived and introduced European species. The current extent of invasion by some of these species, *Lumbricus terrestris* L., *Octolasion tyrtaeum* Savigny and *Dendrobaena octaedra* Savigny, into an aspen forest in the Canadian Rocky Mountains and the effects of the invasion on soil chemistry, microflora, soil microarthropods and vegetation were investigated. Densities of earthworm species, soil structure, plant coverage and abundance were determined along three transects starting at the edge of the forest. At locations with *L. terrestris*, litter was incorporated into the soil, and where *O. tyrtaeum* was present, organic layers were mixed with mineral soil layers. Organic layers disappeared almost entirely when both species occurred together. Carbon and nitrogen concentrations were reduced in organic layers in the presence of *L. terrestris* and *O. tyrtaeum*. Microbial biomass and basal respiration were reduced when *L. terrestris* and *O. tyrtaeum* were present, presumably due to resource competition and habitat destruction. Microarthropod densities and the number of microarthropod species were strongly reduced in the presence of *O. tyrtaeum* (−75% and −22%, respectively), probably through mechanical disturbances, increasing compactness of the soil and resource competition. The coverage of some plant species was correlated with earthworm abundance, but the coverage of others was not. Despite harsh climatic conditions, the invasion of boreal forest ecosystems by mineral soil dwelling earthworm species is proceeding and strongly impacts soil structure, soil chemistry, microorganisms, soil microarthropods and vegetation.

Keywords: Ecological invasion; Microbial community; Mesofauna

1. Introduction

Invasions of natural communities by non-indigenous species are a threat to native biodiversity and are currently rated as one of the most important global-scale environmental problems (Vitousek et al., 1996). Much of the focus on exotic species invasions has been on aboveground invaders (e.g. Stohlgren et al., 2006); however, belowground invasions may become better known as more ecologists begin to recognize the importance of links between aboveground and belowground communities (Scheu, 2001). Invasion of northern forests by exotic earthworms, for example, is receiving increasing attention (Bohlen et al., 2004a).

The native earthworm fauna of North America became almost entirely extinct during glaciations (Gates, 1982) except at Pacific coastal regions (McKey-Fender and Fender, 1982). After the ice retreated native earthworm populations did not recolonize the northern territories. Consequently, the region which today is Canada was almost free of earthworms until European settlers arrived (Gates, 1982). Lumbricid earthworm species introduced by European settlers are now widespread throughout Canada. Currently, a variety of ecosystems are being invaded by earthworms in southern Alberta (Scheu and McLean, 1993). The soil fauna and microflora of an aspen forest in the mountain ranges of the Rocky Mountains west of Calgary (Kananaskis Valley, Alberta) have been

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investigated in detail since 1969 (Mitchell and Parkinson, 1976; Lousier and Parkinson, 1984). The forest was free of earthworms until 1985 (D. Parkinson, unpubl. data), but was colonized by two earthworm species, *Dendrobaena octaedra* Savigny and *Dendrodrilus rubidus* Savigny, about 12 years ago (Dymond et al., 1997). Today the forest is colonized by two additional earthworm species, *Lumbricus terrestris* L. and *Octolasion tyrtaeum* Savigny. These "peregrine" species are characterized by their ability to vigorously colonize new habitats, spread rapidly, and tolerate a wide range of environmental conditions (James and Hendrix, 2004). Human activity, such as the construction of logging roads and releases of unused fishing bait by anglers, facilitate the invasion process (Hendrix and Bohlen, 2002).

Earthworms are a major component of many terrestrial ecosystems (Edwards and Bohlen, 1996). In non-acidic soils they usually dominate the biomass of soil invertebrates and function as ecosystem engineers (Jones et al., 1994), particularly in forest soils, by structuring the environment of the soil community (Lavelle et al., 1998; Scheu and Setälä, 2002). Through burrowing, casting and mixing of litter and soil (bioturbation) they influence aggregate stability, soil structure, infiltration of water, aeration of deeper soil layers, nutrient cycling and mineralization, microbial biomass, and other soil invertebrates (Lee, 1985; Edwards and Bohlen, 1996; McLean and Parkinson, 2000; Bohlen et al., 2004a–c). These changes have important consequences for plant communities and potentially the herbivore system (Scheu, 2003; Bohlen et al., 2004a).

The degree of mixing of soil layers varies with earthworm species, which are categorized into three main ecological groups: epigeic, endogeic and anecic species (Bouché, 1977; Edwards and Bohlen, 1996). Epigeic species, such as *Db. octaedra*, reside mainly in the upper organic layers and cause limited mixing of mineral and organic layers (Bohlen et al., 2004a). Endogeic species, such as *O. tyrtaeum*, live in upper mineral soil layers mainly consuming mineral soil materials. Anecic species, such as *L. terrestris*, form vertical permanent burrows up to 2 m deep and incorporate litter from the soil surface into deeper soil layers but also transport mineral soil materials to the surface by casting.

Invasive earthworms are known to reduce the mass of forest floor litter. In sugar maple dominated forests in northern Minnesota earthworms reduced the forest floor thickness from 10 cm to zero (Mortensen and Mortensen, 1998). This has the potential to alter the microbial community, nutrient cycling, and mineralization and stabilization of soil C and N (Scheu and Wolters, 1991; Tiunov and Scheu, 2000). Indeed, changes in soil organic layers as a result of earthworm invasion greatly altered microhabitats and resources for microorganisms as documented recently (Bohlen et al., 2004a–c). Laboratory and field experiments showed that the invasion of *Db. octaedra* altered soil structure, microbial biomass, microarthropod community and plant growth (Scheu and Parkinson, 1994a–c; McLean and Parkinson, 2000).

Earthworms influence microbial communities directly, through feeding, and indirectly through nutrient-rich casts, changes in decomposition rates and transport of microorganisms (Bardgett et al., 1998). Consequently, the soil fauna is an essential factor regulating microbial abundance and the structure of microbial communities (Bardgett et al., 1996). The interactions between the components of the soil system feed back to roots and, therefore, to plant growth, but only little is known on effects of earthworms on aboveground communities in natural habitats as mediated by modifications in plant growth (Scheu, 2003). The abundance and diversity of native plant species and tree seedlings declined steeply following the invasion by earthworms in a hardwood forest stand in northern Minnesota (Hale et al., 2006). Furthermore, earthworms influence soil microarthropod populations by altering soil structure, soil chemistry and soil microorganisms. The presence of earthworms (*L. terrestris* and *O. tyrtaeum*) decreased the diversity and abundance of microarthropods in a mesocosm laboratory experiment (Migge, 2001). However, in middens of *L. terrestris* the abundance of microarthropods may also be increased (Maraun et al., 1999).

The present study aimed to investigate the extent of invasion by *L. terrestris*, *O. tyrtaeum* and *Db. octaedra* into an aspen forest in southern Alberta (Canada) and to provide a better understanding of the effects of earthworm invasions into North American forest soils on soil chemistry, microorganisms, soil microarthropods and vegetation. For the first time, the effects of invasion of earthworm species belonging to the three main ecological groups on several ecosystem variables were investigated.

2. Materials and methods

2.1. Study site

The study site is located on a south-facing slope at about 1410 m above sea level in Kananaskis Valley in the front range of the Canadian Rocky Mountains in southwest Alberta (80 km west of Calgary; 51°2′N, 115°4′W). Trembling aspen (*Populus tremuloides* Michx.) is the dominating tree species but some balsam poplar (*Populus balsamifera* L.) are also present. The forest understory is dense and consists of herbs (e.g. *Aster conspicuus* Lindl., *Aster laevis* L., *Viola canadensis* L., *Epilobium angustifolium* L., *Delphinium glaucum* S. Wats.), roses (*Rosa acicularis* Lindl., *Rosa woodsii* Lindl.) and grasses (e.g. *Bromus* sp., *Danthonia* sp., *Agropyron* sp.; Scheu and Parkinson, 1994a). More details on the forest flora are given in Lousier (1974). The soil can be separated into L/F and H layer and a mineral soil classified as orthic grey luvisol (Karkanis, 1972). The thickness of the organic layer varies considerably but is generally in the range 1–3 and 4–9 cm for L/F and H materials, respectively. The mean pH