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SHORT COMMUNICATION

Response of endemic and exotic earthworm communities to ecological restoration

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Land conversion and environmental changes associated with agronomic practices are believed to have led to the disappearance of New Zealand endemic earthworms from agricultural land. Introduced European earthworms have since largely replaced endemic species in farming systems. We investigated the impact of vegetation restoration on earthworm communities. Recolonization by endemic earthworms increased with time after restoration at two studied sites in the South Island of New Zealand. However, exotic species did not disappear with restoration of native vegetation, even after 30 years. The persistence of exotic species leads to the cohabitation of the two communities and potential for interspecific competition.

Key words: earthworm abundance, earthworm biomass, interspecific competition, New Zealand, recolonization, soil fauna

Implications for Practice

- Restoration of native vegetation in New Zealand leads to increased recolonization of endemic earthworms that disappeared following conversion to agriculture.
- Restoration of natural vegetation does not cause the disappearance of exotic earthworms, which persist for at least 30 years.
- The proportions of endemic versus exotic earthworms (based on either abundance or biomass) were the best indicators of restoration age in comparison to raw abundance or biomass of endemic or exotic earthworms.
- Native and exotic earthworms coexist under restored vegetation in New Zealand.
- Continued spread of exotic earthworms through agricultural land may be detrimental to endemic species.

Introduction

In recent years, there has been an increased interest in the conservation or reintroduction of keystone species that are essential for the provision of ecosystems services in restoration programs. In terrestrial ecosystems, this includes earthworms, which provide or contribute to a number of ecosystem services essential to restoration including topsoil creation, mineralization of organic matter, improvement of soil structure and chemistry, enhancement of soil macroporosity and water-holding capacity, sustaining a wide range of predators, and so on (for a review, see Boyer & Wratten 2010).

New Zealand has more than 200 endemic earthworm species (Lee 1959*a*, 1959*b*; Boyer et al. 2011*a*), and many putative new species yet to be described (Buckley et al. 2011, 2015; Boyer et al. 2013). Endemic earthworms are all in the Megascolescidae family and mostly found under native vegetation (Lee 1959*a*; Springett et al. 1998). It has been reported that they disappeared quickly from agricultural systems after land conversion first by Maori and then by Europeans in the nineteenth century (Lee 1961). The introduction of exotic grassland and crops with the associated soil disruption through agricultural practices is believed to have been the main drivers of endemic earthworm disappearance (Lee 1961). In addition to these native species, European earthworms (Lumbricidae) have been introduced to pastures and other agricultural land first accidentally with the introduction of European plants and the dumping of ballast soil (Lee 1961). Twenty-three exotic species are currently present in New Zealand; some with widespread distribution in agricultural landscapes where they provide important ecosystem services (Lee 1961; Schon et al. 2011).

Because the introduction of exotic earthworms and their subsequent spread occurred after the disappearance of endemic earthworm communities, it has been suggested that European Lumbricidae do not compete with endemic Megascolescidae (Lee 1961). However, there is very little information about the potential of exotic earthworms to colonize soil under native vegetation or the potential for endemic species to recover from

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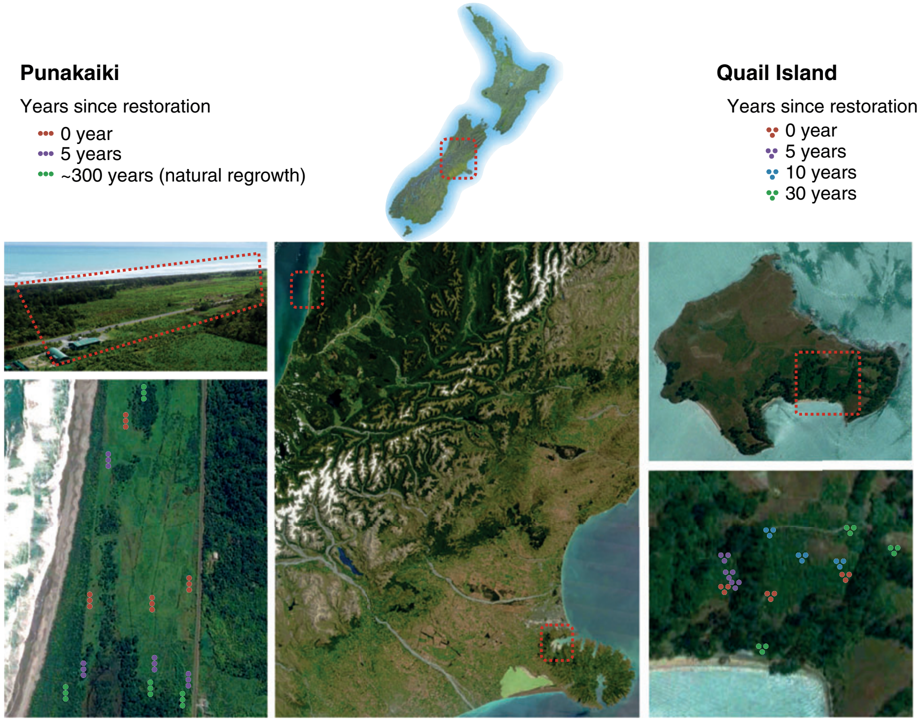

Figure 1. Sample areas and sampling strategy (red squares indicate zoomed areas). Middle: general location. Left: Punakaiki where samples were collected along transects. Right: Quail Island where samples were collected in triangular patterns.

land conversion. In a recent study, we reported the ability of exotic earthworms to move from pasture into adjacent native vegetation particularly into areas affected by leaching of soil nutrients from agricultural land (Bowie et al. 2016).

We hypothesize that restoration from agricultural land to native vegetation may be sufficient to restore endemic earthworm communities providing that nearby source populations are available for natural recolonization. The aim of this study was to evaluate whether restoration of native vegetation leads to recolonization by endemic earthworm communities.

Methods

Sampling Sites

We tested our hypothesis in two sites located on the East and the West Coast of New Zealand's South Island: Quail Island (*Otamahua*), which has been undergoing plant restoration for more than 30 years, and the Punakaiki Coastal Restoration Project (PCRP), where 130,000 trees have been replanted in the last 8 years (Fig. 1). Quail Island (85 ha) is a recreational reserve, administered by the New Zealand Department of Conservation since 1875. The native vegetation was likely cleared by Maori and later almost entirely converted to farmland by Europeans. The PCRP is a 114 ha area originally covered with coastal sandplain forest.

On both sites, non-restored areas were largely dominated by exotic pasture vegetation (mainly ryegrass (*Lolium* spp.) and clover (*Trifolium* spp.)), restored sites were 5, 10, and 30 years old at Quail Island, whilst time since restoration was 5 years in PCRP with additional remnants of native vegetation estimated to be about 300 years old since regrowth.

Sampling and Data Analysis

Sampling occurred in late November 2010 on Quail Island and in early January 2012 at Punakaiki. On both sites, three subsamples of 20 × 20 × 20 cm were excavated from 12 plots. Distance between subsamples was less than 2 m, whereas distance between plots was at least 12 m. The 36 soil cubes were hand-sorted on site and earthworms were then brought to the laboratory for further analysis. Individuals were weighed and identified as endemic or exotic using external morphological features based on Lee (1959*a*, 1959*b*). Adult specimens were further identified to species where possible, although most endemic earthworms seemed to differ from any described species as observed in previous studies (Boyer et al. 2011*b*) and were therefore classified in Recognizable Taxonomic Units (RTUs) based on morphology and DNA barcoding (Boyer et al. 2011*a*).

Abundance and biomass data were calculated by pooling the data recorded from the three subsamples collected at each plot. We then used abundance and biomass ratios between endemic and exotic species to measure native earthworm recolonization at different times after restoration. Data were analyzed using the permutation version of Jonckheere–Terpstra test (JT) with 10,000 permutations. This test was performed using the package *clinfun* of the statistical software R version 3.2.2 (R Development Core Team 2014).

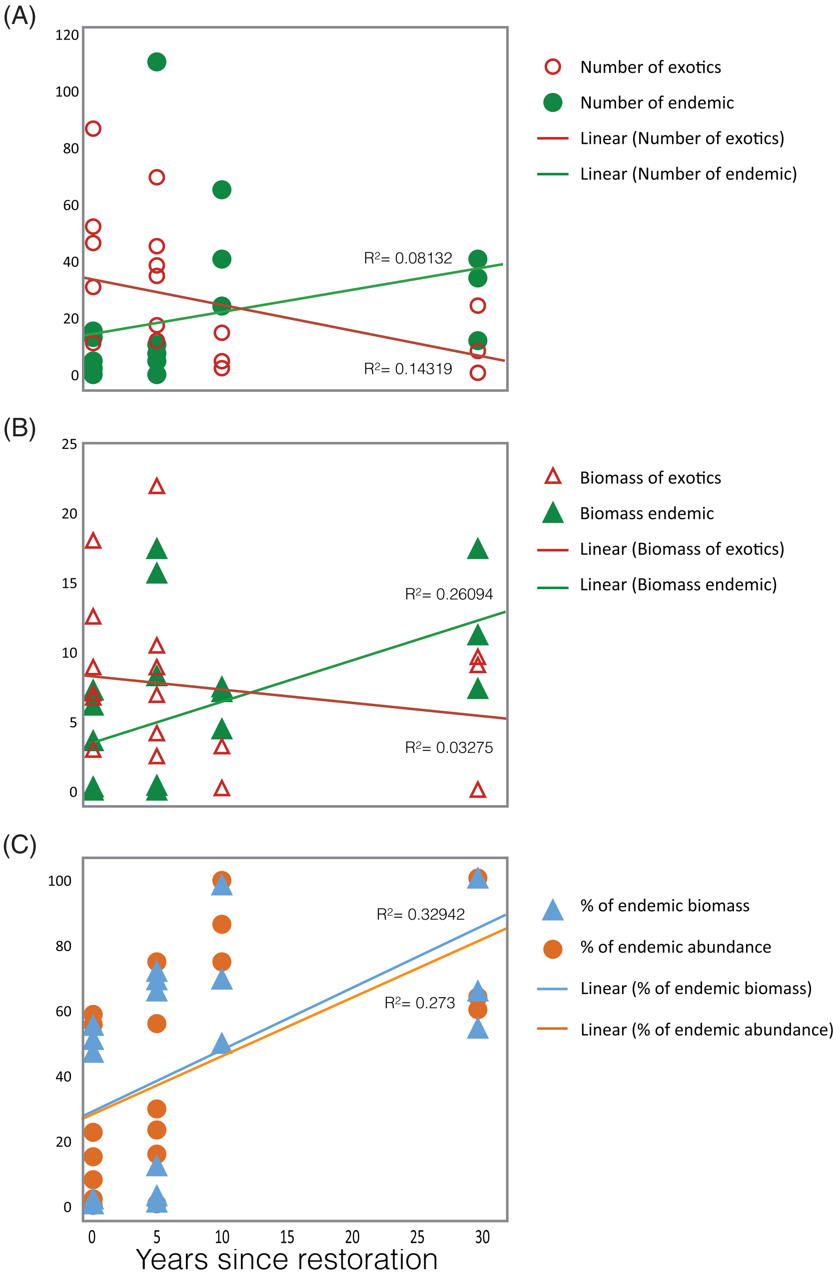

Figure 2. Relationship between various earthworm measurements and age of restoration ($n = 20$). Earthworm abundance (A), biomass (B), and proportions of endemic earthworms (C) were plotted for both study sites across 30 years of restoration. Data from the mature sites in Punakaiki (300 years old) were not used because these plots do not result from active restoration (i.e. replanting) but from natural regrowth. Lines are linear regressions with R^2 indicated. [Correction added on 29 September 2016, after first online publication: The color indicator for "Linear (% of endemic abundance)" in figure 2C has been changed from green to orange.]

Results

A total of 513 earthworms were collected from Quail Island, where three exotic species and three endemic species were found. At Punakaiki, 558 specimens were collected comprising five exotic species and six endemic species.

The number and biomass of endemic earthworms increased with time after restoration, while the number and biomass of exotic species decreased. However, results show that number of endemic or exotic earthworms and the biomass of exotic species were poor indicators of restoration age (Fig. 2A & 2B). The biomass of endemic species was a better indicator and the proportion of endemics based on either abundance or biomass was the best indicators (Fig. 2C).

At Punakaiki, the proportion of endemic earthworms significantly increased with restoration age, both in terms of biomass

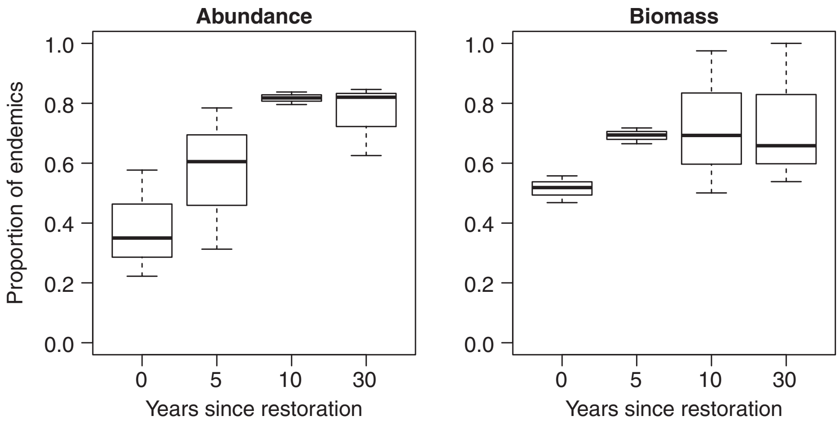

Figure 3. Proportion of earthworm abundance (left) and biomass (right) represented by endemic earthworms in Quail Island. Data are based on 36 soil samples (20 × 20 × 20 cm) collected from 12 plots (three plots per treatment). The bold horizontal bars of each block show the median value, the boxes show where the middle 50% of the data lie, and the whiskers show the maximum and minimum values.

Figure 4. Proportion of earthworm abundance (left) and biomass (right) represented by endemic earthworms at Punakaiki. Data are based on 36 soil samples (20 × 20 × 20 cm) collected from 12 plots (four plots per treatment). See Figure 1 for legend.

(JT = 40.5, $p = 0.0154$) and abundance (JT = 43.5, $p = 0.0026$) (Fig. 3). In Quail Island, the proportion of endemic earthworms increased significantly with time since restoration (JT = 47, $p = 0.00342$) while their contribution to the biomass did not (JT = 36, $p = 0.2333$) (Fig. 4). However, in Quail Island, exotic species did not disappear after restoration of native vegetation but remained stable at an averaged 26%, leading to the cohabitation of the two communities. In Punakaiki, old patches of native vegetation were inhabited by endemic species only, with the exception of few sampling sites located at the edge of the forest.

Discussion

On both sample sites, sequential replanting programs revealed that native earthworm recolonization increased with time after restoration. However, even 30 years post-restoration, exotic earthworms were still present within restoration plots on Quail Island. Our analysis also revealed that the proportions of endemic versus exotic earthworms (based on either abundance or biomass) were better indicators of restoration age than raw abundance or biomass of endemic or exotic earthworms. Although more than 1,000 earthworms were collected as part of this study, the limited number of replicates of soil sample pits (36 in each sampling sites) calls for caution in the interpretation of these results.

It has been well documented that European and Asian lumbricids invading northern temperate forests in the United States have substantially altered soil nutrient storage and availability, and greatly affected populations and communities of flora and soil fauna (Bohlen et al. 2004). Because exotic earthworms can cause such significant changes to native soils and ecosystems, they are usually unwanted in restoration projects (Butt 2008; Boyer & Wratten 2010). Winsome et al. (2006) suggested that interspecific competition has the potential to prevent American native Megascolescidae from recolonizing pastures dominated by an exotic European Lumbricidae. A similar situation could be occurring in New Zealand where at least some endemic species perform better and even show a preference for agricultural soil over native soil (Kim et al. 2015). One of the rare endemic species that can be found in agricultural soil is *Octochaetus* *multiporus* (Beddard). Springett et al. (1998) showed that its abundance was negatively correlated with pasture production and the abundance of lumbricid earthworms. The authors suggested that this could indicate an "inability to compete with lumbricid earthworms at higher soil fertility."

The apparent inability of endemics to survive in agricultural land has encouraged efforts to increase the dispersion of exotic earthworms in New Zealand agricultural land in recent years. At the same time, the ability of exotic earthworms to encroach under New Zealand native vegetation has only very recently been investigated (Bowie et al. 2016). The introduction of similar European species in Australia has led to concerns regarding their potential impact on native Australian soil fauna (Baker et al. 2006). Manono and Moller (2015) recently proposed that prior to the introduction of anecic earthworms into pastures where they are absent, their effects on natural ecosystems should be established. Although introductions of earthworms to New Zealand agricultural lands undoubtedly provide substantial benefits in terms of waste recycling, soil fertility, and crop productivity (Schon et al. 2011), further studies are urgently required to fully understand the potential consequences of earthworm introductions and voluntary propagation in New Zealand agricultural soils.

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