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POPULATION DENSITY AND DISTRIBUTION OF THE NEW ZEALAND INDIGENOUS EARTHWORM *OCTOCHAETUS MULTIPORUS* (MEGASCOLECIDAE: OLIGOCHAETA) IN HILL PASTURES

Summary: The distribution of the indigenous New Zealand megascolecid earthworm *Octochaetus multiporus* (Beddard) in hill pastures of different fertilities in the southern North Island of New Zealand, and the population density throughout a year are described. *Octochaetus multiporus* was most numerous in soils of low to moderate fertility. High fertility soils had a similar population density to that of an adjacent area of native forest, indicating that the exotic pasture environment can favour *Octochaetus multiporus* in some circumstances. Population density of *Octochaetus multiporus* was best correlated with soils which were moist in summer. There was no well defined breeding season for this species, mature and recently hatched individuals being found in most months of the year. *Octochaetus multiporus* is a deeper burrowing indigenous earthworm species which is successful in an exotic environment. In pastures which have moist soils in summer, this species may be improving soil structure and root penetration in the absence of deep burrowing introduced lumbricid earthworms.

Keywords: soil fauna; soil structure; earthworm, density.

Introduction

In most areas of New Zealand, when forest or tussock grasslands are developed for agriculture the indigenous megascolecid earthworm fauna, particularly top-soil species, disappear and eventually lumbricid earthworms colonise the area (Smith, 1894; Lee, 1959; Stockdill, 1982; Yeates, 1991). Although lumbricid earthworms are numerous and widespread in New Zealand hill pastures, the species richness of the fauna is low, as relatively few species have established. Many pastures have only 2 or 3 top-soil species, the most common being (*Aporrectodea caliginosa* (Sav.), *A. trapezoides* (Duges) and *Lumbricus rubellus* Hoff.). Introduction of deeper burrowing, lumbricid species such as *Aporrectodea longa* Ude has been shown to improve pasture production (Springett, 1985) but this species is poorly distributed in New Zealand hill pastures (Springett, 1992).

The indigenous earthworm fauna is rich in species (Lee, 1959); but is usually associated with undisturbed soil and native vegetation. It is not known what factors are associated with high populations of indigenous earthworms. Very little is known about their population densities, life cycles, or of the distribution of indigenous species either in their natural habitat or in hill pastures.

As part of a larger study on the biophysical indicators of sustainability in pastoral ecosystems (Lambert *et al.,* 1996) earthworm numbers have been measured in pastures with differing managements. The native New Zealand earthworm *Octochaetus multiporus* (Beddard, 1885) was commonly found during the routine winter sampling of the soil fauna. Because this species was relatively abundant on some pastures and so little is known of the ecology and biology of native earthworm species in New Zealand it was decided to take the opportunity carry out a more intensive study of *Octochaetus multiporus*. This paper reports on population densities of *Octochaetus multiporus* throughout the year, in pastures of different fertilities.

The biology of *Octochaetus multiporus*

The indigenous earthworm *Octochaetus multiporus* is a large species reaching up to 300 mm in length and 8-10 mm in diameter. It is pink to pale grey with a translucent body-wall and a streak of purple along the dorsal mid-line. The darker pink clitellum of fully mature specimens has prominently developed lateral processes which are used almost like claspers during copulation. The species was first described

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by Beddard in 1885, as *Acanthodrilus multiporus,* from specimens collected in the Canterbury plains where he describes it as occurring in great numbers. It is known to occur in both tussock and forest soils in the south of the North Island and in the South Island of New Zealand and Lee (1959) recorded this species as being 'numerous' in yellow-grey, yellow-brown, and brown-grey earth soils". Although most records are from soils under native vegetation, there are several records of *Octochaetus multiporus* on pasture soils. Stockdill (1959) refers to ' a few' *Octochaetus multiporus* on pastures and describes all native species of earthworms on pastures as sometimes reaching densities of 200 m^{-2} (Stockdill, 1982). Yeates (1993) gives mean winter densities of from 6.7 m^{-2} to 41.7 m^{-2} in hill pastures in the North Island. Lee (1959) also suggested that this species is tolerant of a wide range of environmental conditions and is capable of extending its distribution. He comments on the importance of aspect in the distribution of *Octochaetus multiporus* under native vegetation (common in subsoils at sites where the land slopes away from the sun, and absent at adjacent sites where the land slopes towards the sun) and relates this to the moisture content of the soil in summer. Smith (1893) describes populations of very large specimens of *Octochaetus multiporus* in Canterbury dug out of "unbroken native land on the sides of a water race flowing through a paddock that had been cultivated for 10 years" and attributes the high densities and large size of the worms to moist soils. *Octochaetus multiporus* is a bioluminescent species, with coelomic fluid being expelled from the dorsal pores, mouth and anus when the animal is disturbed. This fluid is thick, slimy and emits a bright orange-yellow light which is easily visible to the dark-adapted eye. Much larger quantities of brightly glowing fluid are exuded if the worm is damaged. This slimy fluid was noticed by Smith (1893) but no mention was made of the bioluminescent properties. Johnson, Shimomura and Haneda (1965) studied the luciferin-luciferase reaction of extracts of the exudate from *Octochaetus multiporus* specimens from the south of the North Island of New Zealand. Bioluminescence is fairly common amongst the Megascolecidae but is rarely noted in the literature (Jamieson, 1977; 1979). Members of New Zealand Maori communities are well aware of the bioluminescent properties of native earthworms and traditionally have used them as bait and lures when fishing (Miller, 1952.)

Experimental field sites

Octochaetus multiporus was studied in hill pasture soils and a native bush remnant at AgResearch's Hill Country Research Station, Ballantrae (40° 40' S, 175° 50' E), at an altitude of 300 m a.s.l., in the southern North Island of New Zealand. Soils are Typic Distrochrepts (yellow-brown earths and

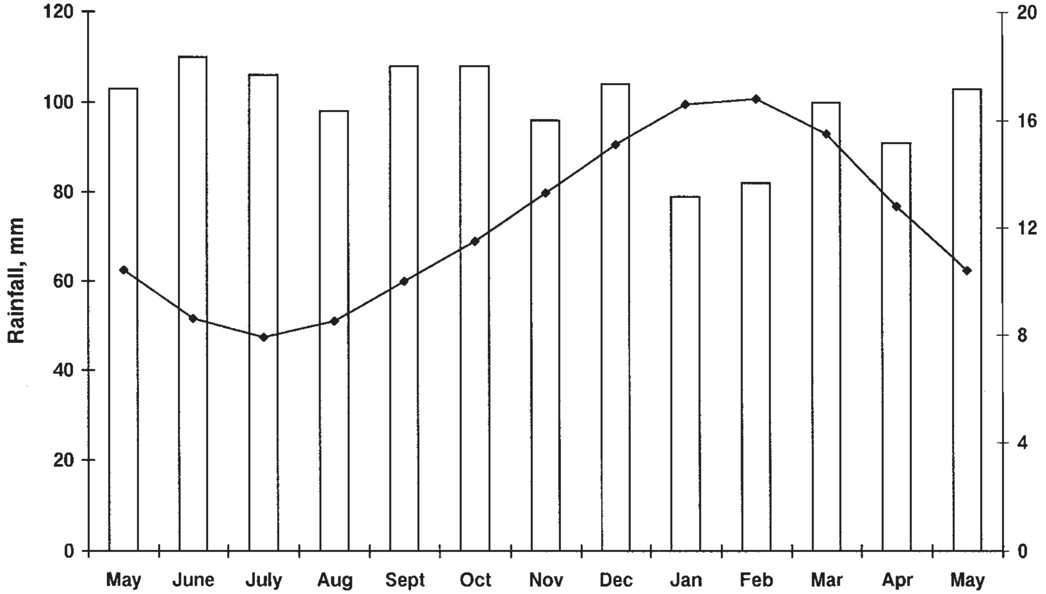

Figure 1: *25 year average monthly rainfall (columns) and air temperature at Ballantrae.*

related steepland soils, formed from tertiary sediments and sedimentary drift material). The average annual rainfall is 1200 mm and the mean annual air temperature 12.2°C. The average monthly mean rainfall and temperature over 25 years are shown in Figure 1.

Hill pastures

Four 7 ha farmlets were divided into 36 paddocks which varied in aspect and slope within farmlets. Two of the farmlets had high (H) and two had low (L) fertiliser application during 1975 to 1980. Fertiliser application was stopped on one low fertiliser (LN) and one high fertilizer (HN) farmlet in 1980 and annual applications of 125 kg ha^{-1}(LL) or 375 (HH)kg ha^{-1} superphosphate were continued for the other two. From 1973 to 1993 total applied phosphorus was 1250, 4625, 4000, and 8875 kg ha^{-1} for LN, LL, HN, and HH respectively, which resulted in Olsen P levels of 6.3, 9.3, 8.9, 33.2 mgP g^{-1} soil in 1994. Agricultural lime (3750 kg ha^{-1} in total) , was also applied to the H farmlets in1975 and 1979 (Lambert *et al* 1996). In 1994 soil pH (soil:water =1:2.5) was 5.4 and 5.7 for L and H farmlets respectively, and soil organic carbon content ranged from 3.7 % to 6.84 % across the four farmlets. Values for soil and vegetation variables across farmlets are given in Lambert *et al* (1996). All paddocks had a mixture of grasses such as ryegrass (*Lolium perenne* L.), yorkshire fog (*Holcus lanatus* L.*),* browntop (*Agrostis capillaris* L.) and legumes: white clover (*Trifolium repens* L.), lotus (*Lotus pedunculatus* L.*).* Other species, including flatweeds and mosses also occurred. The paddocks were continuously grazed with sheep at a rate between 6 and 16 ewes ha^{-1} to maintain above-ground pasture biomass at < 2500 kg dry matter ha^{-1}.

The mean aspect of each paddock was estimated and paddocks were classified based on the deviation of that value from magnetic NW, so that paddocks with lower values of angular deviation were "sunny" and exposed to the prevailing wind, compared to the "shady" paddocks with higher values. Of the 36 paddocks, 12 had sunny aspects (an aspect angle of deviation from NW of less than 45°), 9 had intermediate aspects (between 45° and 90°), and 15 had shady aspects (greater than 90°). Average slope ranged between 7° and 33°.

Native forest remnant

An area of native forest remnant in a steep gully, fenced to exclude stock, adjacent to the hill pastures at Ballantrae was included in the study. Although some native forest trees had been felled and the area had been grazed in the past, much of the native podocarp forest vegetation (Molloy, 1988; Wardle, 1991) has been retained. The soil was similar to that of the hill pasture areas, but the profile differed in being more obviously stratified, with a surface layer of organic litter above the mineral soil. The pH (4.9) was lower than that of the pasture soils and the organic carbon content (4.5%) was within the range of that in the pasture soils. The site is naturally well drained, has the same climate as the hill pastures, and has a shady aspect (>90 ° deviation from NW).

Methods

The *Octochaetus multiporus* population was estimated in each of the 36 paddocks in July 1994 by cutting 10 soil cores per paddock (150 mm diameter, 200 mm depth) and hand sorting them in the laboratory. Soil chemical, physical and biological properties, soil water and vegetation variables were measured in the 36 paddocks in 1993-1994 as described by Lambert *et al.* (1996).

Monthly estimates of *Octochaetus multiporus* population density were made in three of the low fertility (LN) paddocks between May 1995 and May 1996. Large pits were dug (5 pits per paddock, 200 mm x 200 mm to a depth of 300 mm), and the soil from the pits hand sorted in the field. Two of these 3 paddocks were shady, having an angular deviation from NW of 155° and the other had an intermediate aspect (90°). Measurements of population density in the native bush remnant were made by cutting 10 soil cores (150 mm diameter, 200 mm depth) each month from May 1995 to October 1995, and hand sorting in the laboratory. All earthworms recovered were counted, weighed and classified as mature (visible clitellum), non-mature or juvenile (less than 150 mg live weight per individual).

Results

The densities and biomass and standard errors of the mean of *Octochaetus multiporus* in each of the fertility treatments and in the native bush in July 1994 are shown in Figure 2. There were more *Octochaetus multiporus* in the LL and LN treatments than on the HH and HN treatments or in the native bush.

Table 1 lists the significant correlations between *Octochaetus multiporus* and site characters. The population abundance, biomass and the size of individual mature *Octochaetus multiporus* , were significantly positively correlated with soil moisture in summer, the percentage of pasture species other

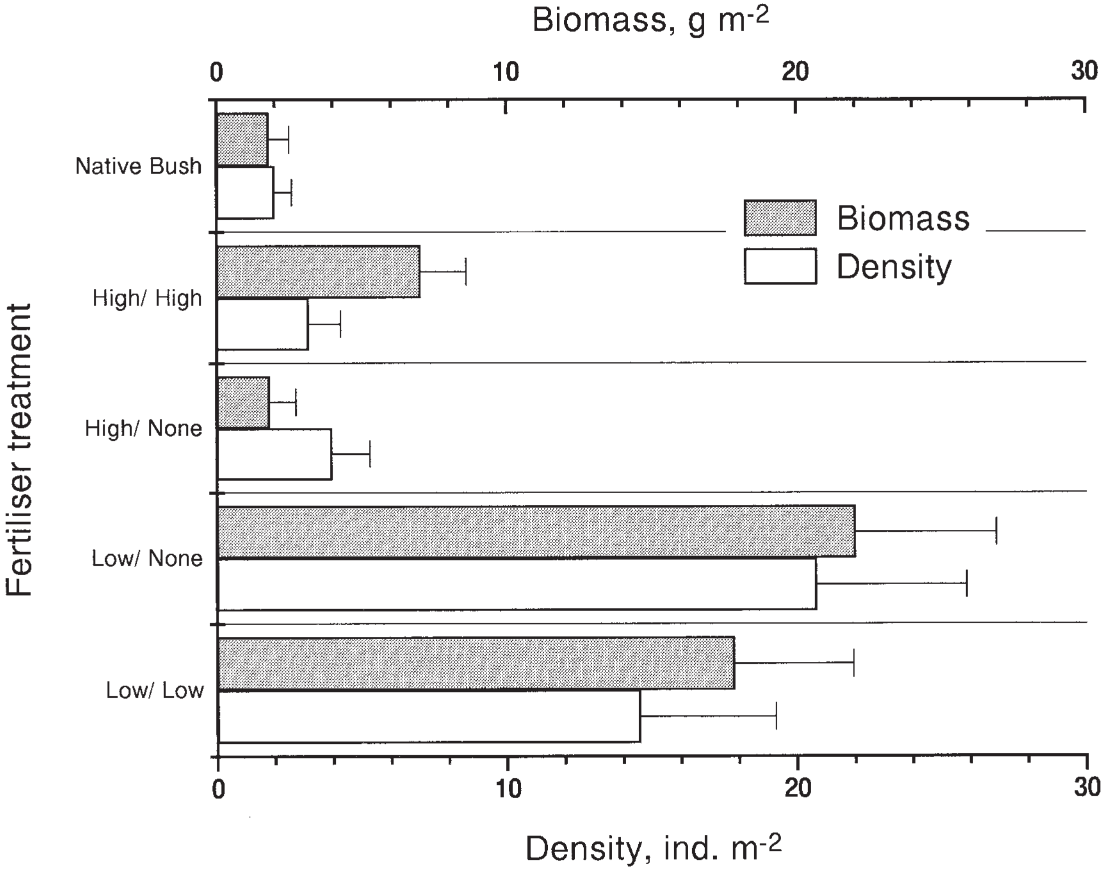

Figure 2: *Biomass and density (mean ± 1 s.e.) of* Octochaetus multiporus *in each of the four fertilizer treatments and in the native bush area, July 1994*

Table 1: *Correlation coefficients between density of* Octochaetus multiporus *and site factors. * = significant at 5%, ** = significant at 1%, *** = significant at 0.1%. Other significant correlations: Aspect and summer soil moisture = 0.413*; Aspect and runoff = 0.506**; Pasture dry matter and soil Olsen P = 0.698***.*

	Octochaetus multiporus characteristics		
Site factor	Density, no. indiv. m^{-2}	Biomass, g m^{-2}	Mean mass of mature worm, g
Summer soil moisture	0.573***	0.515**	0.567***
Aspect	0.357	0.384*	0.456*
Air permeability	-0.398*	-0.328	-0.288
Annual pasture production	-0.384*	-0.308	-0.339
Pasture production Nov.1993	-0.429*	-0.376	-0.417*
Pasture production Oct.1994	-0.443*	-0.399*	-0.419*
OM digestibility, % Oct.1994	-0.479*	-0.316	-0.297
Protein, %, Oct.1994	-0.444*	-0.235	-0.216
Other pasture species	0.437*	0.450*	0.371
Soil LOM	0.374	0.418*	0.169
Lumbricid density	-0.350	-0.386*	-0.364
Soil S	0.521**	0.550**	0.418*
Soil Ca at 75-150 mm	-0.468*	-0.393*	-0.382

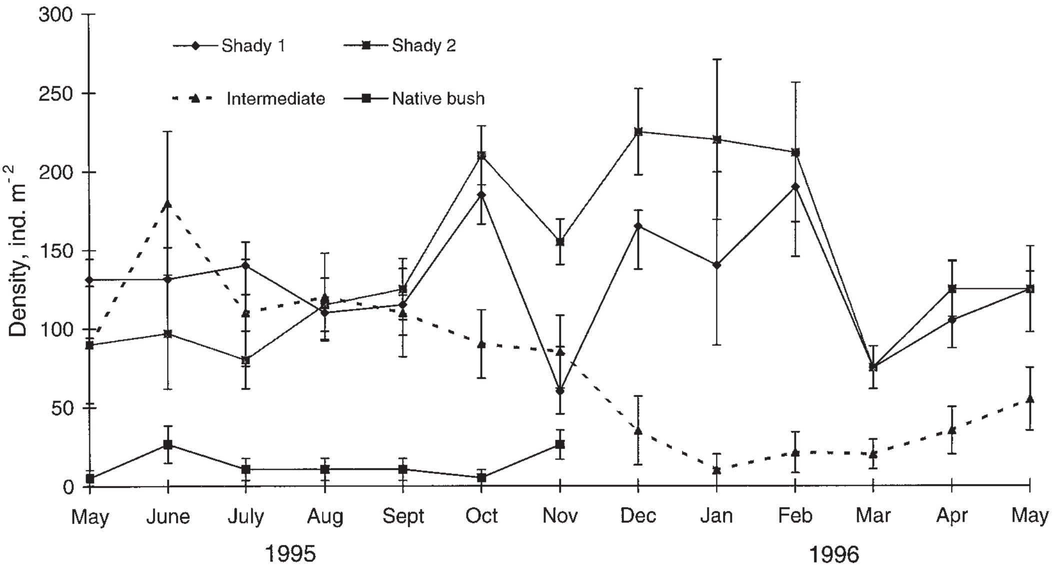

Figure 3: *Density (mean no. of individuals m*$^{-2}$ *± s.e.) of* Octochaetus multiporus *in three low fertility paddocks, two with shady aspects (angular deviation from magnetic NW 155º), and one with intermediate aspect (angular deviation from magnetic NW 90º) between May 1995 and May 1996 and in native bush (intermediate aspect, angular deviation from magnetic NW 90º), May 1995 to November 1995.*

than grasses and legumes, and the soil sulphur content at 0-75 mm. Biomass was additionally significantly positively correlated with aspect and the soil light organic matter fraction. Population abundance, biomass and the size of individual mature earthworms were negatively correlated with spring pasture productivity (October/November), protein content of the pasture and its digestibility, soil calcium content at 75 -150 mm and soil air permeability.

The population density of *Octochaetus multiporus* from May 1995 to May 1996 in 3 low fertility paddocks is shown in Figure 3. There was no difference between these 3 paddocks from May to September 1995 but during the summer of 1995/1996 the density in the two shady paddocks (155º angular deviation from magnetic NW) was higher than that in the paddock with an intermediate aspect (90º angular deviation from magnetic NW). This difference persisted until the end of our sampling period. The population density of *Octochaetus multiporus* in the native bush remnant soil during winter and spring 1995 was much less than in the pasture soils.

The average population density and biomass of each age class (mature, juvenile and non-mature) of *Octochaetus multiporus* for the three paddocks combined are shown in Figures 4a and b. The greatest numbers of juvenile individuals were collected from October 1995 to January 1996.

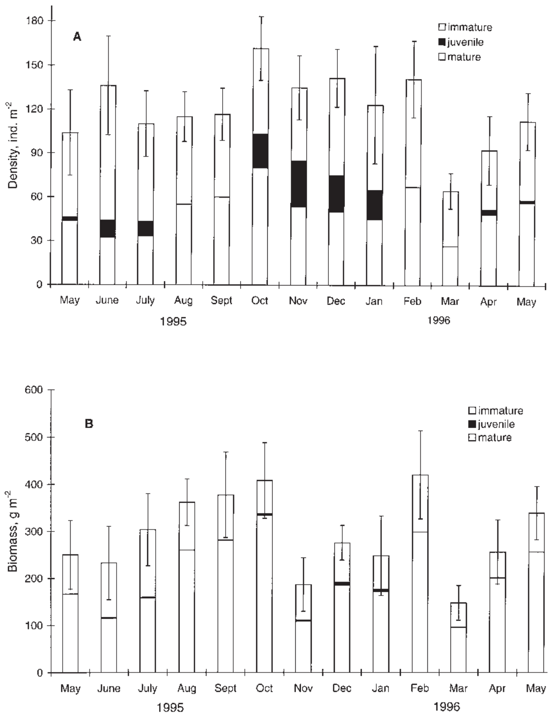

Figure 4: *Density (*A, *mean ± 1 s.e.) and biomass (*B, *mean ± 1 s.e.) of mature, immature and juvenile* Octochaetus multiporus *each month between May 1995 and May 1996*

Mature and immature worms were found in all months. No juveniles were found in August and September 1995 or February and March 1996, and smaller numbers of juvenile worms were found during the winter months than the summer months. There were few significant changes in total abundance throughout the year, with lowest numbers recorded in March and April 1996 and the highest in October 1995. The total biomass of *Octochaetus multiporus* was low in November 1995, when the number of juveniles was greatest but was also low in March 1996 when no juveniles were found.

Discussion

The study site at Ballantrae is slightly north of the boundary for *Octochaetus multiporus* as described by Lee (1959) but is within the range of soil types and climates previously recorded for this species and this species has been recorded from Ballantrae by Yeates (1993). Our data quantify Lee's (1959) observations that *Octochaetus multiporus* was more numerous in soils that slope away from the sun, and this was correlated with higher soil moisture levels during the summer. Even though the native bush site was shady, the population density was low when compared with shady pasture slopes, and was similar to the densities in sunnier, drier pasture slopes. The native bush remnant has 4 other megascolecid species (as yet unidentified), only one of which has been found at low densities in pastures, but even the total numbers of Megascolecidae in the native bush site are less than that of *Octochaetus multiporus* in the pasture sites. This suggests that *Octochaetus multiporus*, rather than being dependent on forest vegetation and litter, and therefore disappearing (or in the short term, unaffected) after bush clearance (Lee, 1959; Stockdill, 1982; Yeates, 1991), may be favoured by the change to pastoral management under some circumstances. The significant negative correlations with both pasture production and lumbricid earthworm numbers could indicate either an inability to compete with lumbricid earthworms at higher soil fertility, or better adaptation to soil organic matter of lower nutrient content. While greater *Octochaetus multiporus* density was correlated with lower air permeability, other work has shown that air permeability is positively correlated with high top-soil lumbricid density (Kretzschmar, 1978). Lumbricid earthworm numbers in these farmlets were positively correlated with pasture production (Lambert *et al.*, 1996). Several of the low-producing paddocks had low lumbricid density but no *Octochaetus multiporus*. In these cases low density of *Octochaetus multiporus* was not directly related to the high density of lumbricids, but the low density of both indigenous and introduced earthworms may be the result of unsuitable environmental conditions, such as summer dryness.

Mature and non-mature *Octochaetus multiporus* were present throughout the year. Juvenile earthworms were most numerous from October to January and were found in most months of the year except August/ September and February/ March. The small numbers found in samples throughout the year suggest that there is no well-defined breeding season for this species at this site. A large sub-soil species such as this is likely to be slow growing, taking more than 1 year to mature, in a cool temperate climate. Development of sexual characteristics and reproduction could be independent of season when earthworms have access to deep moist soils during summer. Smaller total populations and the absence of juvenile earthworms in late summer could indicate that some of the *Octochaetus multiporus* population was present below the 300 mm sampling depth.

Our observations in the field of the burrows of *Octochaetus multiporus* confirm Lee's (1959) and Smith's (1887) description of their burrowing behaviour in the field. This contrasts with Lee's (1959) laboratory measurements of casting behaviour in a thin monolith, when a four inch thick, spongy surface layer of castings was produced. As this experimental observation does not conform with field observations we suggest that the result was caused by the restricted space in the thin monolith.

This paper records the first detailed data on factors affecting the distribution and abundance of *Octochaetus multiporus* in pasture systems. *Octochaetus multiporus* is intrinsically of interest as a member of New Zealand's indigenous fauna which must play an important role in the sustainable management of native forests and tussock grasslands. Additionally much of New Zealand's hill pasture lies within the range of low to moderate fertility and moist summer conditions, which apparently would favour *Octochaetus multiporus*. Several other indigenous New Zealand soil invertebrates have reached high population densities under pasture vegetation, for example grass grub (*Costelytra zealandica* (White)), and porina (*Wiseana* spp.), and these are regarded as significant pasture pests. In contrast *Octochaetus multiporus* is an indigenous species which may be beneficial in New Zealand's agricultural ecosystems. Native New Zealand flatworms, particularly *Artioposthia tiangulata* (Dendy), have decimated lumbricid populations in Great Britain (Blackshaw and Stewart, 1992; Haria, 1995). In New Zealand deep burrowing lumbricids have a restricted distribution which may be related to their susceptibility to predation by native flatworms. This study has shown that *Octochaetus multiporus* occurs in significant numbers in some pastures, and burrows deeply in the soil. Further work on the ecology of native New Zealand earthworms could be justified as *Octochaetus multiporus*, having evolved in the same habitats as New Zealand flatworms, may be more appropriate for improving soil structure, aeration and water holding capacity in pastures than deep burrowing, introduced lumbricids.

Acknowledgements

We wish to thank Don MacDougall, Des Costall, Brian Devantier, Craig Anderson and Philip Budding for technical assistance in the field. Special acknowledgment is made to Amy Brown, (New Zealand author and playwrite, 1940-1996) author of "Earthworms", for her information on the traditional use of earthworms by Maori.

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