EARTHWORMS IN SHEEP-GRAZED PASTURES

N.L. Schon[a], A.D. Mackay[b], and R.A. Gray[b]

[a]AgResearch Lincoln, Private Bag 4749, Christchurch 8140, New Zealand
Nicole.schon@agresearch.co.nz
[b]AgResearch Grasslands, Private Bag 11008, Palmerston North 4442, New Zealand

Abstract
Earthworms beneficial to New Zealand pasture agriculture are all exotic, having arrived accidentally with the first European settlers. Today the distribution of earthworms and their three functional groups (epigeic, endogeic and anecic) remains patchy and it is estimated that up to 6.5 million ha of pastures in New Zealand, may benefit from the introduction of the deep burrowing, anecic earthworms. The two types of surface active earthworms (epigeic and endogeic) are reasonably widespread and abundant. This study explores the distribution of all earthworm functional groups from existing studies in sheep-grazed pastures and looks at what soil functions they contribute to.

Earthworm functional diversity is found to be low in sampled sheep-grazed pastures, with anecic earthworms often absent. Pasture conditions in sheep-grazed pastures are generally suitable for anecic earthworms and it is likely that the anecic earthworms are often absent from sheep-grazed pastures because they have not yet reached these pastures. In pastures where the anecic earthworm, *A. longa*, has been introduced initial rates of spread are less than 4 m annually, with rates of spread reaching 12.5 m/year as the time since introduction increases.

The presence of all three earthworm functional groups present in a pasture improves the functioning of the soil. This is reflected in greater amounts of organic matter incorporated from the soil surface to depth in the soil, also increasing the availability of nitrogen to plants. The presence of anecic earthworms moderates the nitrous oxide emissions generated by the surface active epigeic earthworms, reflecting in part differences in pore structure. Anecic earthworms have more continuous and deeper burrows to aid preferential flow in comparison to endogeic earthworms, and a study found gas diffusion to be most efficient when both endogeic and anecic earthworms were present. All this would explain the increased pasture growth during autumn when anecic earthworms were introduced into pastures already containing surface active epigeic and endogeic earthworms. There is also evidence to suggest that with all three functional groups present, soils and pastures are more resilient to treading pressure and extremes of climate.

Anecic earthworms while absent from many sheep-grazed pastures are easy to establish. A fully functional soil should contain all three types of earthworms for sustained production throughout the year. To gain a better understanding of earthworm functional diversity a comprehensive nationwide survey is required, along with more research on their contribution to soil ecosystem services.

Introduction
Earthworms beneficial to New Zealand pasture agriculture are all exotic, having arrived accidentally with the first European settlers. Today the distribution of earthworms and their

three functional groups remains patchy and it is estimated that up to 6.5 million ha of pastures in New Zealand may benefit from the introduction of deep burrowing, anecic earthworms (Schon *et al.*, 2011b).

There are three recognised earthworm functional groups based on their diet and activity through the soil profile (Fig 1). The two types of earthworms which are active in the soil surface are widespread and abundant. The most common is the ‘grey earthworm’, an endogeic earthworm that improves nutrient cycling by feeding on organic matter within the soil, and improving soil structure through its burrowing in the soil. The second most common is the ‘dung earthworm’, an epigeic earthworm that improves organic matter incorporation and nutrient cycling by feeding on dung and other organic matter on the soil surface but spends little time burrowing within the soil. The third type of earthworm which is often absent from pastoral soils is the deeper burrowing ‘blackhead earthworm’. This is an anecic earthworm which improves organic matter incorporation and nutrient cycling by feeding on dung and other organic matter on the soil surface, and improves soil structure as it burrows deeper into the soil, taking the organic matter with it.

Sheep-grazed pastures are often further away from points of initial (accidental) introduction with the settlers and understanding both the distribution and function earthworms play in New Zealand’s sheep-grazed pastures is the crucial first step to manipulating the soil biology to improve the efficiency of our pastures. This study explores the distribution of the earthworm functional groups in sheep-grazed pastures and looks at what functions these earthworms contribute to.

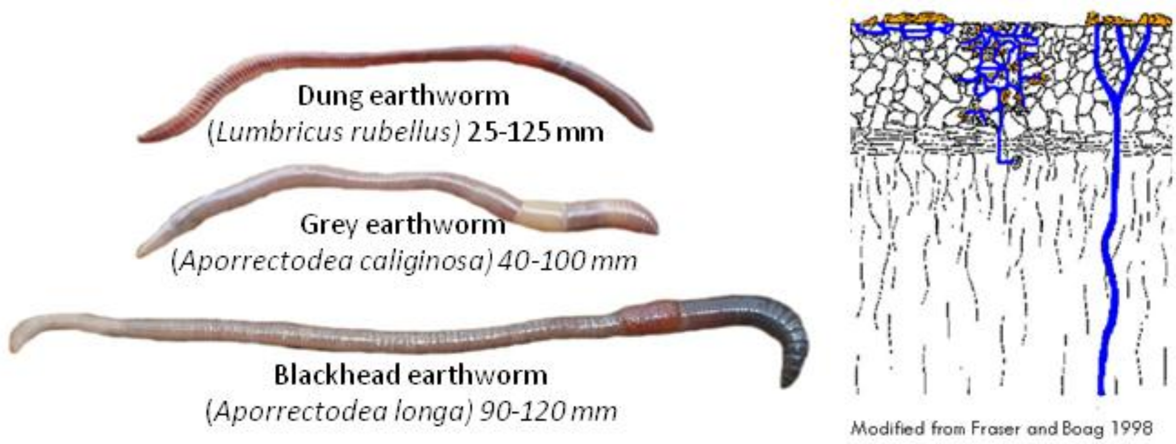

Figure 1. Earthworm functional groups: Epigeic (dung) earthworms feed on organic matter on the soil surface and do not form permanent burrows. Endogeic (grey) earthworms ingest topsoil and its associated organic matter, forming semi-permanent burrows. Anecic (blackhead) earthworms draw organic matter from the soil surface into their deep, permanent burrows to feed on. Figure from Fraser and Boag (1998), photos courtesy of R. Gray.

Methods

Published literature and unpublished studies were used to determine the presence or absence of the three different earthworm functional groups from sheep-grazed pastures in New Zealand (Table 1).

Table 1. Earthworm functional diversity in sheep-grazed pastures from both the literature and unpublished records.

Region	Site	Epigeic	Endogeic	Anecic	Reference
Canterbury	Winchmore	✓	✓	×	(Fraser *et al.*, 2012)
Wairarapa	Castlepoint	✓	✓	×	(McColl *et al.*, 1982)
Hawkes Bay	Rangitoto*	✓	✓	×	Schon (submitted)
Manawatu-	Ballantrae*	✓	✓	×	(Schon *et al.*, 2008)
Wanganui	Ballantrae	✓	✓	✓	(Schon *et al.*, 2011c)
Rangitikei	Flockhouse	✓	✓	×	(Yeates *et al.*, 2003)
Taihape	Mounganui*	✓	✓	×	Schon (submitted)
Waikato	Whatawhata	✓	✓	×	(Schon *et al.*, 2011a)
Waikato	Hobbiton	✓	✓	✓	unpublished
Waikato	Tokanui	✓	✓	✓	unpublished

*****These sites have since had introductions of anecic earthworms (see Table 2)

Sites where anecic earthworms (*Apporectodea longa*) were introduced into pastures since 1981 were revisited between 2009 to 2013. The successful establishment of anecic earthworms was confirmed and the rate of spread determined by collecting soil monoliths (20 cm width x 20 cm length x 30 cm diameter) at increasing distances from point of introduction (Schon *et al.*, 2014b).

Results and Discussion

Earthworm functional diversity was low in the majority of the reported sheep-grazed pastures (Table 1). As previously reported the epigeic and endogeic earthworms were common in pastures and it was the deep-burrowing, anecic earthworms which were often absent. There are still a number of regions which have not been surveyed for earthworms, and a more comprehensive nationwide survey is required.

Pasture conditions in sheep-grazed pastures appear suitable for anecic earthworms, with *A. longa*, successfully establishing in five sheep-grazed pastures after their introduction (Table 2). The movement away from the point of introduction reflects time since introduction, with initial rates of spread being slow as populations need time to establish (Stockdill, 1982; Butt *et al.*, 2004). In the pastures where the introduction was more recent rates of spread were less than 4 m annually, where rates of spread reached 12.5 m/year for earlier introductions. Anecic earthworms have also successfully established in recently converted dairy-grazed pastures in the Central Plateau (Mackay pers. comm.). It is likely that the anecic earthworms are often absent from sheep-grazed pastures because they have not yet reached these pastures, as they are further away from areas colonised by the European settlers.

Table 2. Details of earthworm introduction and their rate of spread.

Site	Year anecics introduced	Anecics established	Distance travelled (m)	Average rate of spread (m/year)	Reference
Ballantrae	2008	Yes	20	4	unpublished
Mounganui	1989	Yes	250	12.5	Schon (submitted)
Rangitoto	1981	Yes	200	6.7	Schon (submitted)
Te Kuiti	2010	Yes	6	2	unpublished
Onga Onga	2010	Yes	2	0.7	unpublished

Evidence is accumulating that having high functional diversity (all three earthworm functional groups) improves the functioning of the soil. For example, in the presence of anecic earthworms there is a greater amount of organic matter incorporated from the soil surface to depth in the soil (Schon *et al.*, 2014c), increasing the availability of nitrogen to plants (Schon *et al.*, 2014a). The presence of anecic earthworms also moderates the nitrous oxide emissions generated by the surface active epigeic earthworms (Lubbers *et al.*, 2011). This reflects differences in pore structure as anecic earthworms have more continuous and deeper burrows to aid preferential flow in comparison to endogeic earthworms, and a study by Bastardie *et al.* (2003) found gas diffusion to be most efficient when both endogeic and anecic earthworms were present. All these factors would explain the increased pasture growth during autumn when anecic earthworms were introduced into pastures already containing surface active epigeic and endogeic earthworms (Syers and Springett, 1983). There is also evidence to suggest that with the three functional groups present that the soils and pastures are more resilient to treading pressure (Schon *et al.*, 2010) and extremes of climate (Mackay pers. comm.).

Conclusion

Anecic earthworms while absent from many sheep-grazed pastures are easy to establish. A fully functional soil should contain all three types of earthworms for sustained production throughout the year. To gain a better understanding of earthworm functional diversity a comprehensive nationwide survey is required.

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