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EARTHWORMS OF THE MALHAM TARN ESTATE (YORKSHIRE DALES NATIONAL PARK)

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ABSTRACT

Sampling for earthworms was undertaken in a variety of habitats around Malham Tarn in May 1998. A combination of soil-sorting followed by vermifuge application produced quantitative data from a number of habitats and qualitative data from others. In October 1998, further sampling compared earthworm collection techniques using two chemical and one electrical method in three selected habitats.

In total, fourteen earthworm species were recorded. The largest number of individuals (412 m^{-2}) was recorded from the Kitchen Garden area (in May), and the largest mass (180 g m^{-2}) from Shoreside Woods (in October). Several species, including *Aporrectodea rosea*, *Lumbricus terrestris* and *Octolasion cyaneum*, were widespread, whereas others, including *Lumbricus eiseni* and *Eiseniella tetraedra*, had very restricted distributions. Grassland and woodland habitats tended to contain diverse earthworm communities. Soil environmental conditions and past human activity appear to have influenced the observed differences. Chemical application was found to be superior to electrical stimulation for earthworm extraction but digging and handsorting of soil tended to produce the highest numbers.

INTRODUCTION

THE NATURAL HISTORY of the Malham estate has been the focus for a number of detailed studies, often specific to a particular group of organisms (*e. g.* Duffey (1963) for spiders; Cameron & Redfern (1972) for terrestrial Molluscs). Such research has often grown from initial findings, collected during residential fieldwork at Malham Tarn Field Centre, as did the current survey of earthworms.

It appeared that few data were available and that an initial survey of the area immediately around the Field Centre might yield beneficial results because a number of very different habitat types are present in that relatively small geographical area. The primary aim was, therefore, to assess the distribution and abundance of earthworm species within habitats on the Malham Estate.

Two major constraints were apparent prior to any sampling:

(1) There would be time to survey only a limited number of habitats.

(2) As the area is in a National Nature Reserve, minimal site damage was desired during sampling.

Earthworm Collection Techniques

A number of techniques are available to obtain estimates of earthworm number and biomass (see Edwards & Bohlen, 1996). Due to the soil-dwelling habit of earthworms, nearly all require that the animals are brought to the soil surface in some way, although one exception is to count the number of casts at the soil surface in a given area (see Evans & Guild 1947). Potential methods available include digging, addition of a chemical vermifuge to the soil, a combination of the aforementioned or electrical stimulation of the soil. These techniques are described in brief, to demonstrate some of the advantages and problems associated with each.

Digging and hand-sorting of soil

This method is probably the most obvious for earthworm extraction, but is both time-consuming and laborious. If an area of 0.1 or 0.2 m^2 is dug to a depth of 0.15 m, the soil removed can be carefully sorted in the field (on plastic sheeting beside the hole). However, heavy soils, dense plant roots or wet weather make this task less simple. Nevertheless, this method permits potential recovery of all earthworm present, adults and immatures, although larger deep-burrowing species may retreat into the soil during digging. This method does however severely disrupt the upper soil layer of the area sampled.

Vermifuge application

Pouring a chemical onto the soil surface allows it to seep into soil pores and, more directly, enter the vertical burrows of larger earthworms. A dilute solution (0.04 %) of formaldehyde (formalin) is widely used (Raw, 1959) and has been a standard vermifuge for decades. Recently however, it has been reported as carcinogenic, so alternatives have been sought. Gunn (1992) suggested using a suspension of table mustard in water, but field trials (*e. g.* Butt, 1998) have shown that mustard powder (50 g in 10 litres water) is both cheaper and more effective. East & Knight (1998) have proposed detergent as another alternative.

Any vermifuge, applied by watering can, will tend to favour extraction of deeper burrowing species and may under-record those which have shallow horizontal burrows. This technique is quick and simple but a negative aspect is the chemical residue left in the soil. Mustard powder should be preferable to formalin, if extraction efficiency is equal, because of a lesser impact on other soil organisms (and researchers).

Digging and hand-sorting of soil plus the addition of a vermifuge

By digging a hole, sorting through the soil removed and adding a recognised vermifuge to the hole created, any deep-burrowing earthworms, which have retreated into their burrows during digging, should be extracted. Of the traditional methods, this combination should give rise to best results.

Electrical stimulation

This has been used for at least 40 years (Satchell, 1955) but has been refined recently. The Octet method of Thielemann (1986) employs 8 steel electrodes pushed into the soil in a regular pattern forming a circle with an area of 0.2 m^2. (Earthworms brought to the surface using this method were collected from within this area.) The power source is a 12 volt battery and a number of voltages, with a range of 'switching frequencies', can be applied across the whole range.

This method would appear attractive as little or no damage occurs to the area sampled. Only fallen leaves and overgrown ground vegetation need to be removed prior to sampling. No chemicals are added to the sampling area. However the cost of the Octet apparatus is prohibitively high.

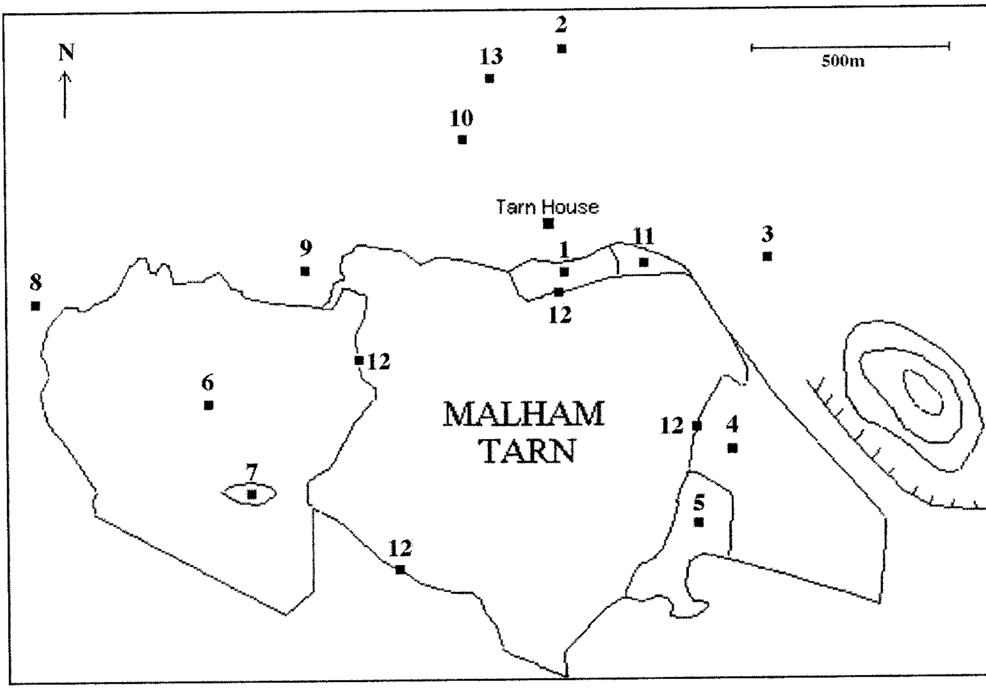

FIG. 1.

Sketch map showing the areas around Malham Tarn which were sampled for earthworms. 1 Tarn Close; 2 Highfolds; 3 Great Close Hill; 4 Ha Mire; 5 Ha Mire Wood; 6 Tarn Moss; 7 Spiggot Hill; 8 coniferous woodland; 9 fen/carr; 10 Kitchen Garden; 11 shoreside woods; 12 tarnside; 13 woodland.

After collection, all the earthworms must be identified. This is relatively simple for adult (clitellate) specimens with the most comprehensive guide provided by Sims & Gerard (1985; 1998) although the illustrated key of Piearce (1979) is also useful.

MATERIALS AND METHODS

To discover as much about the earthworms of the Malham estate as possible, combinations of the above methods were used during two sampling periods in the spring (May) and autumn (October) of 1998. (All locations sampled are marked on Fig. 1.)

Sampling Period 1 (May 1998)

A standard sampling procedure was used. This was to dig and hand sort soil from an area of 0.2 m^2 and then apply a mustard vermifuge (50 g in 10 litres water) to the hole (dug to a depth of approximately 0.15 m). A minimum of 5 replicates were processed in each of the chosen habitats. If it proved impossible to sample in this way, *e.g.* due to water inundation or the presence of rocks, then qualitative sampling was undertaken to try and obtain representative earthworm species from each habitat.

The following areas were selected for sampling: Tarn Close (ungrazed limestone grassland); Highfolds (limestone pavement); Great Close Hill (grazed limestone grassland); Ha Mire (marshy grassland); Ha Mire Wood (plantation); Tarn Moss (raised bog); Spiggot

TABLE 1. *Summary data of earthworm distribution on the Malham Estate*

Earthworm species	Tarn Close	Gt Close Hill	Ha Mire Wood	Ha Mire	Spiggot Hill	coniferous woodland	Kitchen Garden	Highfolds	Shoreside Woods	Tarn Moss	fen / carr	Tarnside
Allolobophora chlorotica (green)	✔	✔	✔	✔	✔						✔	
Allolobophora chlorotica (pink)	✔	✔			✔		✔		✔			
Aporrectodea caliginosa	✔	✔	✔		✔		✔		✔			
Aporrectodea longa	✔	✔	✔				✔		✔			
Aporrectodea rosea	✔	✔	✔	✔	✔		✔		✔		✔	
Dendrobaena octaedra	✔	✔			✔	✔	✔		✔	✔	✔	
Dendrodrilus rubidus	✔		✔		✔		✔	✔	✔			
Eiseniella tetraedra					✔							✔
Lumbricus castaneus	✔		✔		✔	✔	✔		✔			
Lumbricus eiseni					✔					✔		
Lumbricus friendi	✔	✔										
Lumbricus rubellus	✔		✔		✔		✔					
Lumbricus terrestris	✔	✔	✔		✔	✔	✔	✔	✔			
Octolasion cyaneum	✔	✔	✔		✔	✔	✔	✔	✔			
Satchellius mammalis					✔		✔					
Species richness	12	9	9	2	13	4	11	3	9	2	3	1

Hill; coniferous woodland; fenland; Kitchen Garden.

Additional sampling on Great Close Hill employed mustard as a vermifuge without recourse to digging in advance. Here ten replicates of 0.2 m^2 were each treated with 10 litres of a standard mustard vermifuge. A general inspection was also made around and within the (new) sewage treatment plant close to Tarn House and directly around the shoreline of the Tarn. Investigations were also made of earthworm surface casting observed upon the path leading through the woodland up to Highfolds. Here, dilute formaldehyde was poured directly into 2 burrows and the emerging animals were kept for identification.

Sampling Period 2 (October 1998)

A direct examination of earthworm extraction techniques was undertaken, comparing electrical stimulation, formalin extraction and the use of mustard powder, in three habitats - Great Close Hill; Shoreside Woods (oak-dominated woodland) and Tarn Close (a minimum of 5 replicates per treatment). The techniques employed were:

(a) 0.4 % formaldehyde (formalin) as a vermifuge (10 litres);

(b) A suspension of mustard powder in water as a vermifuge (50 g in 10 litres of water);

(c) Electrical stimulation using an Octet apparatus (Thielemann, 1986). The whole range of voltages using a variety of switching frequencies were used over a 30 minute period per sample.

Each technique was applied to a sample site with an area of 0.2 m^2. In most instances (where quantitative data was required), the collected earthworms were preserved in 4 %

TABLE 2. *Earthworm densities (numbers m^{-2}) from the areas sampled in May 1998 (percentages for each site in parentheses)*

Earthworm species	Tarn Close	Highfolds	Gt Close Hill	Ha Mire Wood	Spiggot Hill	coniferous woodland	Kitchen Garden
A. chlorotica (green)			33 (21)	5 (5)	1 (<1)		
A. chlorotica (pink)	76 (26)		9 (6)		16 (9)		100 (24)
A. caliginosa	4 (1)		13 (8)	15 (14)	21 (12)		34 (8)
A. longa	45 (15)		5 (3)	4 (4)			36 (9)
A. rosea	65 (22)		46 (29)	6 (6)	21 (12)		53 (13)
Aporrectodea spp.	71 (24)		6 (4)	11 (10)	26 (15)		92 (22)
D. octaedra	1 (<1)				21 (12)	1 (6)	2 (<1)
D. rubidus		8 (17)		15 (14)			10 (2)
E. tetraedra					4 (2)		
L. castaneus	3 (1)			1 (1)	9 (5)	1 (6)	1 (<1)
L. eiseni					1 (<1)		
L. rubellus				2 (2)	10 (6)		18 (4)
L. terrestris	8 (3)	3 (6)	12 (8)	1 (1)	3 (2)	8 (47)	2 (<1)
Lumbricus spp.	4 (1)	5 (11)	20 (13)	40 (38)	21 (12)		31 (8)
O cyaneum	14 (5)	31 (66)	16 (10)	6 (6)	7 (4)	7 (41)	15 (4)
S. mammalis					12 (7)		18 (4)
Total	291	47	160	106	173	17	412

TABLE 3 *Earthworm masses ($g.m^{-2}$) from the areas sampled in May 1998 (percentages for each site in parentheses)*

Earthworm species	Tarn Close	Highfolds	Gt Close Hill	Ha Mire Wood	Spiggot Hill	coniferous woodland	Kitchen Garden
A. chlorotica (green)			4.92 (8)	1.04 (3)	0.24 (<1)		
A. chlorotica (pink)	14.91 (17)		1.39 (2)		2.96 (8)		18.48 (18)
A. caliginosa	1.30 (2)		6.01 (9)	4.14 (13)	7.91 (21)		7.23 (7)
A. longa	31.73 (37)		1.59 (2)	4.23 (13)			29.99 (30)
A. rosea	10.25 (12)		6.38 (10)	0.83 (3)	2.28 (6)		6.56 (7)
Aporrectodea spp.	4.41 (5)		0.45 (<1)	0.63 (2)	1.84 (5)		7.22 (7)
D. octaedra	0.93 (1)				2.84 (8)	0.08 (<1)	0.13 (<1)
D. rubidus		0.41 (1)		1.48 (5)			0.54 (<1)
E. tetraedra					0.30 (1)		
L. castaneus	0.47 (<1)			0.19 (<1)	1.25 (3)	0.25 (1)	0.21 (<1)
L. eiseni					0.18 (<1)		
L. rubellus				1.43 (5)	7.12 (19)		4.55 (5)
L. terrestris	9.08 (11)	17.97 (61)	20.44 (31)	4.25 (13)	4.34 (12)	18.22 (76)	7.00 (7)
Lumbricus spp.	0.37 (<1)	0.94 (3)	4.26 (7)	9.19 (29)	1.88 (5)		5.43 (5)
O cyaneum	12.72 (15)	10.09 (34)	20.09 (31)	4.02 (13)	2.85 (8)	5.33 (22)	10.89 (11)
S. mammalis					1.50 (4)		1.51 (2)
Total	86.17	29.41	65.53	31.43	37.49	23.88	99.74

formaldehyde for accurate identification (Sims & Gerard, 1985, 1998) and mass determination. When comparing results from different techniques in the same habitat, or when comparing the same technique and habitat in different seasons, statistical analysis made use of 't tests' (*e.g.* Sokal & Rohlf, 1981).

RESULTS

Table 1 summarises the distribution of earthworm species encountered during this investigation. The nomenclature follows Sims & Gerard (1985; 1998).

Sampling Period 1 (May 1998)

Table 2 details the catches during the May sampling period. The total of 13 species includes all three earthworm ecological groupings (see, *e.g.*, Sims & Gerard, 1985; 1998). Litter dwelling species were represented by *Dendrobaena octaedra*, *Dendrodrilus rubidus*, *Eiseniella tetraedra*, *Lumbricus castaneus*, *L. eiseni*, *L. rubellus* and *Satchellius mammalis*.

Shallow-burrowing species included *Allolobophora chlorotica* (both green and pink morphs), *Aporrectodea caliginosa*, *A. rosea* and *Octolasion cyaneum*. Two deep-burrowing species, *Aporrectodea longa* and *Lumbricus terrestris* were also found.

Table 3 presents the masses of these earthworms with percentage divisions for each species at each site.

Several of the habitats sampled are not included in Tables 2 and 3, as quantitative

TABLE 4. *Mean earthworm numbers and masses from sampling in 3 habitats in October 1998, using 3 collection techniques*

(a) Earthworm density ($n.m^{-2}$)

Technique	Tarn Close		Great Close Hill		Shoreside Woods	
Mustard	126	a	101	a	122	a
Formalin	74	a	64	b	93	a
Electrical	105	a	80	ab	47	b

(b) Earthworm mass ($g.m^{-2}$)

Technique	Tarn Close		Great Close Hill		Shoreside Woods	
Mustard	47.0	a	81.08	a	180.74	a
Formalin	38.1	a	56.93	ab	112.60	a
Electrical	14.2	b	32.53	b	16.45	b

Means followed by the same letter in any column are not significantly different ($p<0.05$)

sampling proved impossible. At Ha Mire, digging revealed *Allolobophora chlorotica* (green morph) in saturated soils, where leeches (Hirudinida) were also present. *A. chlorotica* and *Aporrectodea rosea* were also found below mosses near the Tarn. On Tarn Moss, *Dendrobaena octaedra* was found and cocoons of *Lumbricus eiseni* were also located from soils close to pine trees. A grassy area, south of the bridge on Tarn Moss, revealed the presence of *L. eiseni* and *Dendrodrilus rubidus*. Within the fen area leading towards Tarn Moss, *Allolobophora chlorotica* (green morph) and *Aporrectodea rosea* were present in streamside soils. In an area of birch carr, beside the walk-way to Tarn Moss, there were small numbers of *Dendrobaena octaedra*.

Sampling with a mustard vermifuge on Great Close Hill, obtained a mean earthworm density of 67.5 m^{-2} with a mean mass of 70.14 g m^{-2}. Of these, *Lumbricus terrestris* accounted for 84 % by number and 97 % by mass.

Within the sewage treatment plant, *Aporrectodea rosea* was present on top of the filter bed but most individuals appeared to be trying to escape. *Eiseniella tetraedra* was present within the stones/gravel at the Tarn margin. The latter was located from shoreside sites all around the Tarn. Pouring formalin into burrow openings in the woodland leading up to Highfolds led to the emergence of mature *Lumbricus terrestris*. Only one earthworm was extracted from below each set of castings.

Sampling Period 2 (October 1998)

Within Shoreside Woods (above the east boathouse), use of a vermifuge (either formalin or mustard) produced significantly more earthworms ($p<0.05$) with a significantly greater biomass ($p<0.05$) than electrical extraction. Differences between the two vermifuges were not significant for either density or biomass (Table 4). Total sampling within the Shoreside Woods revealed the presence of 9 earthworm species, all of which had been recorded in the

May sampling programme.

On Great Close Hill, the Octet apparatus did not produce significantly different numbers of earthworms to either vermifuge. However, significantly more worms ($p<0.01$) were extracted by mustard application compared with formalin. When biomasses were examined, a significant difference ($p<0.05$) was recorded only between use of mustard and the Octet apparatus : a greater mass of earthworms was extracted using the mustard vermifuge.

In the grassland area of Tarn Close, the different techniques only produced differences in biomass: electrical extraction producing a significantly lower mass of worms than either of the vermifuges ($p<0.05$).

Sampling in October added one species, *Lumbricus friendi*, to those listed in Table 2. This was present in Tarn Close and also on Great Close Hill.

Comparisons between May and October

Significantly more earthworms ($p<0.01$) were obtained from sampling with a mustard vermifuge on Great Close Hill in October (mean density = 101 m^{-2} of which *L. terrestris* accounted for 46 %) than in May, but masses were not significantly different ($p > 0.05$) (mean mass = 81.08 g m^{-2} of which *L. terrestris* accounted for 82%).

DISCUSSION

Few records of earthworms appear in the literature at Malham, with the exception of Holmes (1965) who noted the presence of the semi-aquatic *Eiseniella tetraedra* as commonly found amongst stones on the north shore and in wet moss by the outflow of the Tarn. This species was again recorded in similar areas. Bullock (1971) discussed earthworms in relation to their role in soil formation on limestone, but only recorded earthworm casts in the A-horizon of a mesotrophic brown earth soil at Seaty Hill.

The current investigation also revealed that half of the earthworm species found in Britain (Sims & Gerard, 1985; 1998) are present on the Malham Estate. However, the distribution of these species is not uniform, but a function of their environmental requirements, particularly soil physico-chemical status. The Kitchen Garden produced the greatest density of earthworms, which may reflect former management practices associated with soil conditioning. Greatest species diversity was obtained from Spiggot Hill, which may be a function of soil moisture status across this site.

Some earthworm species, including *Aporrectodea rosea*, *Lumbricus terrestris* and *Octolasion cyaneum*, were widespread. These relatively common species are often found in association with undisturbed, mature soils (Sims & Gerard, 1985; 1998). The largest individual specimens found were of mature *L. terrestris* (mean mass 8.7 g) and came from Highfolds. These earthworms, collected from the grikes, would have experienced relatively protected environmental conditions, and although the habitat could only support a limited number of individuals, they compared with a mean mass of only 3.9 g for similar animals from other sampled habitats.

The presence of both colour morphs of *Allolobophora chlorotica* is of some interest, as each has a preferred habitat type. The pigmented green morph is more common in pasture and moist soil situations (Sims & Gerard, 1985; 1998) whereas the pink morph is found more in garden and woodland soils. The results obtained here support these observations, but since both were found in close proximity on Great Close Hill and Spiggot Hill, it strongly suggests that these two habitats have a range of soil conditions.

That seasonal differences in earthworm numbers were apparent at Great Close Hill was not unexpected. Changes in population size are common as new recruits are added in spring and to a lesser extent in autumn (Edwards & Bohlen, 1996). Therefore not only will numbers of individuals vary but so will the age composition of each species.

Seasonal differences between numbers obtained using chemical extraction may also be influenced by earthworm activity. Some species from the genus *Aporrectodea* enter a resting period (diapause) during periods of drought or cold (Evans & Guild, 1947). During such periods, digging may reveal these species coiled within mucus-lined cells in the soil, but vermifuge application will tend only to kill these animals.

Earthworm castings on the soil surface are a good index of deep-burrowing adults, as recorded for *Lumbricus terrestris*. Therefore, for adults of this species, quadrat sampling may be appropriate if minimal soil disturbance is desired. However, for other deep-burrowing surface-casting species, such as *Aporrectodea longa*, a simple 1:1 ratio of casting to adult worms cannot always be guaranteed (Butt *et al.*, 1997). Earthworms which do not cast on the surface (the majority), cannot be sampled in this manner.

Earthworms are a major component of temperate soil ecosystems and their activities have been shown to lead to greater soil fertility (see, for example, Edwards & Bohlen, 1996). For these reasons alone, studying this group is important. Simple experiments, relating to species presence, number and biomass with respect to soil physico-chemical properties in different habitats, therefore, offer ideal opportunities for ecological investigations. Data presented in this paper may provide a starting point for such projects.

For practical purposes, where only a single visit to a site is possible, the most efficient method of collection should be utilised. At present this appears to be a combination of vermifuge application following handsorting of surface soil. However, at a NNR such as Malham Tarn, this might be discouraged to prevent unnecessary despoilation of the soil. Over-zealous collection, or frequent re-use of the same site could have long-term detrimental effects on soils and soil fauna.

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