Biological Recording Company

Hay Time Project
Earthworm Survey Report

Keiron Derek Brown

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2 Acknowledgements

Earthworm Surveys

The author would like to thank:

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- Catherine Mercer for organising all of the site permissions and participating in every single survey at the Westmorland Dales sites.
- The volunteers who contributed to the earthworm surveying at various sites and helped with sampling, whatever the weather.
- The site owners and managers who kindly granted access to their sites.

Earthworm Identification

The author would like to thank those who contributed to the earthworm identification for this project:

- Sheila Warbus

3 Project aims

Hay meadows are one of our rarest habitats and a priority for conservation and enhancement in the UK Biodiversity Action Plan. In May of 2012, the Forest of Bowland National Landscape joined forces with the Yorkshire Dales Millennium Trust to deliver a Hay Time hay meadow restoration project in Bowland, funded with help from the Lancashire Environment Fund.

The Hay Time project works with farmers in the Forest of Bowland National Landscape to harvest wildflower seed and 'green hay' from species-rich meadows and use this to restore meadows which have lost some of their characteristic plants. The project also aims to increase public awareness, enjoyment and understanding of the hay meadows found in the area, improve public access to meadows, and survey meadows to record the variety and number of plant species they contain.

The Biological Recording Company was commissioned in January 2023 by the Yorkshire Dales Millennium Trust to undertake earthworm surveys and engagement events in the Forest of Bowland National Landscape as part of the Hay Time Project. This work was expanded to cover the Yorkshire Dales from 2025.

The Hay Time earthworm activities consisted of three components, aiming to engage the public and farmers with earthworm ecology and improve understanding of the earthworm assemblages associated with hay meadows and how the earthworm communities change over time:

1. Earthworm Training Courses and Webinars
2. Hay Meadow Soil Pit Survey Transects
3. Earthworm Microhabitat Searches

The Hay Meadow Soil Pit Survey Transects aim to establish baseline values for comparing the earthworm communities of hay meadows undergoing restoration with the pre-restoration habitat (pasture) and the post-restoration habitat (species-rich grassland). Specifically, these surveys will investigate how earthworm abundance, species richness, species composition and functional group composition vary between pasture and species-rich grassland habitats, and how these characteristics evolve depending on the number of years a site has been undergoing hay meadow restoration.

4 UK earthworms

The UK and Ireland are home to 33 species of earthworm, which can be broken down into groups based on their morphology, ecology and behaviour. Traditionally, the separation of species into groups has been into ecological categories based on their morphology, using three poles on a triangular scale:

- **Anecic earthworms** make permanent vertical burrows in soil. They feed on leaves on the soil surface that they drag into their burrows. They also cast on the surface, and these casts can quite often be seen in grasslands. Some anecic earthworm species also make middens (piles of casts) around the entrance to their burrows. Anecic species are the largest species of earthworms in the UK. They are darkly coloured at the head end (red or brown) and have paler tails.
- **Endogeic earthworms** live in and feed on the soil. They make horizontal burrows through the soil to move around and to feed and they will reuse these burrows to a certain extent. Endogeic earthworms are often pale colours, grey, pale pink, green or blue. Some can burrow very deeply in the soil.
- **Epigeic earthworms** live on the surface of the soil in leaf litter, deadwood, dung and compost. These species tend not to make burrows. Epigeic earthworms are also often bright red or red-brown, and sometimes even stripy.

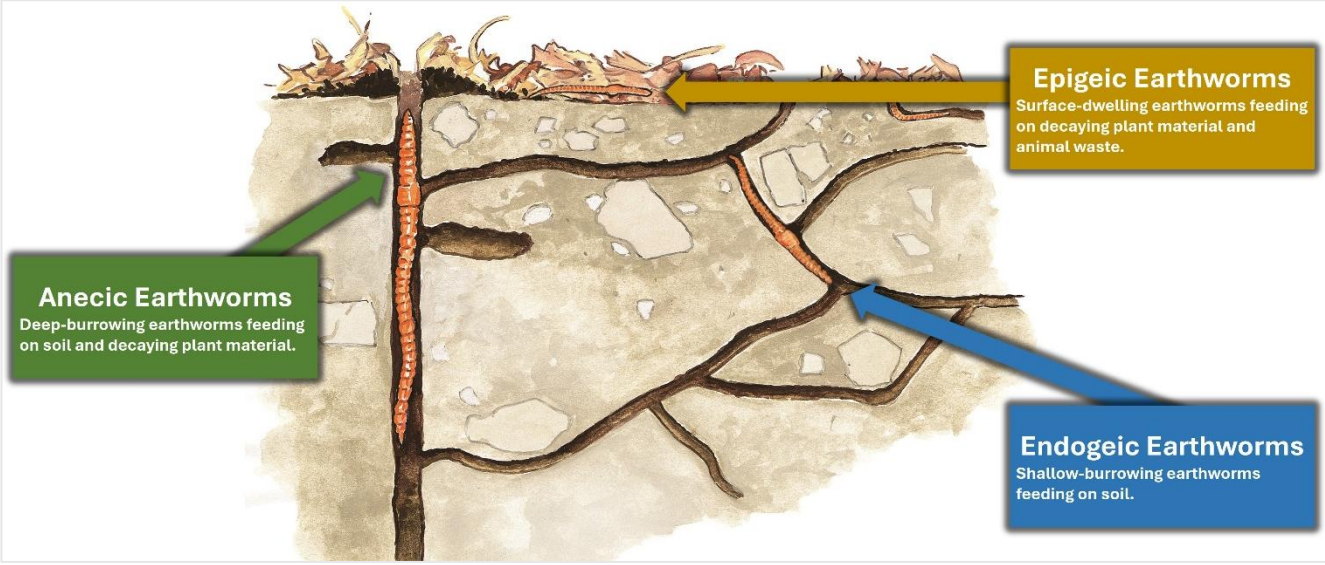

Figure 1: Earthworm ecological categories. Illustration (c) Rick Kollath https://kollathdesign.com/

Earthworms were selected as an indicator of general soil biodiversity health as they are widely regarded to be of great ecological importance, with different ecological categories of earthworm contributing to soil processes and resulting in a number of ecosystem services (**Figure 2**) (Keith & Robinson, 2012).

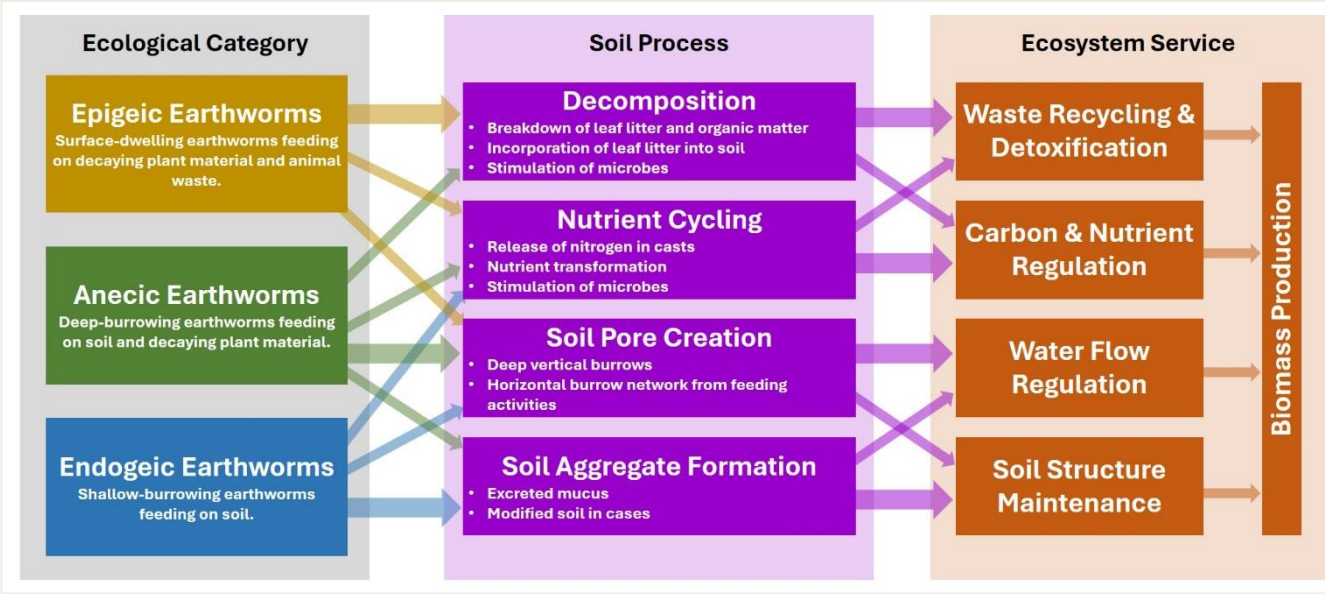

Figure 2: Earthworm ecosystem services adapted from Keith & Robinson 2012.

More recently, earthworms have been categorised into one of 6 functional groups based on their bioturbation behaviour, as illustrated in **Figure 3** (and including an additional intermediate grouping) (Capowiez, Marchán, Decaëns, Hedde, & Bottinelli, 2044):

- **Litter dwellers** were described as small, pigmented earthworms with very high surface activity which make a few shallow galleries in the soil. A link can be made with the epigeic ecological category.
- **Burrowers** were described as large, pigmented earthworms which feed and cast on the surface. They create a limited number of true burrows and exhibit higher activity near the surface. A link can be made with the epi-anecic ecological category.
- **Intense tunnelers** were described as very large, pigmented earthworms that also feed and cast on the surface. However, they make extensive burrow systems. A link can be made with the anecic ecological category.
- **Shallow bioturbators** were described as small, unpigmented earthworms that display very low surface activity and make refilled and shallow galleries in the soil. A link can be made with epi-endogeics.
- **Deep bioturbators** were described as average to large, unpigmented earthworms with low surface activity. They make refilled galleries, which can be found deeper in the soil profile. These may also be referred to as hypo-endogeics.
- A sixth category was classified as the **Intermediate** group. This included species without marked characteristics and included both pigmented and non-pigmented species.

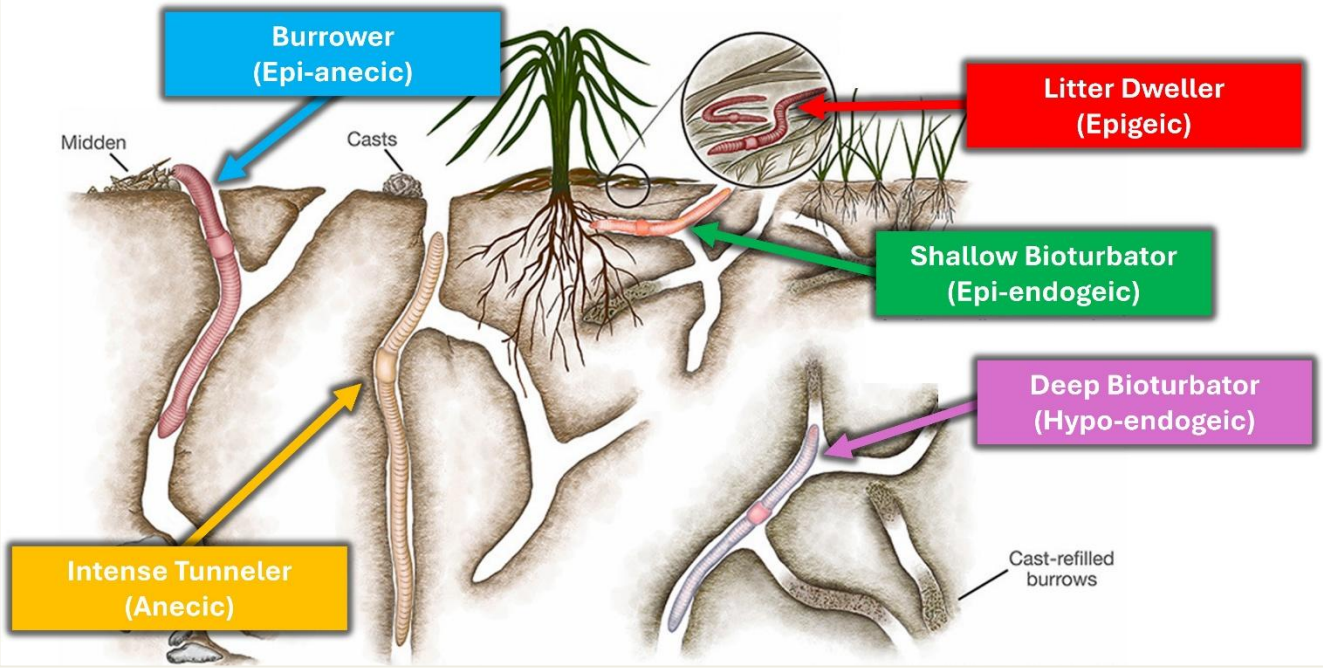

Figure 3: Earthworm Functional Groups adapted from Capowiez et al (2024).

5 Training courses and webinars

Two one-day in-person earthworm training courses were delivered in Northwest England, with the aim of engaging people with earthworm ecology and identification. These were complemented by two free-to-attend webinars focusing on British earthworms and their ecology.

Details of the training courses and webinars delivered can be found in Table 1.

Table 1: List of training courses and webinars delivered.

Name of training course	Venue	Tutor	Date	Attendees
Introduction To Earthworms	Online - webinar	Keiron Brown	27/04/2023	115
Earthworm Biology & Ecology	Gisburn Forest	Keiron Brown	02/05/2023	12
Earthworms of the UK Part 1	Online - webinar	Keiron Brown	08/04/2024	234
Earthworm Identification	World Museum (Liverpool)	Keiron Brown	23/04/2024	10

A total of 22 learner days were completed across the two in-person training courses.

The **Earthworm Biology & Ecology** course started in the classroom, explaining what earthworms are, their place in the tree of life, and key aspects of their biology, including the life cycle. It also covered earthworm diversity, earthworms' roles as ecosystem engineers and threats to British species. Learners were taught how to classify British earthworms into ecological groups based on colour and size, then applied these skills during an afternoon field session.

The **Earthworm Identification with Microscopes** course began with an introduction to annelid taxonomy and the key features used to identify British earthworms, followed by a microscope activity to build confidence in their use. The remainder of the course was spent with learners building guidance identifying specimens using a curated collection covering many British species throughout the day. All identifications were checked by the tutor.

A total of 915 webinar spaces were booked and there were 349 live attendees. All of those booked received an email directing them to the webinar recordings so that those unable to attend the live event could catch up at a time that was convenient to them. As of 29th December 2025, the webinar recordings have achieved a combined total of over 8,600 views on YouTube, with the Introduction to Earthworms video proving particularly popular.

6 Hay meadow soil pit survey transects

This survey involved undertaking soil pit survey transects at sites across the Forest of Bowland and Westmorland Dales in various stages of hay meadow restoration, ranging from potential sites that were yet to begin undertaking hay meadow restoration measures through to sites that have been undergoing restoration for up to 10 years.

6.1 Methodology

Sampling was undertaken during spring (April/May) each year for 3 years (2023, 2024 and 2025) in the Forest of Bowland, and during May 2025 in the Westmorland Dales. A total of 25 fields, across 16 sites, were surveyed at least once during the three years. Three fields were sampled during two of the three years, and four fields were surveyed during all three years of the survey.

Control sites for both pasture and species-rich grassland were also surveyed. Hereafter, the acronym CP is used to refer to control sites for pasture and the acronym CG is used to refer to control sites for species-rich grassland.

A full list of the fields surveyed during this project, organised by region and site, is provided in Table 2 below.

Table 2: Details of the survey sites and fields sampled within this project.

Region		Site Code and Name		Field Code and Name		Years Surveyed			Restoration Start Year
B	Forest of Bowland	**BA**	Cockshots Farm	**BAA**	Top Row Field	1	2	3	CP
				BAB	Wildflower Meadow	1	2	3	2018
		BB	Crook o' Lune	**BBA**	Hermitage Field Community Meadow	1	2	3	2020
				BBB	Life 4 Life Community Meadow	1	2	3	2017
		BC	Botton Head	**BCA**	Midge Holme	1		3	CG
				BCB	The Barn Field		2	3	2023
				BCC	The Middle One		2	3	2023
		BD	Field Head Farm	**BDA**	Field Head Farm	1			CG
		BE	Little Middop Farm	**BEA**	Little Middop Farm	1			2023
		BF	New Laithe	**BFA**	New Laithe	1			2015
		BG	The Inn at Whitewell	**BGA**	The Inn at Whitewell	1			2013
		BH	Briercliffe Farm	**BHA**	Wildflower Meadow		2		2022
		BI	Cobble Hey	**BIA**	Cobble Hey		2		2022
		BJ	Lower Lythe	**BJA**	Lower Lythe		2		CG
		BK	Studio Bakery	**BKA**	NE Meadow			3	2020
				BKB	NW Meadow			3	2021
		BL	The Gathering Fields	**BLA**	Brenda's Meadow			3	2019
W	Westmorland Dales	**WA**	Bowber Head	**WAA**	Big Bottom			3	2021
				WAB	Capsticks			3	Control
				WAC	High Burnhills			3	Control
		WB	Bowderdale Beck	**WBA**	Beckside Meadow			3	2019
				WBB	Muddybeck Meadow			3	2023
		WC	Little Asby Common	**WCA**	Mazonwath			3	2022
		WD	Low Greenside Farm	**WDA**	East Meadow			3	Control
				WDB	West Meadow			3	2025

CG = Control site for species-rich grassland habitat. CP = Control site for pasture habitat.

Each transect was assigned a 4-digit reference code relating to the location of the transect (in terms of region, site and field locations) and the year the survey was undertaken (see Figure 4).

B	C	B	3
Region (e.g. B refers to Forest of Bowland and W refers to Westmorland Dales)	Site (each site within a given region is allocated a consecutive letter)	Field (each field within a given site is allocated a consecutive letter)	Year Surveyed (each consecutive survey year is allocated a number, with 1 indicating 2023)

Figure 4: Transect code structure using the example transect code BCB3.

36 soil pit survey transects were undertaken in total. Details of the location and dates of these surveys are provided in **Table 3** below. The number of years that each transect site had been undergoing restoration at the point of sampling was recorded for future analysis.

Table 3: Details of the transects undertaken during this survey.

Transect Code	Transect Name	Survey Date	Grid Reference	Years in restoration
BAA1	Cockshots Farm (Top Row Field)	17/05/2023	SD778379	CP
BAA2	Cockshots Farm (Top Row Field)	23/04/2024	SD778379	CP
BAA3	Cockshots Farm (Top Row Field)	07/05/2025	SD778379	CP
BAB1	Cockshots Farm (Wildflower Meadow)	17/05/2023	SD778378	5
BAB2	Cockshots Farm (Wildflower Meadow)	23/04/2024	SD778378	6
BAB3	Cockshots Farm (Wildflower Meadow)	07/05/2025	SD778378	7
BBA1	Crook o' Lune (Hermitage Field)	03/05/2023	SD521649	3
BBA2	Crook o' Lune (Hermitage Field)	25/04/2024	SD521648	4
BBA3	Crook o' Lune (Hermitage Field)	08/05/2025	SD521649	5
BBB1	Crook o' Lune (Life 4 Life)	03/05/2023	SD523645	6
BBB2	Crook o' Lune (Life 4 Life)	25/04/2024	SD522644	7
BBB3	Crook o' Lune (Life 4 Life)	08/05/2025	SD522644	8
BCA1	Botton Head (Midge Holme)	16/05/2023	SD651639	CG
BCA3	Botton Head (Midge Holme)	09/05/2025	SD651638	CG
BCB2	Botton Head (The Barn Field)	24/04/2024	SD654632	1
BCB3	Botton Head (The Barn Field)	09/05/2025	SD654633	2
BCC2	Botton Head (The Middle One)	24/04/2024	SD653635	1
BCC3	Botton Head (The Middle One)	09/05/2025	SD653635	2
BDA1	Field Head Farm	03/05/2023	SD726521	CG
BEA1	Little Middop Farm	16/05/2023	SD839457	0
BFA1	New Laithe	17/05/2023	SD702487	8
BGA1	The Inn at Whitewell	16/05/2023	SD657467	10
BHA2	Briercliffe Farm (Wildflower Meadow)	25/04/2024	SD846415	2
BIA2	Cobble Hey	23/04/2024	SD537451	2
BJA2	Lower Lythe	24/04/2024	SD662631	CG
BKA3	Studio Bakery (NE Meadow)	07/05/2025	SD792493	5
BKB3	Studio Bakery (NW Meadow)	07/05/2025	SD791492	4
BLA3	The Gathering Fields (Brenda's Meadow)	08/05/2025	SD537528	6
WAA3	Bowber Head (Big Bottom)	21/05/2025	NY734034	4
WAB3	Bowber Head (Captsicks)	21/05/2025	NY735032	CP
WAC3	Bowber Head (High Burnhills)	21/05/2025	NY739035	CG
WBA3	Bowderdale Beck (Beckside Meadow)	22/05/2025	NY677048	6
WBB3	Bowderdale Beck (Muddy Beck Meadow)	22/05/2025	NY678047	2
WCA3	Little Asby Common (Mazonwath)	22/05/2025	NY686083	3
WDA3	Low Greenside Farm (East Meadow)	23/05/2025	NY716041	CP
WDB3	Low Greenside Farm (West Meadow)	23/05/2025	NY717041	0

Each transect consisted of 5 soil pits, selected at random points across the sample site. The National Earthworm Recording Scheme guidance on soil pit sampling (Brown, Earthworm Recorders Handbook [Version 8], 2019) was followed as outlined below.

6.1.1 For each soil pit

1. A soil pit measuring approximately 25 × 25 cm was excavated to a depth of around 25 cm. The base and sides of each pit were checked to ensure no earthworms remained within the excavation.

2. Excavated soil was transferred to a sorting tray for inspection.

3. Adult earthworms located within the soil were removed and placed into labelled sample tubes.

4. Juvenile earthworms were returned to the soil pit, and the number of individuals returned was recorded.

5. Following hand-sorting, the soil was returned to the pit and compacted to restore a level surface and prevent trip hazards.

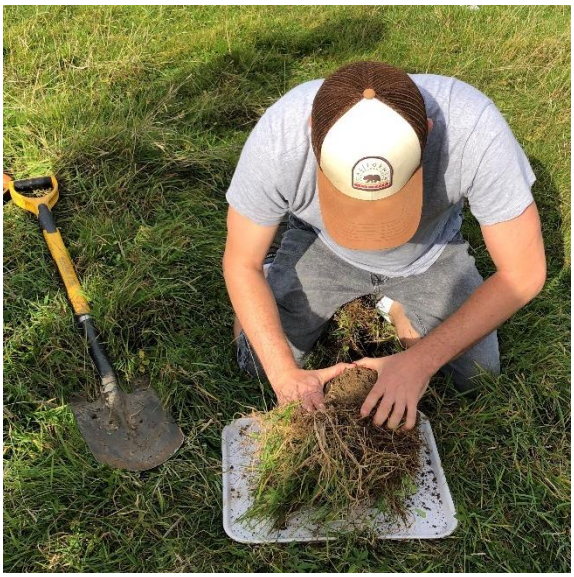

Figure 5: Hand-sorting of excavated soil for earthworms. Image: Anna Rebmann.

6.1.2 For each transect

1. Five replicate soil pits were excavated within the same 100 m OS grid square.

2. A Soil Pit Survey Form was completed, recording the sampling date, transect code (e.g. BCB3), name of the field and location (e.g., Wildflower Meadow, Cockshots Farm), name of the lead surveyor (recorder name), 6-figure OS grid reference, habitat, number of soil pits sampled (i.e. 5) and any other notes regarding the sampling site.

3. Collected earthworms were examined and identified, where possible, using a microscope and the Key to the Earthworms of the UK & Ireland (2nd Edition). Where specimens were not originally identified by Keiron Derek Brown, they were checked and species determination verified by Keiron Derek Brown.

4. The total number of unidentified earthworms was calculated by combining the number of unidentifiable specimens in the sample tubes with the number of individuals returned directly to the soil during fieldwork.

5. Data for each site was submitted to the National Earthworm Recording Scheme via the Soil Pit Survey Form on iRecord. All records were subsequently verified and accepted into the National Earthworm Recording Scheme in accordance with its verification protocol (Brown, Verification, 2022).

Soil Pit Survey Form

Biological Recording Company

Field Data (transects)	
Date: *(dd/mm/yyyy)*	Sample Code:
Site Name:	Grid Reference:
Habitat:	Habitat Notes:
No. of Soil Pits Sampled:	Recorder Name(s):
Location Notes:	

Field Counts (earthworms returned to the soil)			
Soil Pit No.:	Count	Soil Pit No.:	Count
01		06	
02		07	
03		08	
04		09	
05		10	

Species Counts (total)			
Species	Quantity	Species	Quantity
		Unidentified	

Figure 6: Soil Pit Survey Form used to record sample site details and number of unidentified earthworms returned to the soil.

6.2 Limitations of the survey methodology

1. **Patchy earthworm distributions**: Soil conditions can vary greatly within a single site, and are known to have a significant influence on earthworm populations. It is therefore recommended that more than 5 sample points per site are surveyed to gather robust data to inform any conclusions regarding earthworm abundance and diversity at any given location. The budget and capacity for this survey were limited so it was decided to opt for a lower number of replicates per site in order to gather data on a larger number of sites.

2. **Inter-annual and seasonal variation**: Weather can exert consider influence on earthworm surveying as it has a direct impact on soil conditions, particularly soil moisture. Survey results may need to be taken in context with seasonal and annual weather cycles. It is recommended that sites are surveyed multiple times, across seasons and over a period of at least 3 years to gather robust data to inform any conclusions regarding earthworm abundance and diversity at any given location.

3. **Sampling method biases**: Soil pit surveying is effective for extracting many earthworm species and can easily be standardised and used to gain good quantitative data for research. However, as a sampling method, it is biased towards soil-dwelling species (particularly shallow bioturbators) and less effective than mustard sampling for extracting deep-burrowing species (such as burrowers and intense tunnelers) and surface-dwelling species (litter dwellers).

6.3 Survey results

A total of 2,433 individual earthworms were recorded across the 36 transects. Of these specimens, 636 were identifiable to species level.

Earthworm abundance varied widely across the surveyed transects (see **Table 4**), ranging from very low counts of fewer than 10 individuals to a peak count of 180 individuals per transect. The highest abundances were recorded at Cockshots Farm (Wildflower Meadow) and Cockshots Farm (Top Row Field), while the lowest recorded abundances were at Bowber Head (High Burnhills) and Bowderdale Beck (Muddy Beck Meadow).

Species richness showed a narrower but nevertheless notable spread, ranging from zero to seven species across all transects (see **Table 4)**. Most sites supported between three and six species, with the highest richness values recorded at Cockshots Farm (Top Row Field), Cockshots Farm (Wildflower Meadow), and Little Middop Farm. Transects with no identifiable earthworm species were limited to a small number of sites, and occurred in both restored and non-restored fields.

6.3.1 Years in restoration

It was originally intended to assess the impact of the number of years in restoration on earthworm populations by analysing the earthworm abundance and species richness results. However, there was a noticeable drop in both the number of earthworms recorded and the number of species recorded by site during the 2025 survey period. The soil conditions across survey sites were also noticeably drier than in previous years (likely due to a prolonged period without substantial rainfall preceding the surveys).

Therefore, it was decided to first evaluate whether earthworm abundance and species richness varied across years (2023–2025) in general, as was recently reported in another earthworm survey undertaken during the same period (Brown, Sapperton Wilder Baseline Earthworm Survey Report, 2025).

In the event of significant differences in earthworm abundance and species richness between years, baseline metrics for future comparisons will be calculated using the results to date (see Conclusions section).

Table 4: Summary of earthworm abundance, species richness and years in restoration by transect.

Transect Code and Name		Earthworm Abundance	Species Richness	Years in Restoration
BAA1	Cockshots Farm (Top Row Field)	139	7	CP
BAB1	Cockshots Farm (Wildflower Meadow)	159	6	5
BBA1	Crook o'Lune (Hermitage Field)	41	2	3
BBB1	Crook o'Lune (Life 4 Life)	51	4	6
BCA1	Botton Head (Midge Holme)	74	4	CG
BDA1	Field Head Farm	139	5	CG
BEA1	Little Middop Farm	64	7	0
BFA1	New Laithe	116	4	8
BGA1	The Inn at Whitewell	58	3	10
BAA2	Cockshots Farm (Top Row Field)	138	6	CP
BAB2	Cockshots Farm (Wildflower Meadow)	180	7	6
BBA2	Crook o'Lune (Hermitage Field)	102	5	4
BBB2	Crook o'Lune (Life 4 Life)	90	6	7
BCB2	Botton Head (The Barn Field)	97	6	1
BCC2	Botton Head (The Middle One)	14	4	1
BHA2	Briercliffe Farm (Wildflower Meadow)	100	5	2
BIA2	Cobble Hey	127	6	2
BJA2	Lower Lythe	144	6	CG
BAA3	Cockshots Farm (Top Row Field)	50	1	CP
BAB3	Cockshots Farm (Wildflower Meadow)	45	2	7
BBA3	Crook o' Lune (Hermitage Field)	11	2	5
BBB3	Crook o' Lune (Life 4 Life)	64	5	8
BCA3	Botton Head (Midge Holme)	26	5	CG
BCB3	Botton Head (The Barn Field)	31	3	2
BCC3	Botton Head (The Middle One)	32	5	2
BKA3	Studio Bakery (NE Meadow)	55	3	5
BKB3	Studio Bakery (NW Meadow)	49	2	4
BLA3	The Gathering Fields (Brenda's Meadow)	49	3	6
WAA3	Bowber Head (Big Bottom)	31	3	4
WAB3	Bowber Head (Captsicks)	32	2	CP
WAC3	Bowber Head (High Burnhills)	8	1	CG
WBA3	Bowderdale Beck (Beckside Meadow)	23	1	6
WBB3	Bowderdale Beck (Muddy Beck Meadow)	17	0	2
WCA3	Little Asby Common (Mazonwath)	24	0	3
WDA3	Low Greenside Farm (East Meadow)	32	1	CP
WDB3	Low Greenside Farm (West Meadow)	21	0	0

6.3.2 Interannual Variation

To test for significant variation between years, Generalised Estimating Equations (GEEs) were used. This approach appropriately:

- Includes **all available transect data** rather than only sites sampled repeatedly.
- Accounts for **non-independence of repeated observations** at the same sites.
- Uses distribution-appropriate models for count data:
  - **Negative binomial GEE** for total earthworm counts (see Box 1).
  - **Poisson GEE** for species diversity (see Box 2).
- Field location was used as the clustering variable to adjust standard errors for repeated sampling where it occurred.

Statistical analysis: Earthworm abundance by year
Test: Negative binomial GEE (log link), Year as predictor, field clusters.

Overall effect of year:

- **Wald $\chi^2(2) = 33.88$**
- **p = 0.0000000440** (p<0.001 Extremely significant)

Pairwise year comparisons (model-based contrasts, Holm-adjusted).

Comparison	Effect	Adjusted p-value	
2024 vs 2023	~20% increase	p = 0.214	(p≥0.05 Not significant)
2025 vs 2023	~60% decrease	p = 0.0000076	(p<0.001 Extremely significant)
2025 vs 2024	~66% decrease	p = 0.000000023	(p<0.001 Extremely significant)

Box 1: Statistical analysis summary for earthworm abundance data.

A negative binomial GEE revealed there is a highly significant association between survey year and total earthworm abundance across the dataset. This means that the differences in earthworm counts among years are unlikely to be due to chance, even after accounting for repeated site sampling.

Pairwise year comparisons (Holm-adjusted) showed that earthworm abundance was similar between 2023 and 2024. 2025 had significantly lower abundance than both 2023 and 2024, with counts roughly 2.5–3 times lower.

Statistical analysis: Species richness by year
Test: Poisson GEE (log link), Year predictor, field clusters.

Overall effect of year:

- **Wald $\chi^2(2) \approx 13.6$**
- **p ≈ 0.001** (p<0.01 Highly significant)

Pairwise year comparisons (model-based contrasts, Holm-adjusted).

Comparison	Effect	Adjusted p-value	
2024 vs 2023	~21% increase	p = 0.077	(p≥0.05 Not significant)
2025 vs 2023	~47% decrease	p ≈ 0.001	(p<0.01 Highly significant)
2025 vs 2024	~62% decrease	p < 0.01	(p<0.01 Highly significant)

Box 2: Statistical analysis summary for species richness data.

A Poisson GEE revealed that year had a statistically significant effect on the number of earthworm species recorded per transect, indicating real temporal variation in species richness across the survey period after accounting for repeated sampling at some sites.

Pairwise year comparisons (model-based contrasts, Holm-adjusted)showed that species richness was slightly higher in 2024 than in 2023, but this difference was not statistically significant after adjustment for multiple comparisons. 2025 showed a pronounced and statistically significant reduction in species richness compared with both 2023 and 2024, with less than half the number of earthworm species recorded in earlier years.

In summary, Generalised Estimating Equations revealed no significant differences between 2023 and 2024 for either earthworm abundance or species richness, but both metrics declined sharply and significantly in 2025, with reductions of approximately 60–66% in abundance and 47–62% in species richness relative to earlier years.

Such pronounced year-to-year variation is typical of earthworm communities and reflects the sensitivity of earthworms to environmental conditions, particularly soil moisture and temperature during the spring sampling period.

Differences in spring weather conditions provide a strong explanatory framework for the observed patterns:

- **Spring 2023** was broadly near average in terms of temperature and rainfall (Met Office, 2023). These conditions are likely to have supported moderate earthworm activity but may have limited surface movement during sampling, resulting in relatively low recorded abundance and diversity.
- **Spring 2024** followed an exceptionally wet winter and was both warmer and wetter than average (Met Office, 2024). Soils are likely to have remained moist throughout the sampling period, creating highly favourable conditions for earthworm activity, feeding and surface movement. This provides a robust explanation for the increased abundance and species richness recorded across sites in 2024
- **Spring 2025** was characterised by warmer, drier and sunnier conditions, leading to reduced soil moisture during sampling (Met Office, 2025). Under such conditions, earthworms typically retreat deeper into the soil profile, reducing detectability in shallow soil pits. This is consistent with the observed decline in abundance and species richness relative to previous sampling years.

This combined evidence strongly supports the conclusion that **interannual weather variability has influenced earthworm communities in these meadows**, alongside any habitat restoration effects. It is therefore important to ensure that some sites are monitored annually to ensure that interannual variability due to weather can be detected, so it is recommended that 8 sites are monitored on an annual basis going forward.

6.3.3 Species composition

A total of 14 different earthworm species were recorded across the sites out of a total of 33 species known to occur in the UK and Ireland. 7 of the 9 species recorded are classed as very common or common, one species is regarded as uncommon, and one species is regarded as rare.

All of the species detected at the control sites were also detected at at least one of the hay meadow restoration sites.

Table 5 on the following page presents the earthworm species data by transect for all 3 years of the survey.

A summary of the species recorded through the hay meadow soil pit survey transects is provided in **Table 6**, including notes on functional group, rarity and habitat specificity (Ashwood, et al., 2024) (Bottinelli, Hedde, Jouquet, & Capowiez, 2020) (Hoeffner, et al., 2022) (Brown, UK Earthworm Provisional Conservation Status Assessment Report, in prep).

A species-by-species summary is provided following Table 4 and Table 5. Where these descriptions reference National Earthworm Recording Scheme data, refer to the References section for lists of the occurrence datasets used to establish any statistics referenced.

Table 5: Breakdown of earthworm species recorded by transect.

	Species														
Transect	*Allolobophora chlorotica*	*Allolobophora icterica*	*Aporrectodea caliginosa*	*Aporrectodea limicola*	*Aporrectodea longa*	*Aporrectodea rosea*	*Eiseniella tetraedra*	*Lumbricus castaneus*	*Lumbricus festivus*	*Lumbricus rubellus*	*Lumbricus terrestris*	*Octolasion cyaneum*	*Octolasion lacteum*	*Satchellius mammalis*	Unidentified
BAA1	25		4	8	2		1	1						1	97
BAB1	13		7	24	4				3					3	105
BBA1			3									1			37
BBB1	1	3	5									2			40
BCA1	11						1			1			5		56
BDA1	16		1		1	2					1				118
BEA1	2		8			1				3	1	4		1	44
BFA1	15		5			1					1				94
BGA1	2		1					1							54
BAA2	8		3	12	11	1								1	102
BAB2	19		2	11	3	4				1				5	135
BBA2	3	1	6	15						2					75
BBB2		13	9	5	2					1				1	59
BCB2	18		1			4				1	1	3			69
BCC2	4					2		1		1					6
BHA2	38		1		7	4	2								48
BIA2	18		14	3	1	3				1					87
BJA2	15		18			7				2		1	1		100
BAA3	10														40
BAB3	2			2											41
BBA3	1									1					9
BBB3	2	2	1			8								2	49
BCA3	6		3		2			1				1			13
BCB3	9		3	1											18
BCC3	8					2		1		1			2		18
BKA3	5			1		4									45
BKB3	5			5											39
BLA3	9		1			2									37
WAA3	16		2			1									12
WAB3	3					1									28
WAC3	1														7
WBA3	1														22
WBB3															17
WCA3															24
WDA3	1														31
WDB3															21

Table 5: Breakdown of earthworm species recorded by transect.

	Species													
Transect	*Allolobophora chlorotica*	*Allolobophora icterica*	*Aporrectodea caliginosa*	*Aporrectodea limicola*	*Aporrectodea longa*	*Aporrectodea rosea*	*Eiseniella tetraedra*	*Lumbricus castaneus*	*Lumbricus festivus*	*Lumbricus rubellus*	*Lumbricus terrestris*	*Octolasion cyaneum*	*Octolasion lacteum*	*Satchellius mammalis*	Unidentified
BAA1	25		4	8	2		1	1						1	97
BAB1	13		7	24	4				3					3	105
BBA1			3									1			37
BBB1	1	3	5									2			40
BCA1	11						1			1			5		56
BDA1	16		1		1	2					1				118
BEA1	2		8			1				3	1	4		1	44
BFA1	15		5			1					1				94
BGA1	2		1					1							54
BAA2	8		3	12	11	1								1	102
BAB2	19		2	11	3	4				1				5	135
BBA2	3	1	6	15						2					75
BBB2		13	9	5	2					1				1	59
BCB2	18		1			4				1	1	3			69
BCC2	4					2		1		1					6
BHA2	38		1		7	4	2								48
BIA2	18		14	3	1	3				1					87
BJA2	15		18			7				2		1	1		100
BAA3	10														40
BAB3	2			2											41
BBA3	1									1					9
BBB3	2	2	1			8								2	49
BCA3	6		3		2			1				1			13
BCB3	9		3	1											18
BCC3	8					2		1		1			2		18
BKA3	5			1		4									45
BKB3	5			5											39
BLA3	9		1			2									37
WAA3	16		2			1									12
WAB3	3					1									28
WAC3	1														7
WBA3	1														22
WBB3															17
WCA3															24
WDA3	1														31
WDB3															21

Table 6: Summary of earthworm species recorded within this survey.

Species	Functional group (ecological category)	Distribution	Habitat specificity	Rarity
Allolobophora chlorotica	Shallow bioturbator (Epi-endogeic) [3]	Widespread	Low	Very common
Allolobophora icterica	Deep bioturbator (Hypo-endogeic) [3]	Restricted	High	Rare
Aporrectodea caliginosa	Shallow bioturbator (Epi-endogeic) [1 4]	Widespread	Low	Very common
Aporrectodea limicola	Shallow bioturbator (Epi-endogeic) [4]	Restricted	High	Rare
Aporrectodea longa	Intense tunneler (Anecic) [2]	Widespread	Low	Common
Aporrectodea rosea	Shallow bioturbator (Epi-endogeic) [1 4]	Widespread	High	Rare
Eiseniella tetraedra	Litter dweller (Epigeic) [1 3]	Widespread	Low	Common
Lumbricus castaneus	Litter dweller (Epigeic) [1 3]	Widespread	Low	Common
Lumbricus festivus	Burrower (Epi-anecic) [1]	Moderately widespread	Moderate	Uncommon
Lumbricus rubellus	Litter dweller (Epigeic) [1 3]	Widespread	Low	Common
Lumbricus terrestris	Burrower (Epi-anecic) [1 2 3]	Widespread	Moderate	Common
Octolasion cyaneum	Deep bioturbator (Hypo-endogeic) [3]	Widespread	Low	Common
Octolasion lacteum	Deep bioturbator (Hypo-endogeic) [4]	Moderately widespread	Moderate	Uncommon
Satchellius mammalis	Litter dweller (Epigeic) [3]	Moderately widespread	Low	Uncommon

[1] Ecological category is based ecological category model presented in Bottinelli et al 2020.
[2] Functional group is based on categories provided in Hoeffner et al 2022.
[3] Functional group is based categories provided in Capowiez et al 2024.
[4] Functional group estimated based on the author's experience.

Allolobophora chlorotica (**Figure 7**) was by far the most recorded species across most sites (accounting for 45% of all adult earthworms and recorded from 31 out of 36 transects). This shallow bioturbator species is likely the most common species of earthworm within the UK and accounts for 11.4% of all earthworm records submitted to the National Earthworm Recording Scheme. It is disturbance-tolerant, has its optimal conditions in dry soils (Jones & Eggleton, 2014) and is commonly recorded in large numbers (including agricultural soils). It accounted for 61% of all identifiable earthworms in 2025 when soil conditions were noticeably drier than usual. It is one of only 3 species also detected in the Westmorland Dales sites.

Allolobophora icterica (**Figure 7)** is a rare deep bioturbator that prefers grassland habitats, particularly synanthropic sites such as amenity lawns and parks. This species was only detected in hay meadow transects, specifically the two community meadows at the Crook o'Lune.

Aporrectodea caliginosa (**Figure 8**) is a shallow bioturbator and was the second-most recorded species (accounting for 15% of adults and recorded from 21 of 36 transects). Like *A. chlorotica*, it is often abundant at sites where it occurs and is classed as very common. It is also known to be disturbance-tolerant and often recorded in large numbers in agricultural soils. It is one of only 3 species also detected in the Westmorland Dales sites.

Aporrectodea limicola (**Figure 8**) is a rare species that is believed to be a shallow bioturbator. It is a wet soil specialist with a western distribution in the British Isles. The Forest of Bowland may be an important

area nationally for this species, with it detected at 5 of the 12 sites surveyed. This species was only detected in hay meadow and pasture habitats.

Aporrectodea longa (**Figure 9**) is an intense tunneler species, meaning that it is important for soil pore creation and therefore soil aeration and drainage. This species was detected in small numbers at relatively few sites in 2023 and 2025, but was noticeably more widespread and abundant in 2024. It is regarded as a common species and found in a wide range of habitats.

Aporrectodea rosea (**Figure 9**) is another shallow bioturbator species and is considered common. It consisted of around 14% of total adult earthworms and was the third-most abundant species. Like both *A. chlorotica* and *A. caliginosa*, it is also considered disturbance-tolerant and found in a wide range of habitats, including agricultural soils. It is one of only 3 species also detected in the Westmorland Dales sites.

Eiseniella tetraedra (**Figure 10**) is a common and widespread litter dweller that specialises in wet soils, commonly found in wetlands but also other habitats where wet soil conditions are present. This species is morphologically variable, with the position of the male pores and clitellum differing by variant. This species was detected in small numbers (1-2 individuals) at 3 sites (one from each habitat type).

Lumbricus castaneus (**Figure 11**) is commonly found in both the soil and above-ground microhabitats and is categorised as a litter dweller species. It is regarded as a common species and found in a wide range of habitats (including agricultural soils). It was recorded in small numbers at 3 sites and across all habitat types.

Lumbricus festivus is an uncommon burrower species that specialises in damp acidic soils (Sims & Gerard, 1999). It was recorded just at just one site: with 3 individuals recorded from the wildflower meadow at Cockshots Farm (a field undergoing hay meadow restoration that had undergone 5 years of restoration).

Lumbricus rubellus (**Figure 11**) is commonly found in both the soil and above-ground microhabitats, and is categorised as a litter dweller species. It is regarded as a common species and is thought to have the lowest habitat specificity of all UK earthworm species. It has been recorded across hay meadow and species-rich grassland habitats in the Forest of Bowland each year, but was noticeably more widespread in 2024.

Lumbricus terrestris (Figure 12) is the largest species of earthworm occurring in the UK. Single individuals were detected at three sites in 2023 and at one site in 2024. It is a burrower species that creates middens at the entrances to its deep burrows, going down to depths of up to 2.5 metres. It is known to feed on soil throughout the soil profile as well as surface material (such as leaf litter). It is a common species and often found in agricultural soils.

Octolasion cyaneum (Figure 12) is a large species of deep bioturbator that favours damp conditions, with adults found at depths down to 50 cm below the soil surface. Although common, this species can be hard to detect due to its deep burrowing habits. It has been detected at some hay meadow and species-rich grassland transects, but not at any of the pasture transects.

Octolasion lacteum (Figure 13) is also estimated to be a deep bioturbator that prefers wet soils. In comparison to *O. cyaneum*, it is generally smaller, less common, and less likely to be detected in agricultural environments (Ashwood, et al., 2024). It was only detected on 3 occasions (once per year), twice in species-rich grassland habitats and once in a hay meadow (The Middle One at Botton Head). It was not detected in any pasture habitats.

Satchellius mammalis (Figure 13) is another litter dweller that is found in both the soil and above-ground microhabitats. It is regarded as uncommon due to the known distribution being patchy in comparison to that of common species. It was recorded in both pasture and hay meadow habitats, but not from species-rich grassland habitats.

Figure 7: Images of earthworm species. Left image: *Allolobophora chlorotica* © Frank Ashwood https://www.frankashwood.com/. Right image: *Allolobophora icterica*.

Figure 8: Images of earthworm species. Left image: *Aporrectodea caliginosa*. Right image: *Aporrectodea limicola*.

Figure 9: Images of earthworm species. Left image: *Aporrectodea longa*. Right image: *Aporrectodea rosea* © Stephen Barlow.

Figure 10: Images of earthworm species. Left image: *Eiseniella tetraedra* (male pore on 12). Right image: *Eiseniella tetraedra* (male pore on 13).

Figure 11: Images of earthworm species. Left: *Lumbricus castaneus* © Keiron Derek Brown. Right: *Lumbricus rubellus*.

Figure 12: Images of earthworm species. Left: *Lumbricus terrestris*. Right: *Octolasion cyaneum*.

Figure 13: Images of earthworm species. Left: *Octolasion lacteum*. Right: *Satchellius mammalis* © Bob Kemp.

6.3.4 Functional group composition

A breakdown of the percentage of earthworms by functional group and habitat is provided in **Figure 14** below. All five functional groups were represented within the data collected from this survey in both the hay meadow and species-rich grassland habitats, whereas only three of the five functional groups were detected at pasture sites.

Shallow bioturbators comprised the majority of the adult earthworms collected (>80%). Soil pit sampling transects can cause biases towards the detection of these species, so a high representation of this functional group is expected. This functional group was represented by 4 species, including one rare species. The proportion of shallow bioturbators was consistent across all habitat types.

Both intense tunnelers and litter dwellers were also detected across all habitat types. **Litter dwellers** were relatively well represented, considering that soil pit surveying is not optimal for detecting species from this group. A total of 4 species of litter dweller were detected, with at least 3 species detected for each habitat type. Intense tunnelers were represented by a single species, though it should be noted that the UK only has one common species of this group, and this group was particularly well represented within the pasture habitat (14%).

No **burrowers** or **deep bioturbators** were detected within the pasture control sites, but were both detected at the hay meadow and species-rich grassland sites. This suggests that the transition from pasture to hay meadow diversifies the earthworm functional group composition.

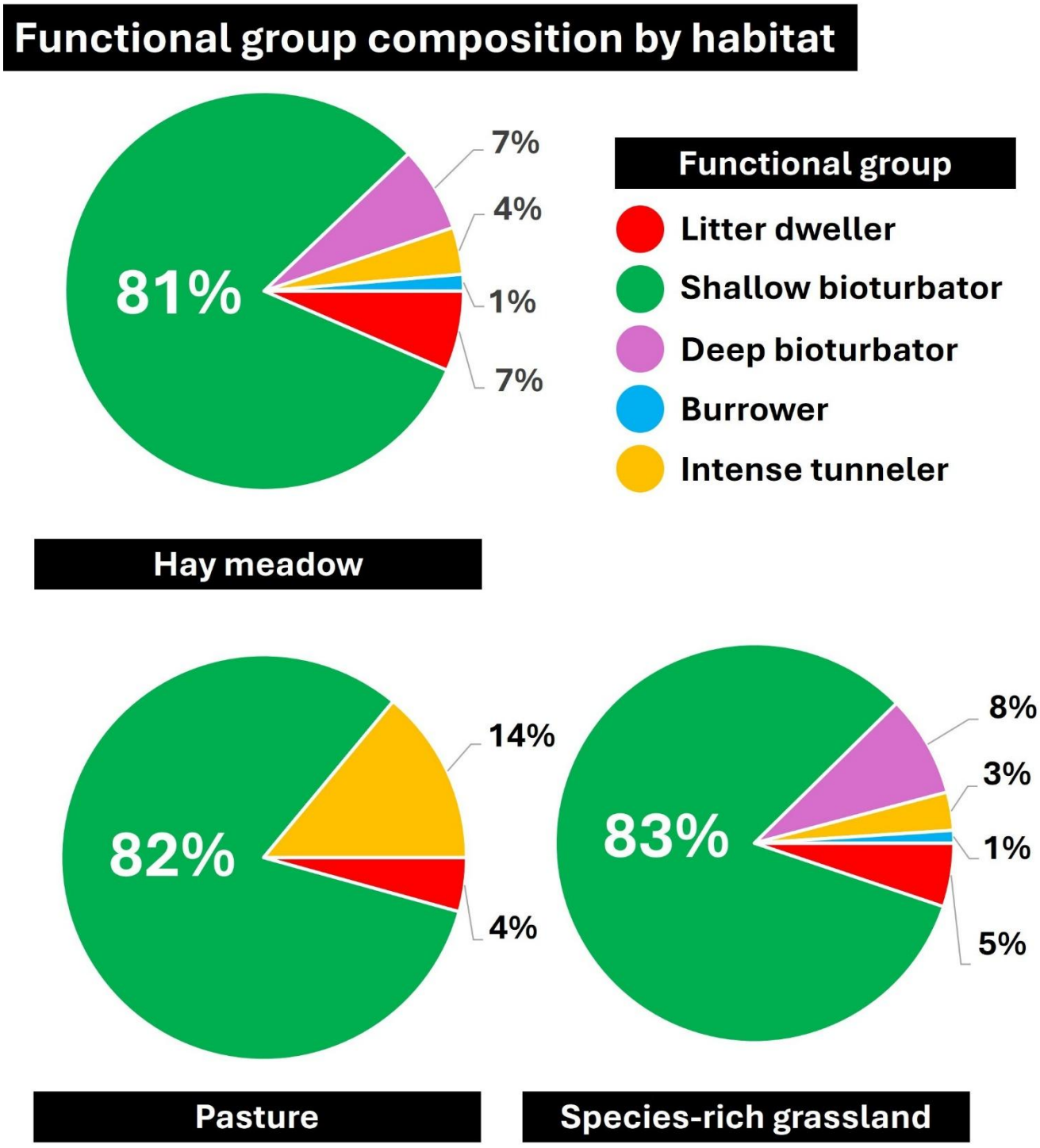

Figure 14: Pie chart displaying the composition of earthworms detected by functional group and habitat. Pie chart slice colours indicate the functional group of the represented species. Hay meadow (n=446). Pasture (n = 93). Species-rich grassland (n=97).

7 Earthworm Microhabitat Searches

This survey involved searching a range of above-ground habitats for earthworms to establish the presence of earthworm species less likely to be detected through soil pit sampling.

7.1 Methodology

Any adult earthworms that were found through additional searches were collected into a labelled sample tube for each different location, sampling method and habitat. A total of 11 microhabitat searches were undertaken that resulted in the collection of identifiable earthworm specimens (see **Table 7** for more details).

Table 7: Details of earthworm microhabitat searches undertaken as part of this study.

Site		Microhabitat Searched	Survey Date	Grid Reference
X1	Gisburn Forest	Grassland soil	03/05/2023	SD746560
X1	Gisburn Forest	Bog area soil	03/05/2023	SD746559
X1	Gisburn Forest	Under moss on wood	03/05/2023	SD746560
X1	Gisburn Forest	Inside deadwood	03/05/2023	SD746560
X1	Gisburn Forest	Under stone	03/05/2023	SD746560
BAB	Cockshots Farm (Wildflower Meadow)	Under deadwood	17/05/2023	SD778378
BBA	Crook o' Lune (Hermitage Field)	Base of the hedgerow soil	03/05/2023	SD521649
BBB	Crook o' Lune (Life 4 Life)	Molehill	03/05/2023	SD522644
BBB	Crook o' Lune (Life 4 Life)	Decaying grass clippings	03/05/2023	SD523645
BCA	Botton Head (Midge Holme)	Under stones in river	23/04/2024	SD651638
BIA	Cobble Hey	Compost	23/04/2024	SD535449

7.1.1 For each microhabitat search

1. Biological recording forms were completed for each record, including the following information: sampling date, name of the location, name of the recorder, 6-figure OS grid reference, habitat, sampling method and any other notes relevant to the record.

2. All earthworm specimens were examined and identified by Keiron Derek Brown using a microscope and the Key to the Earthworms of the UK & Ireland (2nd Edition).

3. The data for each record was submitted to the National Earthworm Recording Scheme via iRecord. All records have since been accepted into the National Earthworm Recording Scheme and have passed the National Earthworm Recording Scheme verification protocol (Brown, Verification, 2022).

7.2 Limitations of the survey methodology

1. Comprehensive earthworm surveys were not undertaken, so the resulting records only convey the confirmed presence of a species and do not infer absence.

7.3 Results

A total of 47 adult earthworms were recorded through microhabitat searches. Of the 14 species recorded through microhabitat searches, 4 species were unique to this sampling method (i.e. not detected within the soil pit survey transects). A breakdown of the species detected by each microhabitat search can be found in Table 8 and a summary of those species is provided in Table 9.

Table 8: Earthworm species detected through microhabitat searches.

Site	Microhabitat searched	*Allolobophora chlorotica*	*Aporrectodea caliginosa*	*Aporrectodea limicola*	*Aporrectodea longa*	*Aporrectodea rosea*	*Bimastos eiseni*	*Bimastos rubidus*	*Dendrobaena attemsi*	*Eisenia andrei/fetida agg.*	*Eiseniella tetraedra*	*Lumbricus castaneus*	*Lumbricus festivus*	*Lumbricus rubellus*	*Octolasion cyaneum*
X1	Grassland soil	X													
X1	Bog area soil	X							X						
X1	Under moss on wood						X	X							
X1	Inside deadwood							X							
X1	Under stone		X			X									
BAB	Under deadwood							X					X	X	
BBA	Base of the hedgerow soil	X	X			X									X
BBB	Molehill											X			
BBB	Decaying grass clippings							X			X			X	
BCA	Under stones in river	X	X	X	X						X				
BIA	Compost				X					X					

Table 9: Summary of earthworm species recorded through microhabitat surveys and not recorded through the hay meadow soil pit surveys.

Species	Functional group (ecological category)	Distribution	Habitat specificity	Rarity
Bimastos eiseni *	Litter dweller (Epigeic) [1]	Widespread	Moderate	Common
Bimastos rubidus *	Litter dweller (Epigeic) [1]	Moderately widespread	Moderate	Uncommon
Dendrobaena attemsi	Litter dweller (Epigeic) [1]	Moderately widespread	Moderate	Uncommon
Eisenia andrei/fetida agg.	Litter dweller (Epigeic) [1 3]	Moderately widespread	High	Uncommon

[1] Ecological category is based ecological category model presented in Bottinelli et al 2020.
[3] Functional group is based categories provided in Capowiez et al 2024.
*** non-native species to the United Kingdom and Ireland.**

Bimastos eiseni is a non-native litter dweller originating from North America that is thought to have been long-established in the UK. It is considered uncommon and found within or above the top layer of soil, often associated with saproxylic microhabitats, including arboreal niches such as under bark and in rot holes. It was detected under moss on deadwood at Gisburn Forest.

Bimastos rubidus is a non-native litter dweller from North America that is long-established in the UK. It is common and widespread, found in a wide range of habitats, through only occasionally recorded from agricultural habitats. It was recorded from 3 sites and a range of microhabitats.

Dendrobaena attemsi is a litter dweller that prefers acidic soils, found within or above the top layer of the soil. It is possibly a recent introduction from continental Europe, though it is not known when it first established in the UK. It was recorded from within soil in a boggy area at Gisburn Forest.

Eisenia fetida is a litter dweller that specialises in microhabitats with high organic content, such as compost, dung and deadwood. It was recorded from compost at Lower Lythe.

8 Conclusions

Following three years of surveying, this project has developed a baseline dataset for assessing the impact of hay meadow restoration on earthworm communities. Review and analysis of this data has highlighted some recommendations for future surveys to improve the quality of the dataset and enable more robust analysis.

8.1 Inter-annual variation

Overall, the results suggest that weather-driven detectability and activity effects are likely to have played a major role in shaping the observed inter-annual differences.

To better equip the project to assess inter-annual variation effects, **it is recommended that a minimum of 8 transects are repeated annually**. This should include at least one site from each control group (pasture and species-rich grassland), and 6 sites undergoing hay meadow restoration.

To define baseline values for comparing the earthworm communities of sites under hay meadow restoration with pasture (pre-restoration habitat) and species-rich grassland (post-restoration habitat) habitats, the results of all sites have been averaged for each habitat type (see Table 10). The 2025 data were not used in these calculations due to both earthworm abundance and species richness results for this year showing a significant inter-annual difference from both 2023 and 2024.

Table 10: List of baseline values based on this study for various earthworm metrics.

Earthworm metric for comparison	Baseline value
Earthworm Abundance Hay Meadow	92.2
Earthworm Abundance Control Pasture	138.5
Earthworm Abundance Control Species-rich Grassland	119.0
Earthworm Species Richness Hay Meadow	5.0
Earthworm Species Richness Pasture	6.5
Earthworm Species Richness Control Species-rich Grassland	5.0

8.2 Control sites

Differences in earthworm abundance, earthworm species richness, earthworm species composition and earthworm functional group composition between pasture and species-rich grassland are relatively poorly understood, making it difficult to assess the impact of hay meadow restoration on earthworm communities.

Preliminary results indicate that functional group composition may improve through hay meadow restoration, though the impacts on species composition, species richness and earthworm abundance are less clear.

The inclusion of a single pasture field within the survey dataset is particularly limiting, **and it is recommended that at least 2 fields are surveyed each year from each control group**.

8.3 Future surveys

Funding for this project has been confirmed for 2026, and will involve 5 days of surveying (3 days in the Forest of Bowland and 2 days in the Westmorland Dales/Yorkshire Dales). As with previous years, all surveying will be undertaken during spring.

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