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Diversity, abundance, and distribution of ground invertebrates in Lower Sharpham Farm

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Abstract

Invertebrates constitute the largest group of animals on Earth and represent the bulk of biodiversity. They are responsible for numerous essential ecosystems services and are at the centre of many terrestrial food webs. Due to habitat loss from land use change and conversion to intensive agriculture, they are experiencing a substantial decline in biodiversity, hence conservation approaches such as rewilding have been sought. There are limited studies of invertebrate biodiversity in rewilding projects, therefore the aim of this study is to investigate the diversity and abundance of ground invertebrates at Lower Sharpham Farm and the influences of vegetation structure in a rewilded field and a farmed field. 18 pitfall traps were installed in each field divided into 3 groups of 6 and were left outside for 5 days. After collection, 856 invertebrates were found and identified in the laboratory. During that period, a vegetation survey was also carried out. Results within rewilded field indicate that group 1 showed to have a higher invertebrate abundance (n=205) and species richness (n=15) with higher biodiversity index (H=1.88). Results within farmed field indicate that the area in group 1 showed to have a higher invertebrate abundance (n=124) while group 3 had a higher species richness (n=13) with a higher biodiversity index result (H=2.12). Results between fields comparison indicate that rewilded fields increase invertebrate abundance (n=559), though grazing in farmed fields has little effect on invertebrate richness but decreases abundance (n=297). Farmed field had a slightly higher biodiversity index result (H=1.87) compared to rewilded field (H=1.82) due to the high dominance of springtails (Entomobryomorpha). This study determines that rewilding works as a tool for promoting invertebrate abundance and that organic farms have a positive impact on invertebrate diversity. Overall, long-term regular monitoring is needed to evaluate the success of rewilding for biodiversity overtime. The outcomes of the study not only evidence the importance of rewilding for invertebrate conservation but also the importance of low intensive agriculture practices for biodiversity.

Keywords: Ground invertebrates, rewilding, organic farm, invertebrate biodiversity, invertebrate conservation, low intensive agriculture, invertebrate monitoring, grazing, ecological restoration.

Introduction

Invertebrates are the largest and most diverse group within the animal kingdom and are essential for healthy functioning ecosystems. They are key components in the provision and regulation of valuable ecosystem services such as nutrient cycling, regulation of water, pest control and pollination and they are also an important food source for animals, which are all vital for human welfare (Noriega et al., 2017). However, there's been a large decline of invertebrates during the last decades, over 40% of insects are threatened with extinction (Dirzo et al., 2014), mainly due to habitat loss from land use change and conversion to intensive agriculture, particularly the heavy use of pesticides. Continuing down this path could lead to an ecosystem collapse (Goulson, 2019).

An approach to the recovery and conservation of invertebrates is rewilding or ecological restoration which aims to reverse biodiversity loss and restore the natural ecological functions and interactions with minimal human interference. This allows nature to shape the land and decide its own outcome so in the long term the environment can self-regulate and sustain itself; a higher complexity of microhabitats tends to attract more species (Pettorelli et al., 2019). This is the goal of Lower Sharpham farm and its project partner Ambios.

Sharpham farm is a low intensive organic farm located in Totnes, Devon, and in 2020 its tenants Ambios acquired an additional 50 acres of agricultural land with the vision of rewilding it and enhance biodiversity. Since then, they have done annual surveys to monitor the effect of the rewilding project and seen an increase in birds, mammals, reptiles, and flying insects (Ambios, 2022). But their monitoring of ground invertebrates is limited. Insects are an important species for assessing the ecological value and quality of a site and are indicators of ecosystem health as they are sensitive to environmental change and respond quickly to disturbances or restoration (Borges et al., 2021). Therefore, the purpose of this study is to contribute to this knowledge gap and investigate factors that could influence ground invertebrate populations at Lower Sharpham Farm.

Research questions, aims and objectives

The overall aim of this study is to investigate the diversity and abundance of ground invertebrates in fields that have differing land uses at Sharpham farm and to assess the relationship between vegetation structure and invertebrate diversity. This investigation will address the following research questions:

- How does land use affect invertebrate diversity in Sharpham Farm?
- How does vegetation structure and habitat characteristics influence invertebrate diversity at Sharpham Farm?

To meet the aims the main objectives are: (1) To select two contrasting fields and find appropriate locations within each field to survey invertebrates; (2) to deploy pitfall traps to collect invertebrates and identify all captured species into their taxonomic group in the laboratory; (3) to use quadrats to survey the vegetation structure surrounding the pitfall traps; and (4) to interrogate and analyse the data using relevant graphical presentation and statistical analysis.

Literature Review

Importance of invertebrates

Invertebrates are animals without a vertebrate column, and they comprise around 97% of all Earth's animal species known to science, while only 3% are vertebrates (Salvador et al., 2021). Invertebrates are the most biodiverse and abundant animals in the majority of natural ecosystems and are key in supporting and maintaining a healthy functioning environment (New, 1995). However, given their complex evolutionary history, trophic and ecological roles, abundance, and variety of forms there are still millions of species undiscovered and have merely begun to identify and understand their global importance (Collen et al., 2012). The majority of invertebrates are in the Phylum Arthropoda characterised by their hard exoskeleton, segmented bodies and jointed appendages with an estimate of approximately 7 million species including discovered and undiscovered (Serrano, 2022; Stork, 2017). It is divided into the subphyla Chelicerata (arachnids), Myriapoda (centipedes and millipedes), Crustacea (crustaceans) and Hexapoda (insects and springtails), which is the largest group with approximately 5.5 million insect species (Collen et al., 2012; Stork, 2017).

Invertebrates are keystone species and are crucial for life on Earth. Their importance resides in the ecological services and functions they perform, with almost all species having a unique role in the ecosystem (Silva et al. 2012). Pollinators like bees and butterflies are essential for the reproduction of flowering plants and the growth of agricultural crops (Katumo et al., 2022); decomposers such as earthworms and woodlice break down decaying organisms and organic material recycling nutrients back into the soil which contributes to plant growth and soil formation (Griffiths et al, 2021). Aquatic invertebrates, similar to decomposers, help break down and filter organic matter maintaining the water clean (Bouchard, 2004). Invertebrates also serve as bio controls helping manage pests by feeding and antagonising on harmful organisms, hence they can be used as a natural alternative for chemical pesticides (Williams et al. 2022). Furthermore, they are a vital food source for other animals and are the foundation of many vertebrate food chains (Catherine, 2010). Other services include seed dispersal, waste management and disease regulation. Therefore, invertebrates underpin all terrestrial, freshwater and marine habitats by providing and supporting numerous ecosystem services that are essential for human society, economy and well-being, and are an integral link in food webs as well as maintaining soil and water quality (Eisenhauer and Hines, 2021; Catherine, 2010).

Biodiversity loss and threats

The world is currently experiencing a large decline of biodiversity at an unprecedented rate, primarily driven by anthropogenic activity. The loss of invertebrates could lead to cascading effects and significant consequences to the ecosystem services humankind depends on (Eisenhauer et al., 2019). Substantial changes in invertebrate diversity and composition have been happening almost unnoticed and are underrepresented, but their decline is as severe as of vertebrates, with approximately 40% assessed species considered threatened (Dirzo et al., 2014). Studies in Europe show more than 75% decline in flying insect biomass over 27 years, particularly pollinator species which are vital for food security, and 42% in ground beetles (Hallmann et al., 2019). In the UK, of the 2430 insects assessed by

Natural England, 286 are threatened and 55 have gone extinct (UK Parliament, 2020).

There are numerous anthropogenic pressures facing invertebrate populations, but the main threat is land use change from the mass development of agriculture and industry. Large areas of natural habitats have been converted to intensive agriculture, and the chronic exposure from the heavy application of pesticides can have lethal effects (Goulson, 2019). These leads to the direct decline of invertebrate diversity and the complexity of biotic interactions, which also threatens the productivity and stability of food production systems (Ricketts et al., 2008). The loss, degradation and fragmentation of important habitats such as woodlands, wildflower grasslands, hedgerows, rivers, etc. has contributed to the reduced availability of breeding, sheltering and foraging sites (Fischer and Lindenmayer, 2007). Invertebrate species are also under great stress from climate change and shifts in weather patterns (Musolin, 2007). They can be affected directly by abiotic conditions or indirectly by changes in biotic relationships due to climate change (Prather et al., 2012). Invertebrates are highly sensitive to temperature change as they are poikilothermic ectotherms, which means that they are dependent on the thermal conditions in their environment to regulate their bodies (Everatt et al., 2013). Therefore, temperature is critical for their development and activity, and even small fluctuations can alter the timings of their lifecycle, which can negatively impact their behaviours and emergence patterns (Hegland et al., 2009). Responses to climate change include changes in geographic distributions, population size, genetic composition, and phenology (Prather et al., 2012).

Current conservation context

The monitoring and conservation of invertebrate populations has never been so important, and it requires consideration at international, national and local scale (Schuldt and Assmann, 2010). The alarming declines in biodiversity has push forward decision makers and the public into action. During the last few decades countries have started increasing efforts and as result new biodiversity assessments, monitoring initiatives and measures are being discussed and put into place (Eisenhauer et al., 2019). Internationally, the UN Convention on Biological Diversity (CBD) established the 20 Aichi Biodiversity Targets for 2020 which provide a framework to address the drivers that influence the direct pressures on biodiversity, aiming to mitigate loss and safeguard ecosystems (Proença et al., 2017). Despite not achieving the targets, progress has been made to reach its goals. Building on this, the Kunming-Montreal Global Biodiversity Framework is currently implemented, outlining an ambitious pathway to achieve global targets and goals by 2030/50 (CBD, 2023).

However, less attention is brought to invertebrates and conservation actions are generally applied to vertebrate taxa. Given their immense species richness, global assessments on invertebrate status and available data are often limited, with greater focus on pollinators species (Collen et al., 2012). Only over a million species have been described which remains around 80% to be discovered (Stork, 2017). This knowledge gap hinders the capacity to predict and limit defaunation impacts, and thus there is an urgent need to increase invertebrate assessments and monitoring, and enhance their representation, in order to improve the understanding and knowledge of their biology, dynamics and systems involved as well as understand the changes in global biodiversity, which will lead to effective planning for their conservation and facilitate policy decisions and action plans (Dirzo et al., 2014; Collen et al., 2012).

Conservation importance and approaches
The ecological importance and value invertebrates have in providing an integral functional role in the ecosystem is the vital reason for conserving biodiversity, without them natural biotic systems would not function properly nor the provision of ecosystem services that benefits humanity (Eisenhauer and Hines, 2021). They occupy numerous trophic niches in communities and represent a major biodiversity group in terrestrial ecosystems, particularly ground invertebrates, and thus they serve as tools to monitor the health of natural environments and can help indicate the effects of various anthropogenic impacts and other intrusions or can show the success of conservation management actions (New, 1995). They are key species for assessing the ecological changes and quality of a site as they are sensitive to environmental change and respond quickly to disturbances or restoration, hence they are indicators of ecosystem health and reflect overall levels of community composition, richness and abundance (Borges et al., 2021). To mitigate invertebrate loss, it is essential to understand their key roles and how conservation measures are affecting biodiversity trend (Eisenhauer et al., 2019).

There are various ways to conserve and manage invertebrates, such as through ecological restoration. An increasingly popular measure for ecosystem recovery is rewilding, which aims to reverse biodiversity loss and restore the natural ecological functions and interactions with minimal human interference and return the landscape or ecosystem to what it was before human intervention (Pettorelli et al., 2019). At present, there are different methods to approach rewilding which can be broken down into active and passive rewilding. The former uses more active management in which selected fauna, like keystone species, are reintroduced to the environment to restore the ecological processes and trophic functions lost (Lorimer et al., 2015). This can be divided into two types: Pleistocene rewilding, which focuses on reintroducing specific species that had functionally similar assemblage of species as existed in the Pleistocene Age (Donlan et al., 2006), and Trophic rewilding which uses species reintroductions for the reactivation of top-down trophic interactions and associated trophic cascades (Svenning et al., 2016). On the other hand, in Passive rewilding natural vegetation succession is allowed to follow its own course without the reintroduction of species. This allows nature to shape the land and decide its own outcome so in the long term the environment can self-regulate and sustain itself (Overton, 2022). Passive rewilding usually refers to abandoned post-agricultural landscapes no longer actively managed and uses minimal intervention to facilitate natural processes to regain dominance and enhance ecosystem resilience (Pettorelli et al., 2019). However, challenges arise as the outcomes can be unpredictable and varies between each site. Numerous species may increase in abundance, but others could decline as their habitat changes or risks are not foreseen, and unwanted ecological interactions could increase (Nogués-Bravo et al., 2016). Prior research and regular assessments are necessary to ensure an effective rewilding project (IUCN, 2013).

Restoration and rewilding projects work as a strategy for conserving and restoring complex ecosystem dynamics and have the ability to form microhabitats (Thakur et al., 2020). A higher complexity of habitats tends to attract more species as more diverse structural characteristics in the environment has further available resources that can support and sustain an array of species (Kovalenko et al., 2012). A diverse and structurally complex vegetation can provide greater food sources and food web productivity, protection from predators or physical disturbances, and higher habitat niches. It comprises attributes such as number, size, and spatial arrangement of structural components (Velasco-Charpentier et al., 2021; Contos et al., 2021). Abiotic factors such as temperature and moisture can also play an important role in the invertebrate diversity of soil ecosystems, as well as biotic factors like microorganisms and nutrients are important in the abundance and distribution of soil invertebrates (Juman et al., 2017). Ground dwelling organisms also respond with high sensitivity to anthropogenic perturbations and presence, hence reducing impacts of human interventions and disturbances would increase abundance (Doran and Zeiss, 2000). Habitat heterogeneity has been shown to be positively correlated with invertebrate diversity, and in most habitats plant communities determine the physical structure of the environment thus they have significant influence on the distributions and interactions of species, though the effects of heterogeneity may vary depending on the taxonomic group (Tews et al., 2004). Overall, a wider range of habitats will support a greater abundance and diversity of invertebrates.

Biodiversity restoration in agriculture

Currently, a strategy for improving habitats and increasing biodiversity in agricultural land is through Countryside Stewardships or Agri-environment schemes. They provide financial incentives for farmers, foresters, and land managers to look after and improve the environment as well as manage their land to enhance biodiversity and landscape recovery (Natural England, 2017). It aims to mitigate the negative effects of agricultural intensification and encourages and supports efforts to restore wildlife habitats, reduce pollution, manage flood risk, preserve countryside character, and improve educational access (Chatterton, 2021). There are different ways to achieve environmentally sustainable agriculture which may include the creation of beetle banks, wildflower strips, reduction of pesticides, managing hedgerows, planting wild bird seeds, etc. These has shown to be effective in increasing species richness and abundance (Dicks et al., 2013). Though it is important to consider the baseline of biodiversity before implementation of the scheme and regular monitoring is needed to ensure an effective judgement (Kleijn and Sutherland, 2003). Farmers can make a positive change in reducing biodiversity loss if they are properly engaged.

As land use intensification is a major threat to biodiversity, which involves increased fertilization, use of pesticides, higher livestock densities or increased human intervention, conservation management is key to restore plant, vertebrate and invertebrate taxa (Allan et al., 2014). Terrestrial arthropods like ground dwelling invertebrates are understudied and underrepresented in farmland biodiversity studies and ecological restoration projects across the UK, and there is limited data regarding how land use intensity differentially affects a range of taxonomic groups such as Coleoptera, Isopoda, Araneae, Collembola, etc., and its effects in relationships and interactions between taxa and the environment (Manning et al., 2015). Therefore, this research will contribute to this gap in literature by investigating the diversity and abundance of ground invertebrates at Sharpham Farm.

Methodology

Study location

This study was carried out at Lower Sharpham Farm located in Totnes, South Devon. It is an 80-acre low intensive organic beef and sheep farm managed by The Sharpham Trust and Ambios. They aim to find a balance between agriculture and improving the natural environment by farming sustainably and offering engaging and educational activities (Sharpham Trust, 2023). Livestock grazes the land in a grazing management regime to provide a better habitat for wildlife. An additional 50 acres of agricultural land was acquired in 2020 with the intention of rewilding the area and expanding their conservation training resources, with the aim to restore the biodiversity and habitat, and allow nature to recover and decide its own course. In 2021, they entered into a Higher Tier Countryside Stewardship agreement which supports the project (Ambios, 2022; McMullen, 2020).

The study consisted of a ground invertebrate survey using pitfall traps. It was carried out in Autumn 2023 from 23rd November to 1st December. It required 5 one-day visits to the farm; first to assess the site and decide on which fields to survey, one to place the traps, two days to survey vegetation and one final visit to collect traps. Upon assessment of the site, two contrasting fields were selected: one farmed field and one rewilded field. The site was divided into various fields (see Figure 1); field 9 was chosen in the farmed area as it was not being grazed at the time of the survey so that the traps were not disturbed by the animals. It was also accessible and provided a large area of survey (2.6226 ha). Similarly, field 18 was selected in the rewilded area for its characteristics, ease of access, size (3.2859 ha), and past history of use for biodiversity monitoring.

Pitfall traps

The pitfall trap technique is a simple and effective method to survey ground invertebrates (Kim et al., 2021). It consisted in burying 36 plastic cups flush to the surface of the ground into which the invertebrates fall into. A second cup was fitted inside another acting as a backup if one gets damaged. Inside the cups there was around 30ml of salt solution to prevent the insects from escaping and preserves them for a later collection. Each trap had a cover fitted on top leaving a small gap to prevent rain from filling and protect them from predators (see Figure 2) (Wheater and Cook, 2003; Gibb and Oseto, 2006). Wood sticks were put inside the cups to allow small invertebrates such as shrews to escape if they fall into the traps.

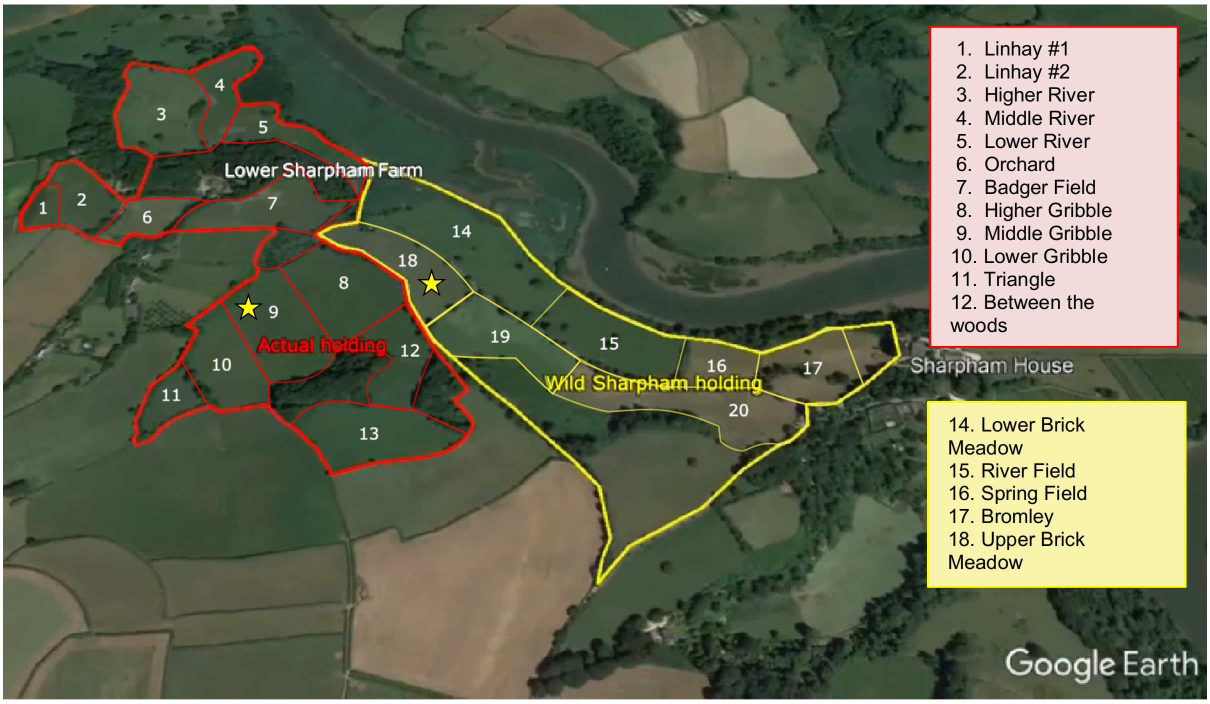

Figure 1: Aerial map of Lower Sharpham Farm holding showing the current farmed area in red and the rewilding project area in yellow, including individual numbered fields. The fields used in this study are marked with a yellow star (fields 9 and 18) [Adapted from Google Earth]. Imagery @2023 Google Earth, data attribution includes TerraMetrics @1999

18 pitfall traps were installed on both rewilded field and farmed field. They were divided into 3 groups of 6, spaced around each field with a distance of 10 meters between each trap. The 3 locations within each field were distributed in different areas so that they covered most of the field and different habitats to ensure a representative sample, and the traps within each group were systematically distributed to avoid bias and easier identification (see Figure 3 for placement of traps). The coordinates of each trap were recorded to mark where they were installed for later collection. The cups were collected five days later, after determining it was an adequate time to sample enough invertebrates to provide sufficient data given the limited study time. The invertebrates were transferred into labelled sample bottles for transport and then taken to the laboratory for identification. Any live insect that fell into the cup while setting up or collecting the traps were removed and not taken into consideration.

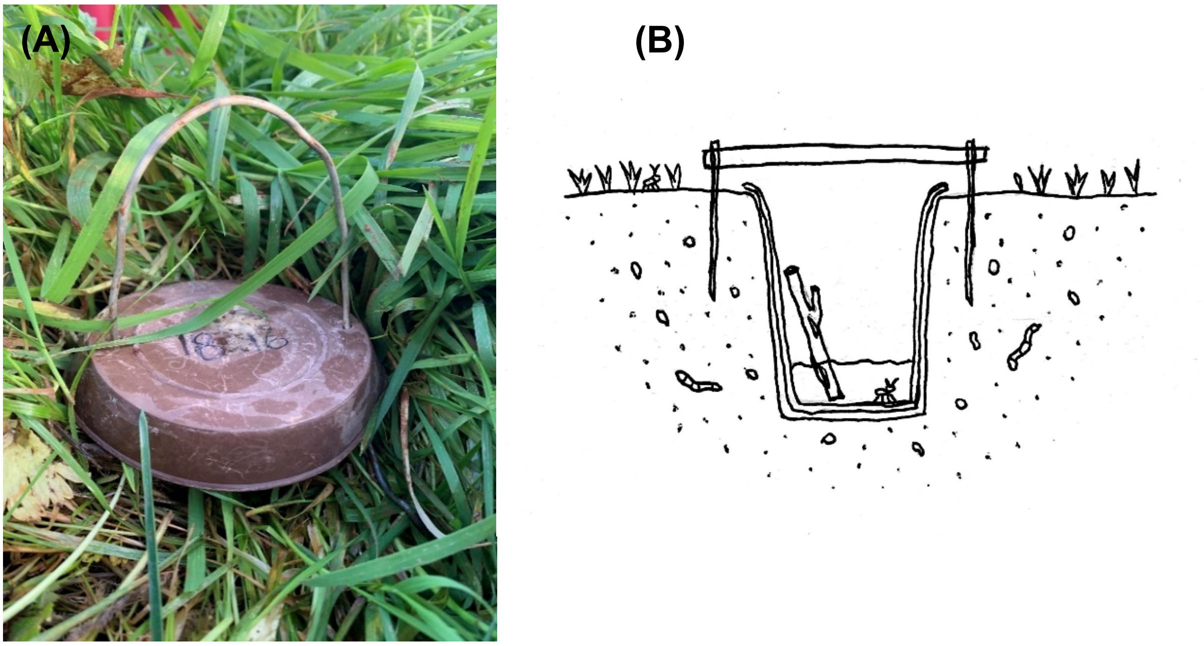

Figure 2: Picture A shows a pitfall trap with rain cover on rewilded field. Picture B shows a sketch of a pitfall trap.

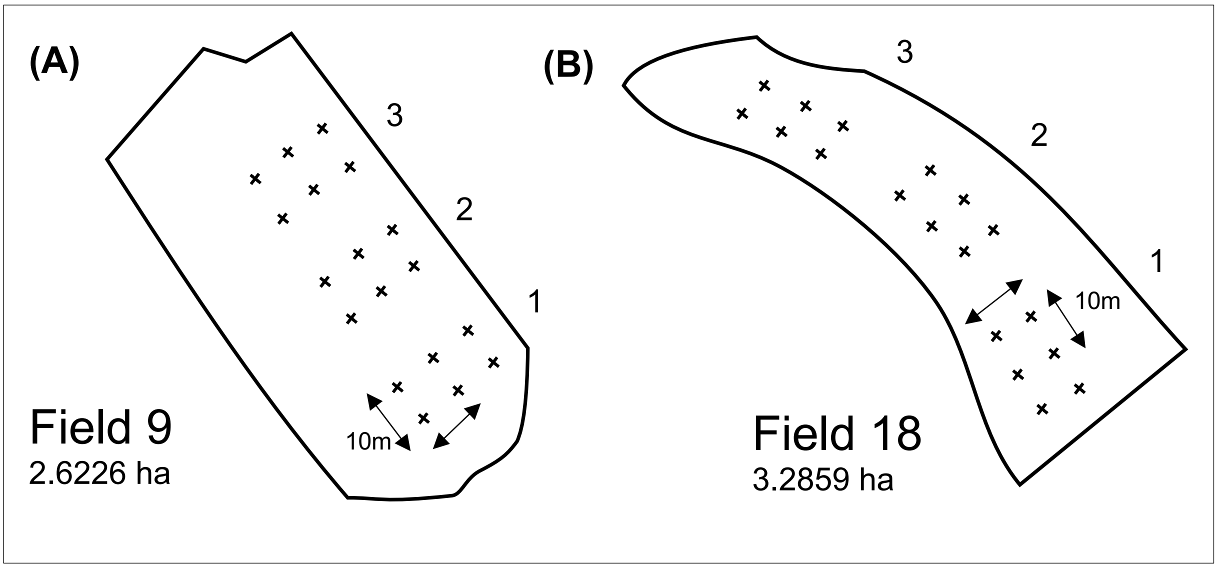

Figure 3: Map of the 18 pitfall trap locations on farmed field (A) and rewilded field (B), divided into 3 groups of 6 with a distance of 10 m between each trap. The numbers 1, 2 and 3 indicate the order of the groups (not to scale).

Vegetation survey
After installing the traps, a vegetation survey was carried out using 50 cm^2 quadrats to assess a representative sample of the surrounding vegetation of each pitfall trap. The present vegetation structure and composition were recorded as well as the plant cover percentage. A ruler was used to measure different vegetation heights within the quadrats and FSC guides and identification keys were used to identify the field plant species. During the survey, habitat characteristics and observations of the overall field and surrounding the traps were also recorded.

Equipment
The following equipment was used in this study:

- 1 First aid kit
- 2 Quadrats (50 x 50cm)
- ID keys/guides for field vegetation and insects
- 1 Bulb corer
- 2 Trowels
- 1 Measuring tape 30m
- 1 Ruler
- 2L Salt solution
- 72 Cups
- 36 Rain covers
- 36 Sample bottles

Invertebrate species identification
Once the samples were collected and taken to the laboratory, all the invertebrates found in each trap were identified under a microscope and grouped into categories of the taxonomic level of Order (see Figure 4 and Table 1). FSC identification guides were used to identify and classify the invertebrates into their correct taxonomic group based on their morphological characteristics and were recorded into Excel worksheet. After identification, they were put into vials with 70% ethanol for preservation. Once completing the identification, they were proceeded to be analysed.

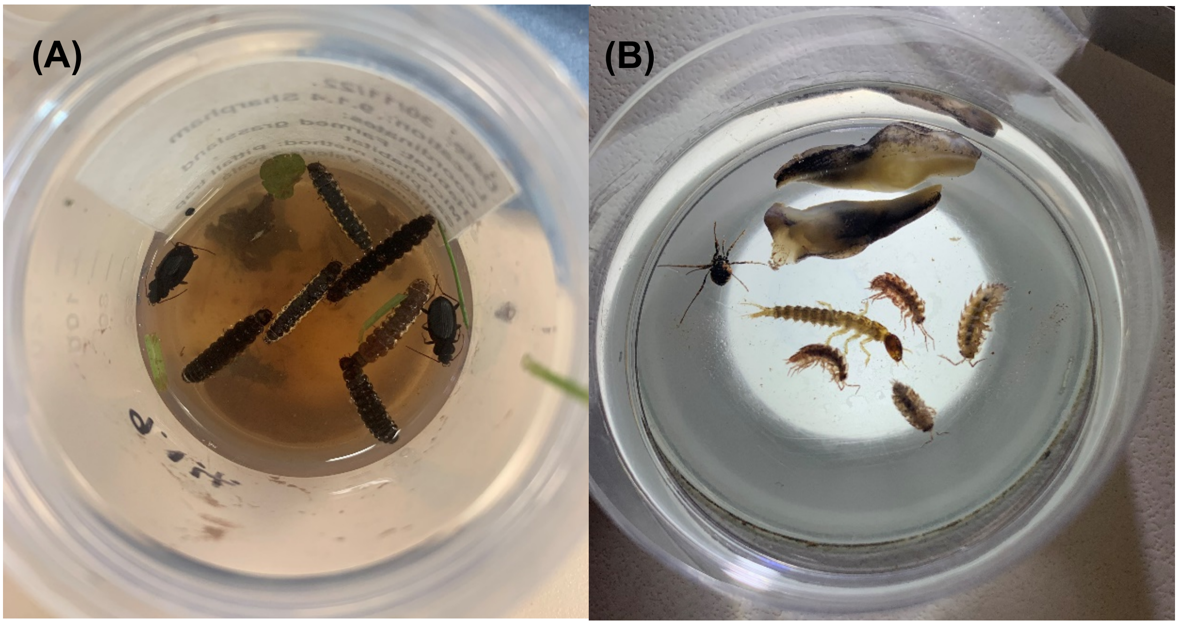

Figure 4: Picture A displays invertebrates collected in a sample bottle and B displays invertebrates before being identified under a microscope.

Table 1: Photos of invertebrate species identified under the microscope.

		
Springtails	Beetles	Woodlice
		
Carabid beetle	Harvestmen	Mites
		
Slugs	Snails	False scorpion

Data analysis

The data was analysed comparing the invertebrate biodiversity and vegetation structure within each rewilded and farmed field and between fields. Tables were produced to compare the invertebrate abundance within the three areas investigated in each field. The Shannon-Wiener Biodiversity Index test (H) is a method used to measure the species diversity within a community based on species richness and abundance, thus it was used to assess the invertebrate biodiversity found in each field. This analysis produces diversity indices which provide information on the community composition. It also considers the relative evenness of the data (Nolan and Callahan, 2006). This method uses the following equation:

$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$

Where *pi* = proportion of entity in sample

In = natural logarithm of proportion

∑ = sum of all entities

Stacked bar charts and pie charts were created to show the composition and comparison of the percentage distribution of invertebrate and plant species within each field. A further bar chart was used to compare the differences in abundance of invertebrate found in both fields. Alongside this, to assess the vegetation structure a scatter plot was created to show the relationship between the average vegetation height and the number of invertebrates found in each trap. From this data, a regression analysis was conducted to assess its significance using p-value. Further statistical tests were carried out to analyse the differences in vegetation height between the three areas investigated within the fields. A normality test was first used to determine whether the data was normally distributed or not. Then an ANOVA and a Kruskal-Wallis test was used to assess whether there was a significant difference between the data.

Results

Rewilded field

Invertebrate biodiversity

The rewilded field observed a total abundance of 559 invertebrates divided into 18 different taxonomic orders within the 3 areas investigated. Table 2 shows that group 1 had a total of 205 invertebrates across 15 different orders of species.

Table 2: Abundance of invertebrate species found in the 3 groups investigated within the rewilded field with their respective means and associated standard deviations.

Species Rewilded Field	Group 1	Group 2	Group 3	TOTAL	Mean	±SD
Entomobryomorpha (Springtails)	77	78	73	**228**	76	2.6
Coleoptera (Beetles)	58	35	41	**134**	45	11.9
Isopoda (Woodlice)	13	37	22	**72**	24	12.1
Opiliones (Harvestmen)	10	3	7	**20**	7	3.5
Stylommatophora (Slugs and snails)	9	6	10	**25**	8	2.1
Araneae (Spiders)	8	7	3	**18**	6	2.6
Mesostigmata (Mites)	8	6	4	**18**	6	2.0
Diptera (True flies)	6	2	4	**12**	4	2.0
Polydesmida (Millipede)	4	0	0	**4**	1	2.3
Symphypleona (Springtails)	4	3	2	**9**	3	1.0
Amphipoda (Sandhoppers and scuds)	3	0	0	**3**	1	1.7
Oribatida (Mites)	2	0	0	**2**	1	1.2
Pseudoscorpiones (False scorpion)	1	0	0	**1**	0	0.6
Poduromorpha (Springtails)	1	0	3	**4**	1	1.5
Hemiptera (True bugs)	1	1	0	**2**	1	0.6
Opisthopora (Earthworms)	0	4	1	**5**	2	2.1
Lithobiomorpha (Centipedes)	0	0	1	**1**	0	0.6
Hymenoptera (Ants and wasps)	0	0	1	**1**	0	0.6
TOTAL	**205**	**182**	**172**	**559**	186	16.9

Group 2 had a total 182 invertebrates in 11 species and group 3 observed a total of 172 in 13 different species within the rewilded field. The most abundant orders of species were Entomobryomorpha (springtails), Coleoptera (beetles) and Isopoda (woodlice), whilst Hymenoptera, Lithobiomorpha and Pseudoscorpiones were the least abundant. Group 1 area showed to have a higher number of individuals and different species within rewilded field. The average of invertebrates found in each area is 186 individuals.

After carrying out the Shannon-Weiner Biodiversity Index, Table 3 shows that group 1 had the highest biodiversity index (H) with 1.88, followed by group 3 with 1.72 while group 2 had the lowest with 1.65 within the field. The overall biodiversity for the rewilded field had a result of 1.82.

Table 3: Shannon-Wiener Biodiversity Index (H) test result for the 3 different areas.

Rewilded	Group 1	Group 2	Group 3
H	1.88	1.65	1.72

The distribution chart (Figure 5) shows that the largest invertebrate group in the overall rewilded field was the springtails (order Entomobryomorpha) with a 41%.

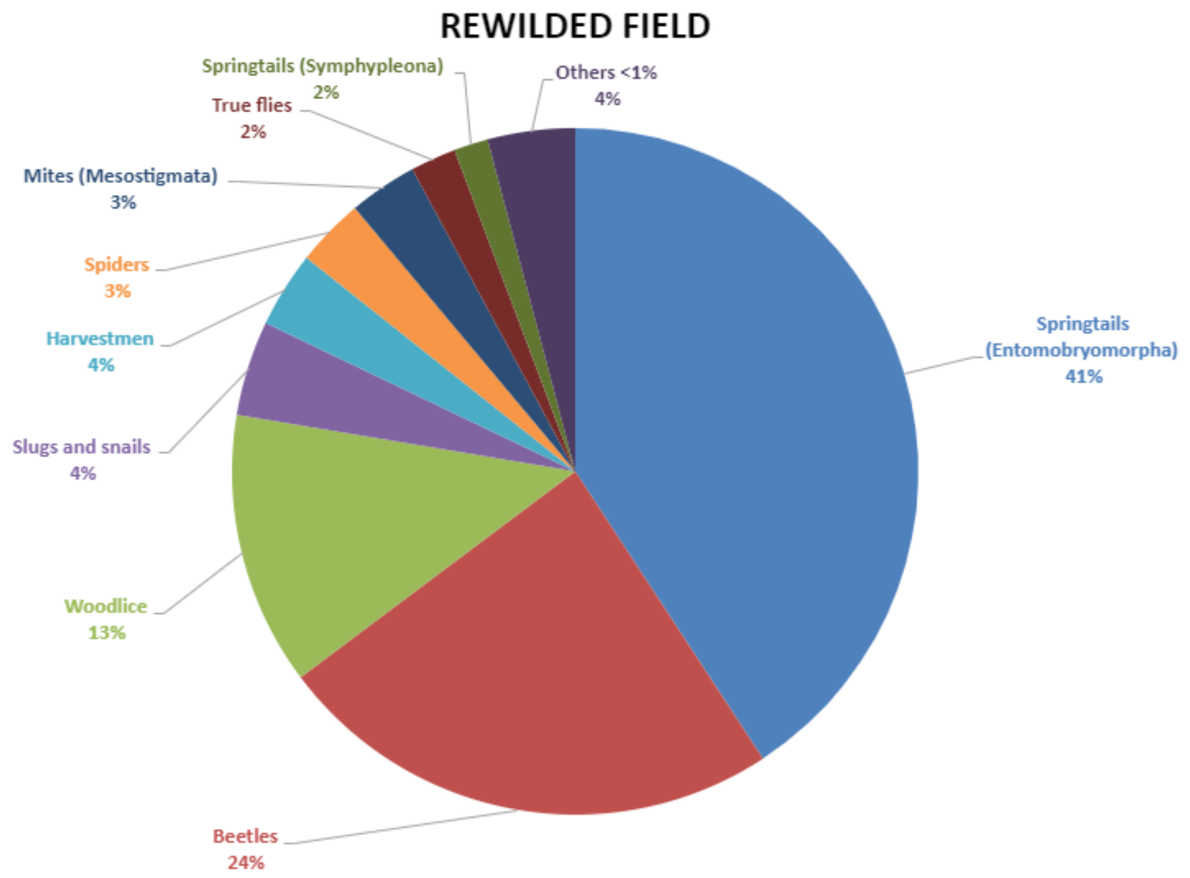

Figure 5: Pie chart showing the overall distribution of percentages of the invertebrate species identified in the rewilded field.

The second largest were the beetles (order Coleoptera) with 24% and then the woodlice (order Isopoda) with 13% out of 559 invertebrates. These groups comprise almost 80% of the whole rewilded field. The 'Others' slice in the chart includes 9 other groups of species found in the field but their percentage was less than 1% of the total.

Vegetation

The rewilded field was composed of 9 different plant species within the three areas investigated. Figure 6 shows that the main dominant vegetation surrounding pitfall traps within the 3 groups was Italian ryegrass (*Lolium multiflorum*) with 66% in group 1, 57% in group 2 and 81% in group 3. In groups 1 and 2, Cocksfoot grass (*Dactylis glomerata*) was the second dominant species with 27% and 28%, whilst in group 3 was Creeping buttercup (*Ranunculus repens*) with 9%, which group 2 had of 11%. Group 3 also had 8% of Common nettle (*Urtica dioica*).

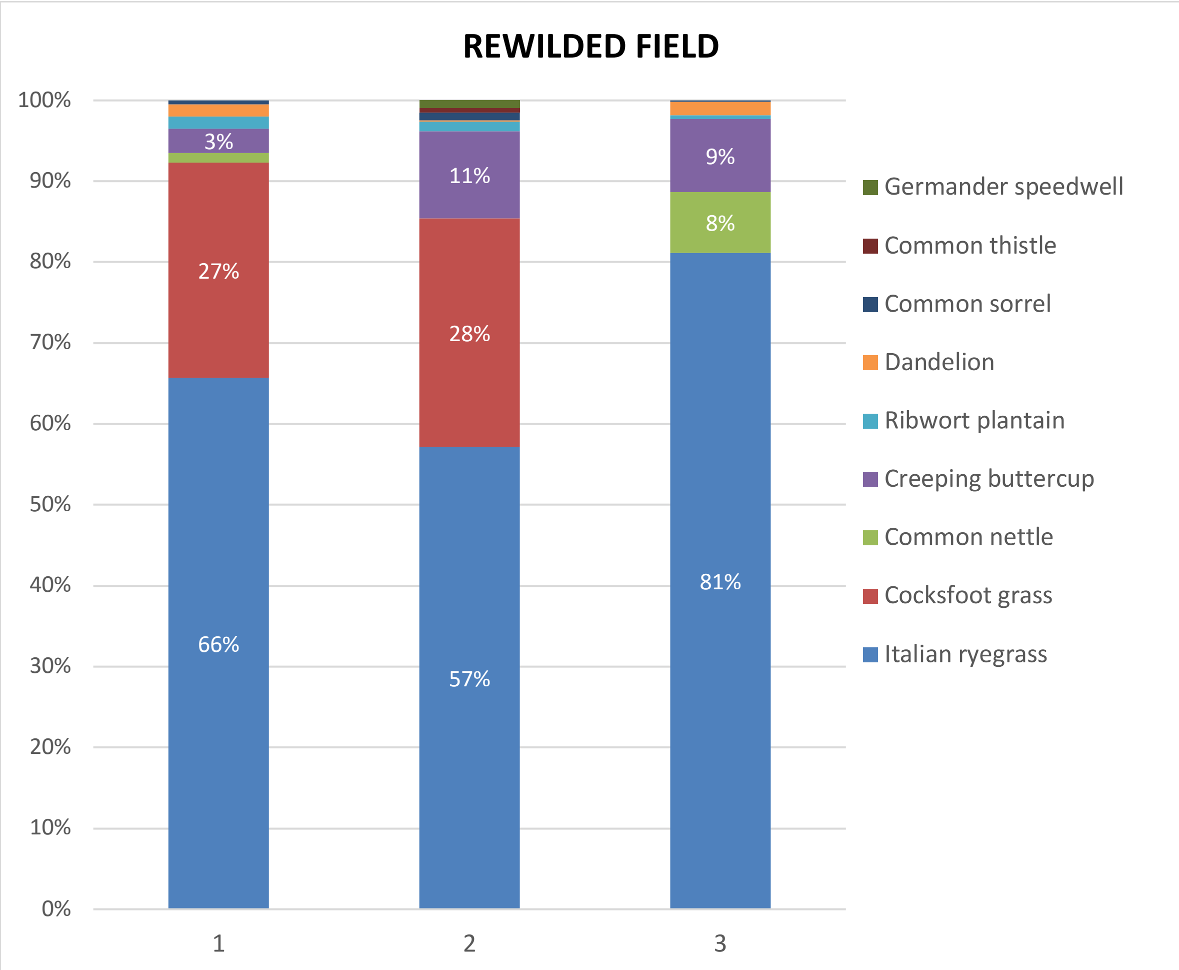

Figure 6: Plant composition percentage within the 3 groups investigated in rewilded field.

Statistical analysis was carried out to assess for significant difference between vegetation heights within the three areas investigated. The normality test result showed a p-value of 0.054, thus the data was normally distributed between sites. Subsequently, an ANOVA test was used, and the results indicate that there was not a significant difference (p-value=0.051) between the average heights of the three groups investigated. Rewilded field vegetation heights ranged from 15cm to 100cm.

Farmed field

Invertebrate biodiversity

The farmed field observed a total abundance of 297 invertebrates divided into 17 different taxonomic orders within the 3 areas investigated. Table 4 shows that group 1 had a total of 124 invertebrates across 10 different orders of species. Group 2 had a total 104 invertebrates in 11 species and group 3 observed a total of 69 in 13 different species within the farmed field. The most abundant orders of species were Coleoptera (beetles), Entomobryomorpha (springtails) and Araneae (spiders), whilst Lithobiomorpha, Hemiptera and Pseudoscorpiones were the least abundant. Group 1 area showed to have a higher number of individuals whilst group 3 had higher species richness within the farmed field. The average of invertebrates found in each area is 99 individuals.

Table 4: Abundance of invertebrate species found in the 3 groups investigated within the farmed field with their respective means and associated standard deviations.

Species Farmed Field	Group 1	Group 2	Group 3	TOTAL	Mean	±SD
Coleoptera (Beetles)	64	49	19	**132**	44	22.9
Entomobryomorpha (Springtails)	24	21	18	**63**	21	3.0
Araneae (Spiders)	10	9	2	**21**	7	4.4
Stylommatophora (Slugs and snails)	8	2	4	**14**	5	3.1
Diptera (True flies)	5	3	2	**10**	3	1.5
Symphypleona (Springtails)	4	4	3	**11**	4	0.6
Opisthopora (Earthworms)	4	5	0	**9**	3	2.6
Mesostigmata (Mites)	2	4	3	**9**	3	1.0
Amphipoda (Sandhoppers and scuds)	2	0	0	**2**	1	1.2
Pseudoscorpiones (False scorpion)	1	0	0	**1**	0	0.6
Isopoda (Woodlice)	0	0	6	**6**	2	3.5
Polydesmida (Millipede)	0	0	0	**0**	0	0.0
Opiliones (Harvestmen)	0	0	2	**2**	1	1.2
Oribatida (Mites)	0	1	4	**5**	2	2.1
Poduromorpha (Springtails)	0	0	1	**1**	0	0.6
Hemiptera (True bugs)	0	1	0	**1**	0	0.6
Lithobiomorpha (Centipedes)	0	0	1	**1**	0	0.6
Hymenoptera (Ants and wasps)	0	5	4	**9**	3	2.6
TOTAL	**124**	**104**	**69**	**297**	99	27.8

After carrying out the Shannon-Weiner Biodiversity Index, Table 5 shows that group 3 had the highest biodiversity index (H) with 2.12, followed by group 2 with 1.70 while group 1 had the lowest with 1.56 within the farmed field. The overall biodiversity for the farmed field had a result of 1.87.

Table 5: Shannon-Wiener Biodiversity Index (H) test result for the 3 different areas.

Farmed	Group 1	Group 2	Group 3
H	1.56	1.70	2.12

The distribution chart (Figure 7) shows that the largest invertebrate group in the overall farmed field was the beetles (order Coleoptera) with a 44%, proceeded by the springtails (order Entomobryomorpha) with 21% and then the spiders (order Araneae) with 7% out of 297 invertebrates. These groups comprise around 70% of the whole farmed field. The 'Others' slice in the chart includes 6 other groups of species found in the field but their percentage was less than 1% of the total.

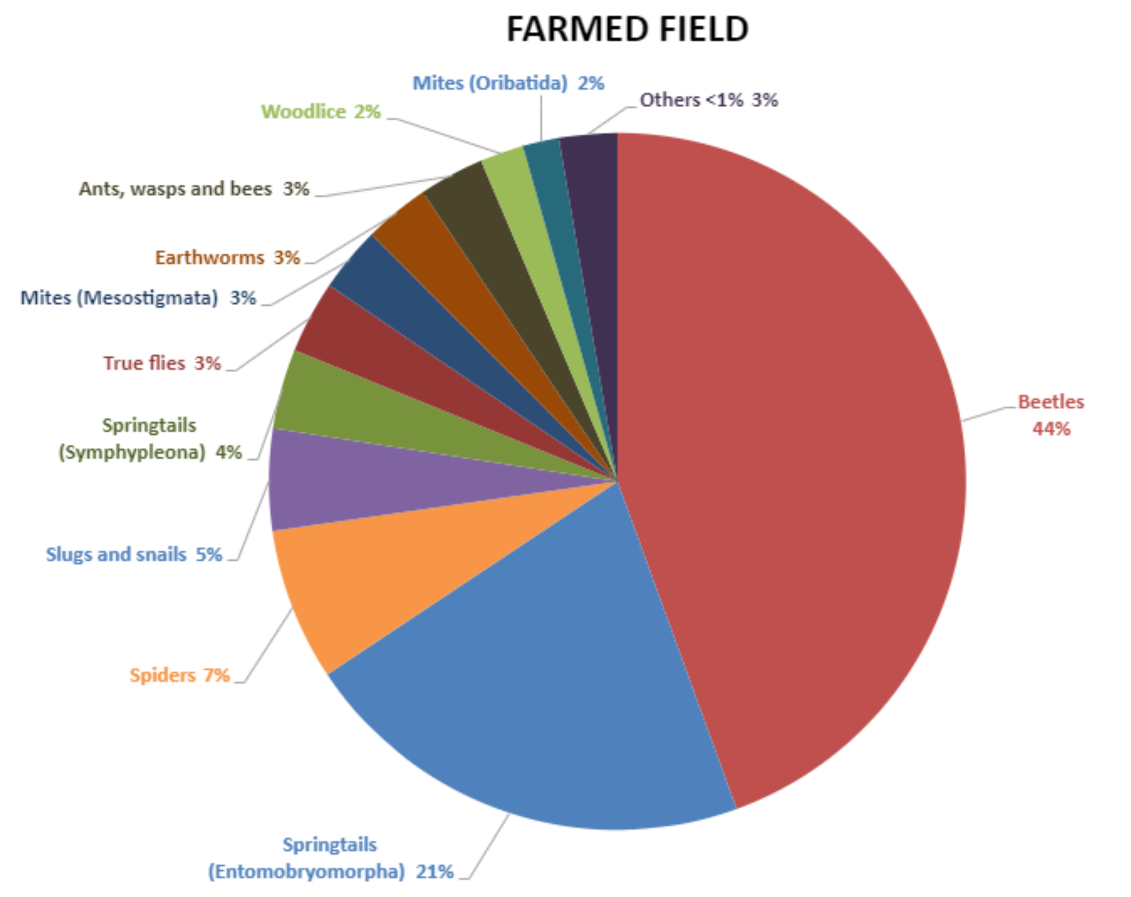

Figure 7: Pie chart showing the overall distribution of percentages of the invertebrate species identified in the farmed field.

Vegetation

The farmed field was composed of 12 different plant species within the three areas investigated. Figure 8 shows that the main dominant vegetation surrounding pitfall traps within the 3 groups was an unknown grass with 41% in group 1, 70% in group 2 and 47% in group 3. Italian ryegrass (*Lolium multiflorum*) was observed in group 1 with a 32% and in group 3 with 11%, but not in group 2. The second dominant species in group 3 was Cocksfoot grass (*Dactylis glomerata*) with 31%, whilst in group 2 was white clover (*Trifolium repens*) with 19%. Group 1 also has 11% of Creeping buttercup (*Ranunculus repens*).

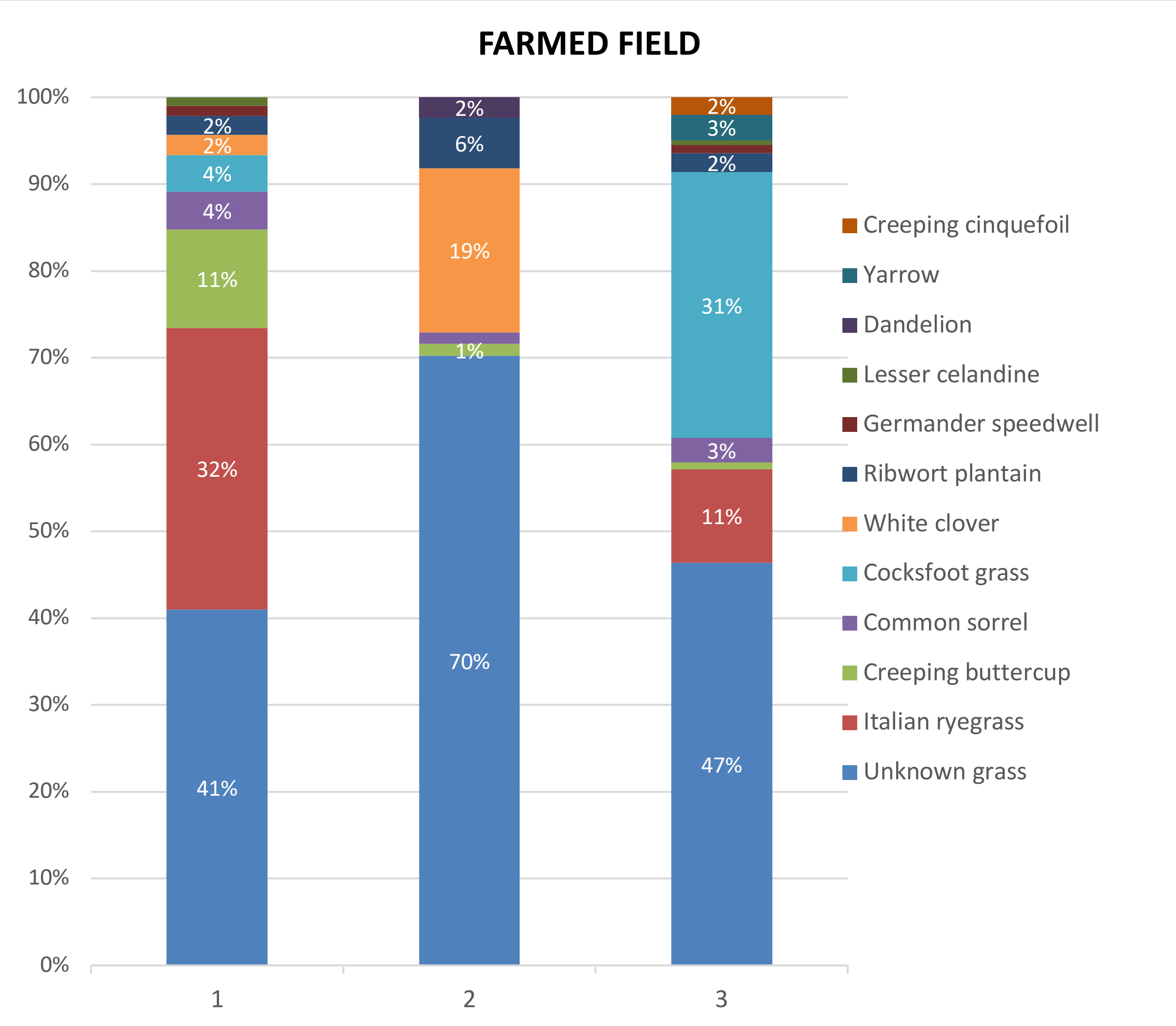

Figure 8: Plant composition percentage within the 3 groups investigated in farmed field.

Statistical analysis was carried out to assess for significant difference between vegetation heights within the three areas investigated. The normality test result showed a p-value of 0.030, thus the data was not normally distributed between sites. Subsequently, a Kruskal-Wallis test was used, and the results indicate that there was a significant difference (p-value=0.004) between the average heights of the three groups investigated. Farmed field vegetation heights ranged from 5cm to 30cm.

Comparison between fields

Invertebrate biodiversity

In total 856 invertebrates were captured during the 5-day sampling period, 559 in the rewilded field and 297 in the farmed field, and were divided into 18 and 17 different taxonomic orders of species. The average of invertebrates found in each trap was 31 insects in the rewilded field and 16 insects in the farmed field.

Table 6 highlights the number of invertebrate species collected in each field. Within the most abundant, rewilded field had a total of 228 springtails (Entomobryomorpha) in contrast with farmed field with 63 springtails. Both fields had a similar number of beetles with 134 in rewilded and 132 in farmed. Woodlice also had a contrasting number with 72 and 6 invertebrates respectively. Within the least abundant, centipedes and false scorpions had 1 individual in each field. Millipedes are absent in the farmed field whilst rewilded field has 4.

Table 6: Summary table of invertebrate species abundance identified under each taxonomical order in rewilded and farmed field.

Invertebrate Species	Rewilded	Farmed
Entomobryomorpha (Springtails)	228	63
Coleoptera (Beetles)	134	132
Isopoda (Woodlice)	72	6
Stylommatophora (Slugs and snails)	25	14
Opiliones (Harvestmen)	20	2
Araneae (Spiders)	18	21
Mesostigmata (Mites)	18	9
Diptera (True flies)	12	10
Symphypleona (Springtails)	9	11
Opisthopora (Earthworms)	5	9
Polydesmida (Millipede)	4	0
Poduromorpha (Springtails)	4	1
Amphipoda (Sandhoppers and scuds)	3	2
Oribatida (Mites)	2	5
Hemiptera (True bugs)	2	1
Pseudoscorpiones (False scorpion)	1	1
Lithobiomorpha (Centipedes)	1	1
Hymenoptera (Ants and wasps)	1	9
TOTAL	**559**	**297**

Figure 9 shows an illustration of the comparison of the number of invertebrates under each taxonomic group found in the fields. There is a large abundance of springtails (Entomobryomorpha) in the rewilded field compared to the farmed field causing a big gap between the fields. There is also a large gap in between the woodlice and harvestmen group. The beetles however have similar numbers in both fields. Also, there are some groups of species that are higher in the farmed field than the rewilded field such as the spiders, earthworms and ants and wasps. Overall, farmed field is slightly more biodiverse (H=1.87) than rewilded field (H=1.82).

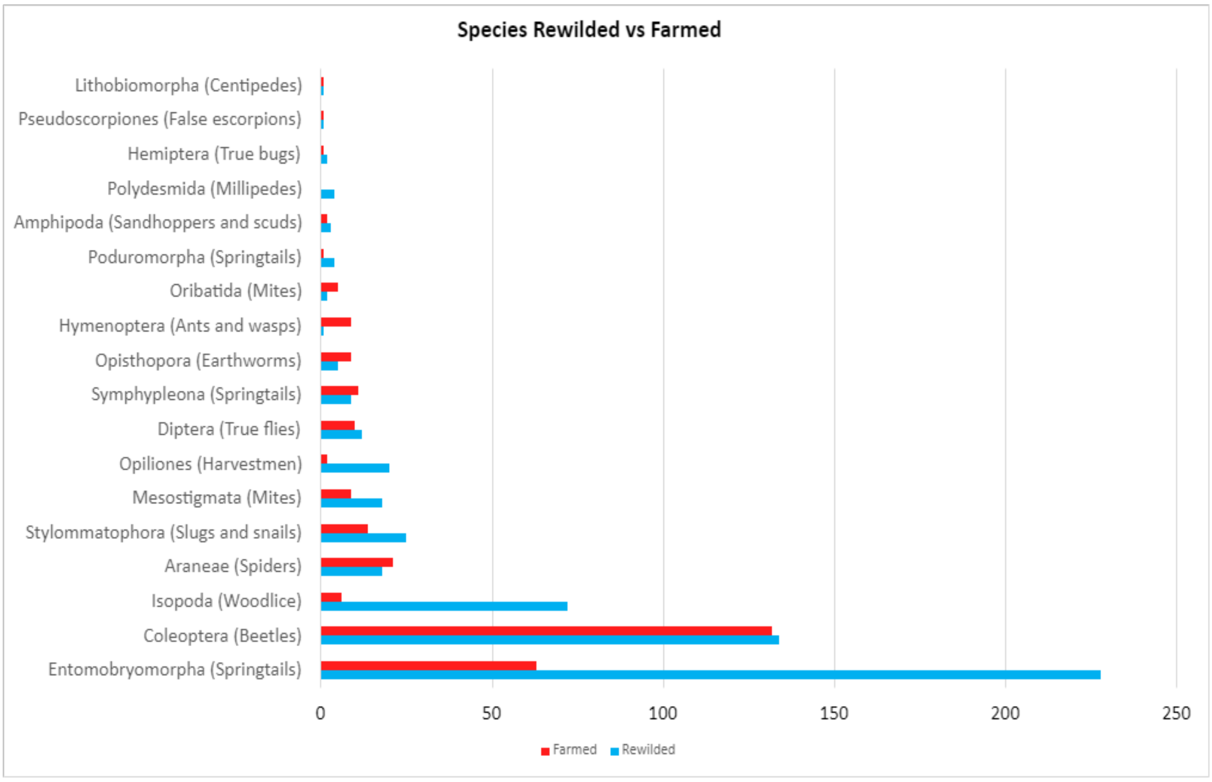

Figure 9: Bar chart comparing the number of invertebrates of each group of species found in the rewilded field and farmed field.

Vegetation

Figure 10 highlights the differences between the overall plant composition in both fields. Italian ryegrass covers a 68% in the rewilded field in contrast with farmed field with 14%. Farmed field has a 53% of unknown grass whilst in rewilded field is absent. Cocksfoot grass is observed with 18% and 12% respectively, whilst creeping buttercup covers an 8% in rewilded and 5% in farmed. White clover is only present in farmed field with 7%. Overall, farmed field has more plant species than rewilded field. However, vegetation structure is more varied in rewilded field (see Table 7 for visual characteristics of the fields).

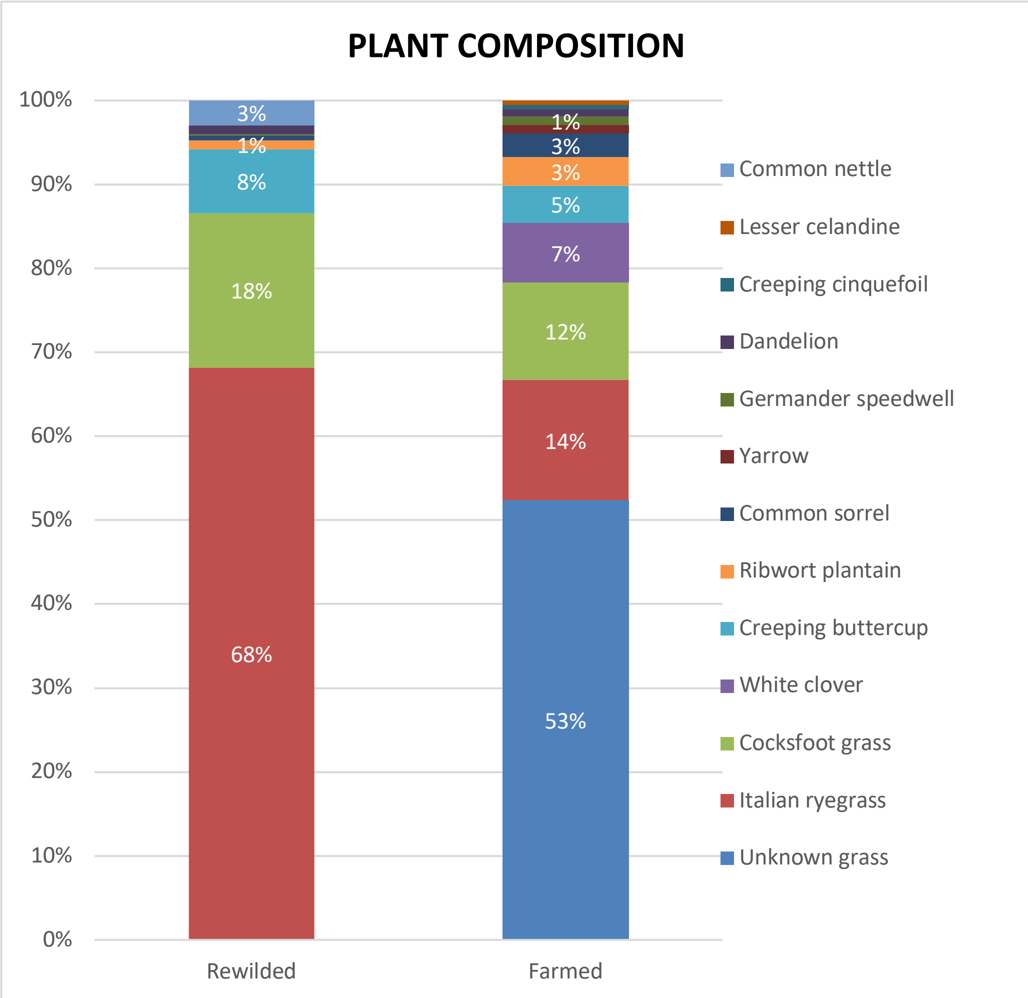

Figure 10: Plant composition percentage comparison between rewilded and farmed field.

Figure 11 shows a weak negative relationship between vegetation height and number of invertebrates in both fields. After carrying out a regression analysis the p-value was higher than 0.05 therefore not significant, though in this study it is likely to find more invertebrates in shorter vegetation. The graph also shows the variation in sizes, the rewilded field has a wider range of heights compared to the farmed field which is more even and uniform.

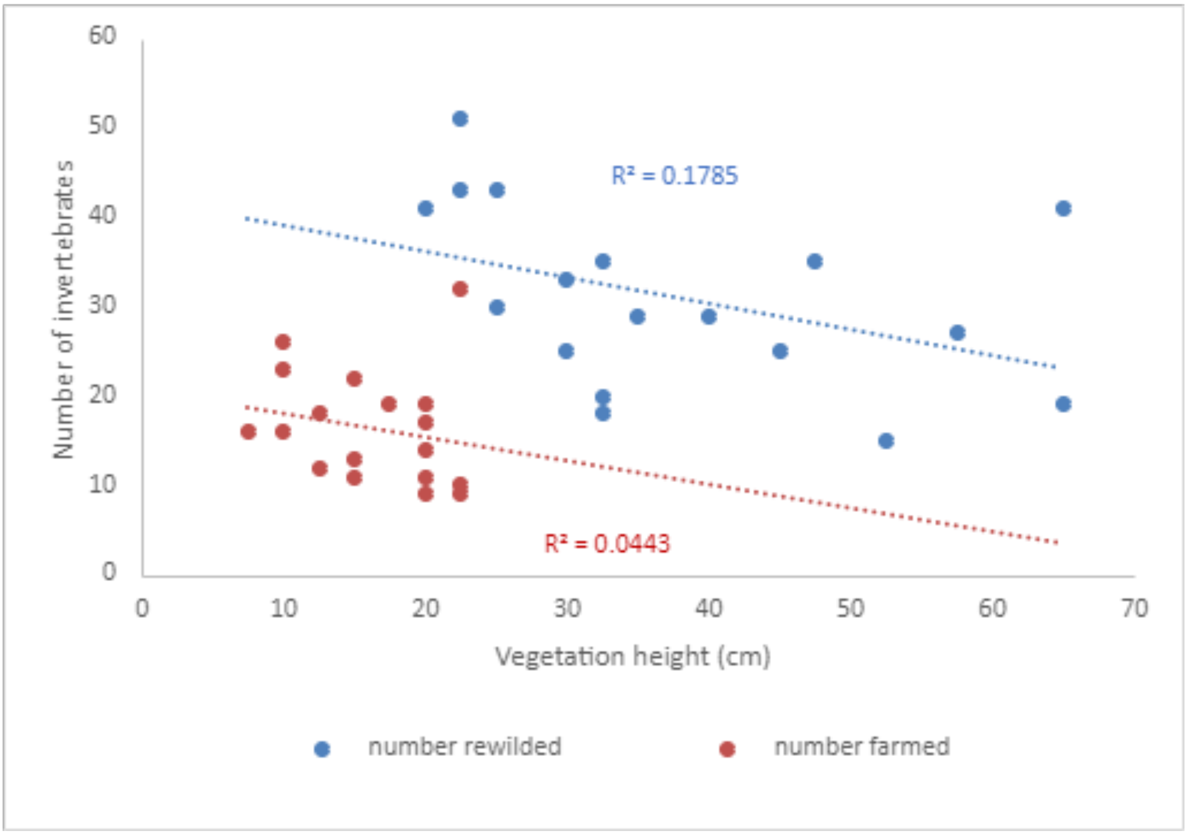

Figure 11: Scatter plot showing the relationship between the average vegetation height and the number of invertebrates found in each trap.

Table 7 and Figure 12 show a comparison between the visual characteristics of the rewilded and farmed field.

Table 7: General characteristics and observations of each field.

Visual Characteristics	Rewilded Field	Farmed Field
Tussocks	Many	Few
Field observations	Patches of 1m nettles No cow dung present	No patches of 1m nettles Cow dung present
Vegetation height	15 to 100cm	5 to 30cm
Luminosity	Generally more shaded	Generally more light
Grass	Dense and uneven	Dense and even
Fallen leaves	Many	Few
Dead wood	Yes	No
Grazed	No	Yes
Slope	Not very steep	Steep
Humidity	Moist	Moist
Neighbouring habitats	Reedbed and river	Woodland and meadow

The rewilded field observes a range of different vegetation height, there was short and long grass as well as tall plants such as sorrel, nettles and thistle. The field had many tussocks scattered around and was moist and more shaded. The farmed field had shorter grass which was more even and uniform in height from being grazed, though the bottom of the field had slightly longer grass and there was a number of tussocks scattered around. The field was also moist and had more light. The surrounding habitats around the fields include hedgerows and reedbed in rewilded field and woodland and a meadow in the farmed field.

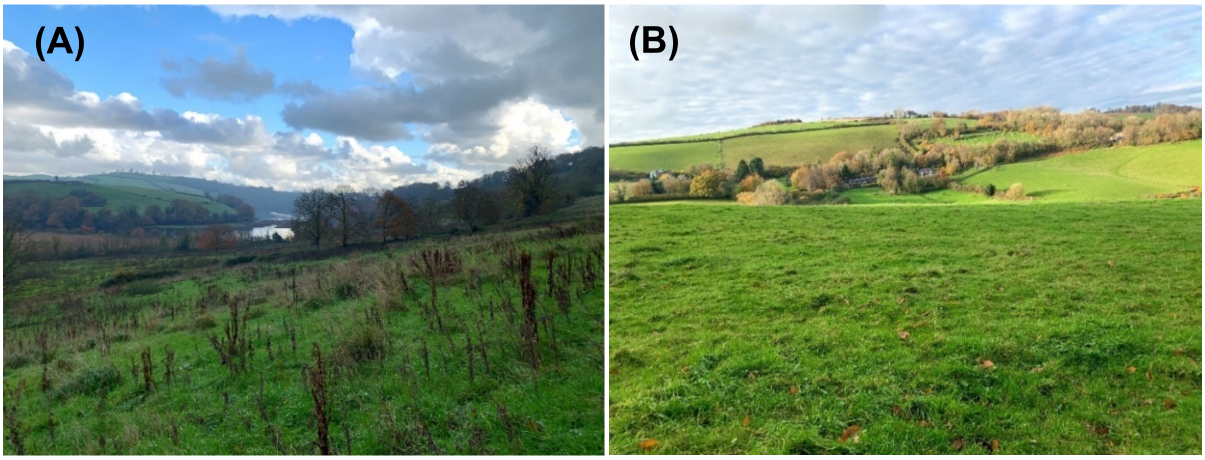

Figure 12: Visual observation comparison of rewilded field (A) and farmed field (B) in photographs.

Discussion

Variations within rewilded field

Results from the three areas investigated within rewilded field indicate that the area in group 1 showed to have a higher invertebrate abundance (n=205) and species richness (n=15) with a higher biodiversity index result (H=1.88). It was located approximately 10m away from hedgerow and trees and was near tall tussocks. Leaf litter was abundant, and area was mostly shaded. A study has shown that being close to field edges in agricultural land increases diversity and richness and is positively related to landscape complexity, stating that as complexity increases so does biodiversity, though some species are not affected (Evans et al, 2016). Another study showed that a higher number of invertebrate species favoured shaded areas than unshaded, particularly invertebrates associated with higher moist conditions as shaded areas tend to have greater soil moisture (Cauwer et al., 2006). Organic matter such as leaf litter tends to attract more decomposers such as springtails, woodlice, earthworms and beetles, this is the case for group 2 (Ruiz-Lupión et al, 2021). However, group 2 had the least species richness compared to other groups. It was located closer to the middle of the field thus confirming the conclusion of the previously mentioned study of field edges. The rewilded field was mainly composed of decomposers and predators.

In terms of plant composition, 9 different plant species were identified with the most dominant being Italian ryegrass which has been showed to benefit wildlife for its nutritive value as food source (Farm Wildlife, n. d.). Group 1 and 2 observed tussocks of cocksfoot grass as well which can provide shelter from predators and creates microhabitats, thus increasing invertebrate abundance (Woodland Trust, 2022). However, group 3 was absent of cocksfoot grass and had a lower plant species diversity which could explain the lower number of invertebrates compared to the other areas. Studies have shown that plant diversity and richness affects and supports invertebrate diversity and populations (Ebeling et al., 2018).

Variations within farmed field
Results from the three areas investigated within farmed field indicate that the area in group 1 showed to have a higher invertebrate abundance (n=124) while group 3 had a higher species richness (n=13) with a higher biodiversity index result (H=2.12). Group 1 was located at the top of the slope and was around 10m away from a woodland area which provides shade and leaf litter. This could explain the higher abundance of invertebrates as they feed on organic matter. The area also had a high amount of cow dung which would have attracted decomposers like beetles and springtails providing suitable microhabitats to reproduce and feed on farmland (Geiger et al, 2010). Group 1 and 2 also have the presence of earthworms which indicate good soil quality as they stimulate organic matter decomposition enhancing soil fertility. Group 3 had a less dung and leaf litter present and was located in a steep area which could affect the number of invertebrates. Despite this, it had a higher biodiversity index which may be due to the high dominance of beetles in group 1 and 2 whilst invertebrates in group 3 were more evenly distributed. The farmed field was mainly composed of decomposers and predators, but it also had a number of herbivores.

In terms of plant composition, 12 different plant species were identified with the most dominant being an unknown grass species. Groups 1 and 3 have the higher plant species and more distributed. However, group 3 does not correlate plant species richness with invertebrate abundance, but it does correlate with invertebrate diversity. Group 3 area also had more light which studies have shown that invertebrates preferred shaded areas which could explain the lower number of invertebrates (Cauwer et al., 2006).

Comparison between fields
The results indicate that rewilding has a positive effect on terrestrial invertebrate abundance (n=559), however there was little effect on species richness and groups such as springtails (Entomobryomorpha) and beetles (Coleoptera) were dominant species. Studies suggests that rewilding can enhance the biodiversity of agricultural landscape were previous farming practices led to a decline in invertebrate populations (Jepson, 2015). The Knepp State is an example of a successful rewilding project which has increase the abundance of insects and their habitats through the use of free roaming herds of grazing animals (Knepp, 2022). The rewilded field is lightly grazed by animals such as sheep and pigs, and studies suggest that animals can stimulate habitat complexity given their different grazing techniques and ability to disperse seeds and transfer nutrients, which can change the landscape causing a positive impact on biodiversity. By creating more natural habitats and mosaics of short and tall vegetation, rewilding can help support a wider range of species (van Klink and WallisDeVries, 2018; Rambo and Faeth, 1999). Natural revegetation increases organic matter content and water holding capacity which can lead to a higher density of decomposers such as springtails and woodlice (Arbelo et al, 2006). However, high densities of grazers and homogeneous vegetation can result in a decreased number of species. The intensity of disturbance

can lead to shorter grazing lawns which reduce the resources needed to support higher invertebrate populations, hence farmed field had lower invertebrate abundance (n=297) as it is systematically grazed by animals (van Klink et al, 2014). Studies show that trampling affects the distribution and population of arthropods and habitat suitability, though depends on disturbance intensity (Bonte and Maes, 2008). A study on grazing in grasslands have found that moderate grazing intensity positively affects species diversity in contrast with intensive grazing (Pulungan et al., 2019).

Nonetheless, in terms of species richness both fields had similar orders of species, 18 in rewilded field and 17 in farmed field. Organic farms, like Sharpham Farm, tend to support higher number of species and abundance across most taxa compared to non-organic farms as they reduce insect mortality from direct exposure to pesticides using alternatives to manage pests (Fuller et al, 2005). Organic farming practices also contribute to soil biodiversity such as earthworms, beetles and springtails, which can improve soil health and nutrient cycling. They promote more natural habitats and heterogeneity which can provide higher food resources for invertebrates thus supporting its diversity (Bavec and Bavec, 2015). Plants also tend to benefit from organic farming as they are directly affected by pesticide or herbicide inputs hence without chemical exposure plant diversity can increase rapidly (Fuller et al, 2005). Furthermore, the surveyed fields were not a long distance away from each other thus movement between fields may occur and cause to have similar species richness. Studies show that habitat connectivity can lead to higher levels of biodiversity and abundance of species as well as conserving invertebrates (Diengdoh et al., 2023).

The biodiversity index test had surprising results, showing that farmed field was slightly more biodiverse (H=1.87) than rewilded field (H=1.82). As mentioned before the Shannon-Wiener test not only considers the abundance and richness of species, but also the evenness of the data. As seen in Figure 7, the farmed field had a slightly higher distribution of species whilst the rewilded field had a large dominance of springtails which cause several groups of species to be lower than 1% (Figure 5) and consequently resulted in a higher biodiversity in farmed field even though rewilded field had higher abundance. Springtails are one of the most abundant invertebrates in the UK and can be found in almost any habitat. These tiny arthropods are often found in soil, organic debris, and areas of high moisture. They have a high reproduction rate hence populations can quickly increase in size, and they are also sensitive to disturbances (Frampton and Hopkin, 2001). Springtails are decomposers and play an important role in nutrient cycling and soil fertility, and they serve as food source for farmland predators such as beetles, predatory mites, and some spiders. They are an understudied taxa, though their functional role in decomposition processes and soil formation makes them important species for soil health (Chen et al., 2007).

Beetles are one of the most diverse taxa of invertebrates and are one of the main studied groups due to their presence in most habitats, functional diversity and ecological roles, covering a variety of niches in trophic networks (Leote et al., 2022). Beetles have various functional roles in the ecosystem such as decomposers, predators and pollinators, which contribute to essential ecological processes. Therefore, they are key in farmland ecosystems working as pest control, pollination, nutrient recycling, and soil health (Jones et al., 2020). A study on beetles in agricultural land show that organic farms have a higher beetle biomass and diversity compared to intensive farms, thus organic farming has positive effects on beetle communities (Hutton and Giller, 2003). Also, as the animals had recently grazed the farmed field, several cow dung was present on the field and given their role as decomposers, this could attract more beetles. These could explain the reason why beetles were as abundant in the farmed field as in the rewilded field. However, dung beetle species were not present in the traps.

Is important to take into consideration the period between the implementation of restoration measures and the time taken for the land to establish new habitats which contribute to ecological processes. Rewilding projects may take longer to be fully realised into habitats of value and to support higher levels of biodiversity (Woodcock et al., 2012). The rewilding project at Sharpham Farm started in 2020 thus it had been almost 3 years into the project at the time of the survey. The results at this stage indicate a difference in abundance but similar richness and biodiversity. In another few years, where vegetation would be allowed to grow and develop further, a stronger relationship could have been identified with vegetation structure and its influence in invertebrate diversity. During the 5 days the traps were outside, enough data was collected to form a representative sample, however numbers may be associated with the time of the year. Coming to the end of autumn, invertebrate numbers are generally lower in comparison to summer months, particularly pollinator species, though ground beetles and springtails are still active during winter (Fitzgerald et al., 2021). Understanding different species behaviours and ecological characteristics can help indicate invertebrate population patterns and establishment in restoration projects within agricultural lands (Woodcock et al., 2012).

Field characteristics and vegetation structure

The results from plant composition indicate that the farmed field had more plants species (n=12) than rewilded field (n=8) (Figure 10). This is unexpected as studies show that vegetation complexity is higher in ungrazed grasslands (Kruess and Tscharntke, 2002; Manning et al., 2015). However, as previously mentioned, other several studies on grazing show that moderate intensive grazing enhances species diversity and richness in grasslands (Pulungan et al., 2019). The distribution of plant species was more even in farmed field whereas rewilded field had a high dominance of Italian ryegrass. Grazers can suppress dominant species which allows other less dominant species to coexist, thus balancing vegetation competitiveness (Pulungan et al., 2019). Over grazing can lead to bare land and decreased species diversity, though neither of the fields had bare soil showing and the grass was very dense. Sharpham Farm grazing regime rotates livestock within farmed fields, this allows plant growth and recolonization of invertebrates. Also, as organic farms don't apply pesticides, it benefits plant species.

Rewilded field had different vegetation sizes and many tussocks scattered around the field which can provide refuge for invertebrate species from predators and increase their abundance. Studies suggests that diverse vegetation structure supports more species and tall grassland can enhance diversity and abundance, though some species are characterised in short swards (Morris, 2000). The farmed field has shorter and even grass from grazing, though the presence of grazers can also modify vegetation and increase richness. The results from the average vegetation height and the number of invertebrates (Figure 11) show surprisingly that in this study it was likely to find more invertebrates in shorter vegetation. A reason for this could be that some invertebrates are more active during sunlight hence they can be found in shorter vegetation (Campera et al., 2022). This could also be due to a pitfall trap limitation as denser and taller grass could impede movement thus invertebrates could have eluded the traps or went over it as there was a small gap between the ground and rain cover (Morris, 2000).

It is important to take into consideration the surrounding habitats around the fields. The rewilded field was next to hedgerows and reedbeds and the farmed field was next to a woodland and a meadow. Studies have shown that interactions between habitats can influence diversity and species composition, and were diverse vegetation surrounds habitats, invertebrate richness increases (New, 1995).

Limitations and further work

Main limitations of this study include the time of the year. The ground invertebrate survey was carried out during the end of autumn thus invertebrates are not as active as in spring and summer months, therefore seasonal surveys would be more representative for future studies (Fitzgerald et al., 2021). Also, vegetation was not in bloom at the time of the study which rendered the identification of plants and grass difficult. Even though there was a lot of invertebrate data, the pitfall traps were only out for five days, and a longer deployment time would generate more data that is representative of each field. Moreover, cups with larger diameter or traps with baits can attract and capture more invertebrates, though for this study average size cups were used without baits thus considering these factors in a further study could increase capture efficiency (Kim et al., 2021).

Due to time restraint and knowledge, the invertebrates were only taken to the taxonomic level of order, biodiversity results may change if they were identified to lower taxa such as genus or species level. Furthermore, a future study could use more different land use fields or compare the data to a more intensive farm. Limited literature of similar studies and lack of past and baseline surveys could limit scope of the study. The results represented in this study are a snapshot of the current state of Sharpham Farm and ideally regular monitoring of invertebrates should be carried out to assess shifts in species diversity and abundance over time as vegetation changes.

Conclusion

In conclusion, this study has shown that rewilding works as a tool for promoting invertebrate abundance in Sharpham Farm, though more time is needed to establish higher levels of biodiversity. The success of rewilding projects in restoring invertebrate biodiversity may depend on factors such as time scale of the project, surrounding landscape context and initial condition of the site (Torres et al, 2018). Rewilding has positive effects on invertebrate biodiversity by restoring habitats which will increase food resources, create niches and microhabitats, and reduce intensive grazing. Organic farms have showed to be beneficial at increasing invertebrate biodiversity and richness by reducing pesticide use and intensive continuous grazing, therefore measures should be aimed at increasing the size and extent of organic farming to restore biodiversity in agricultural land. Even though farmed fields have lower abundance, moderate grazing has a positive effect on invertebrate richness and biodiversity. Overall, long term regular monitoring of invertebrate populations is needed to evaluate the success of rewilding for biodiversity. Monitoring of vegetation succession and structure changes over time can also help understand how invertebrate communities could be affected by ecological restoration approaches. Results of the study also emphasise the importance of effective approaches for the conservation and restoration of invertebrates.

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