Re-wilding the landscape: Large herbivores, dung faunas and conservation at Knepp Castle, Sussex

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Laura E Eadie

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Signature: L. Eadie

Abstract

Due to the collapse of agricultural profitability, Knepp Castle Estate in West Sussex, UK, began to implement its Rewilding Project in 2001. The Rewilding Project began is based on returning previously intensively farmed land to a more natural state using grazing by large herbivorous animals to drive landscape change. The Project is based on work by Vera (2000) which proposed that the natural landscape of Britain was not closed-canopy forest, as previously accepted, but would have in fact been semi-open woodland due to the actions of large herbivorous grazing. This study uses dung fauna as a focal taxon to investigate the wider environmental impacts of the naturalistic conservation strategy. The results showed large variation in dung fauna diversity between the samples taken, due to vegetation changes across the site and also due to climatic variations. Overall the data collected showed high levels of dung fauna diversity. As dung fauna show high sensitivity to environmental change, and because they play an important role in grazing ecosystems, the high abundance has positive implications for the wider environmental impacts of the Rewilding Project at Knepp Estate.

Acknowledgements

I would like to thank my supervisor Eva Panagiotakopulu for her continued support and advice and for helping me to learn new and interesting skills in coleopteran identification, and for guidance in the use of BugsCEP. Thanks must also be made to Charlie Burrell for being helpful and accommodating when I was carrying out the research at Knepp Castle Estate. I am also very grateful to Paul Buckland for travelling a long distance to help with sample collection and to introduce to me to the site, and for his additional help with identification of the specimens.

Table of Contents

List of figures

1. Introduction

Through my dissertation research project I aim to investigate the effects of "naturalistic" conservation practices implemented at Knepp Castle Estate, Sussex. The Rewilding Project began in 2001 and is based on returning previously intensively farmed land to a more natural state using grazing by large herbivorous animals to drive landscape change. The project aims to improve land quality and biodiversity at the site, as well providing further insight into what pre-Neolithic landscapes in Britain may have been. This dissertation aims to examine the impacts of this naturalistic grazing regime using dung beetles (family Scarabaeidae) as a focal taxon, as improvements to the wider environment should result in increased dung fauna diversity.

1.1 Background:

Knepp Estate was previously a site of intensive farming which is now undergoing a process of re-wilding. This involves a naturalistic approach to wildlife conservation and land regeneration with minimum human influence. Due to the collapse of agricultural profitability at the site between 1996-2006, intensive farming was phased out of practice and conservation strategies introduced. These strategies include the conversion of the land into an organic site, the ceasing of ploughing and intensive grazing by sheep, and the re-introduction of native animal species. After the initial re-introduction of the animals the human influence is minimal, with stock density being resource controlled instead of determined through human management.

The Knepp Wildland Project has been implemented to improve the biodiversity of the area and to monitor the changes to the landscape as the project is implemented. It is believed the project will improve the biodiversity of the area by creating a diverse mosaic of grassland habitats through the actions of grazing animals (Hodder and Bullock, 2005). The project also aims to show alternative methods to high intensity farming through the production of high-quality organic meat at the site alongside the re-wilding project.

1.2 Justification

Research on environmental issues is of growing importance with increased awareness of human impacts on the environment, including the impacts of agricultural practices. Intensive agriculture in the UK often involves the use of pesticides and fertilisers to increase yields and the economic profitability of food production, however biocide use has many environmental concerns associated with it. This has resulted in concerns on the impacts of agricultural pesticide use on the environment both from the general public (Crane et al, 2006) and governments, resulting in the implementing of the Thematic Strategy on the Sustainable use of Pesticides (EC, 2006). The environmental issues of biocide use are relevant to Knepp due to the use of them being stopped as the estate is converted to an organic site, and the environmental changes this may result in.

Knepp Estate offers a unique research site in Britain due to the nature of the conservation methods used. Knepp Estate is unusual compared to many other conservation sites as the landscape outcome from the project is unknown and there are few examples from where expected results can be drawn. Research is being carried out on the changes occurring at the site as a result of the Rewilding Project but there have been no studies with a focus on the impacts on dung fauna ecosystems which can offer important information about the site due to the role of dung beetles as a focal taxon.

1.3 Aims and objectives

The key goal of this research is to analyse the affect of naturalistic grazing strategies at Knepp Castle on dung fauna at the site. I aim to do this through fulfilling the following objectives:

- Researching current dung fauna biodiversity through the extraction of beetles inhabiting dung by wet sieving.
- Using the samples collected to provide information on dung beetle variety and abundance.
- Taking additional notes of factors which may explain variations in diversity between the sample, such as the surrounding vegetation, climatic conditions and the age of the dung.
- Comparing my results with the results of the Invertebrate Baseline Survey carried out at Knepp Estate in 2005 as the Rewilding Project was being implemented. This will provide further indication of the impacts that the conservation strategy is having on the dung fauna.

As I am using dung fauna as a focal taxon I also aim to relate my findings on dung beetle diversity to the wider environmental changes as a result of the Rewilding Project.

2. Literature Review

2.1 What is natural?

If the aim of a conservation strategy is to maintain the natural biodiversity of a landscape, then it is important to understand what the natural landscape and biodiversity of an area would be without human disturbance. Therefore an understanding of the role of large herbivores in grazing systems is needed for suitable management of landscape-scale conservation programmes (Kirby, 2005). The Knepp estate provides a useful example.

2.1.1 Vera Hypothesis

There are many debates on what the natural landscape of Britain would be if there were no anthropogenic disturbances to the environment. For a long time it has been accepted that the natural landscape of Britain was continuous closed-canopy woodland (Svenning, 2002). In 2000 Vera introduced a new theory on the natural landscape of Britain, taking into consideration the impacts of large grazing herbivores. Vera proposed that the natural landscapes of Europe and North America would in fact be mosaics of open and wooded vegetation due to the effects of the browsing, grazing and trampling of large herbivores. The so-called Vera Hypothesis has been used to inform decision making for large nature reserves such as the Oostvaardersplassen in the Netherlands, and in relation to the New Forest National Park in the UK (Kirby, 2004).

2.1.2 Benefits and disadvantages of re-wilding strategies

The Vera hypothesis on the role of herbivorous grazing supporting mosaics of open and wooded vegetation has influenced numerous conservation strategies across the world (Faison et al 2006). As research has shown that pre-Neolithic environments with large herbivorous grazing were likely to result in varied landscapes, with some areas with vegetation cycles resulting in open land, and others with more permanent vegetation, including closed forest (Hodder and Bullock, 2005), it is hoped that naturalistic grazing strategies will recreate similarly varied landscapes. However, it is understood that re-wilding strategies will never completely recreate pre-Neolithic landscapes as present day environmental conditions differ from those of the past (Hodder and Bullock, 2005). The impacts of the re-wilding of landscapes are controversial, and the advantage and disadvantages of such projects are widely debated. There are numerous examples of sites across the world which have attempted to recreate past, more natural landscapes, those which pre-date large-scale alteration by human actions, and there have been numerous environmental trajectories documented for many sites.

In 2005 Donlan and others took the model a stage further and proposed "Pleistocene re-wilding" in North America. This proposal is based on re-creating environments suitable for the preservation of large vertebrate species. It is argued that the re-introduction of large vertebrates to areas of North America will create new grassland habitats and restore evolutionary and ecological potential of the sites. There are many ethical and aesthetic justifications for Pleistocene re-wilding and it is argued that humans have a moral obligation to restore the ecological potential of areas (Donlan, 2005). Pleistocene re-wilding is concerned with the benefits of grazing by large vertebrates, but as many of the large herbivorous species present then are now extinct, the projects are reliant on the use of surrogate species. These species would be extant descendants of the now extinct Pleistocene species, or introduced modern-day proxies (Zimov, 2009). On a more local scale the use of surrogate species is also seen in the Dutch Oostvaardersplassen reserve, a reserve which intends with minimal interference to recreate how European landscapes may once have looked, using surrogate breeds to replace those that are now extinct, such as Konik horses instead of the now extinct tarpan, and Heck cattle to replace the extinct aurochs (Marris, 2009).

Although it has been argued that attempts to recreate past environments will increase the biodiversity of reserves, others have argued that projects that aim to recreate ecological conditions from the past are more "sentiment than science" (Marris, 2009, pp.30). Conservation strategies, such as that on the Oostvaardersplassen reserve, raise the question of whether re-creating the past is actually a viable conservation strategy for the present day. Introducing surrogate species to a landscape that is now radically different from the Pleistocene landscape of 13,000 years ago has been considered to be an approach which will cause more damage than improvements to North American landscapes (Rubenstein *et al.*, 2006). Re-wilding with exotic substitutes may in fact be deleterious to currently indigenous species. Instead it is recommended that resources are better spent on reintroducing species to historical ranges from which they have only recently extirpated (Rubenstein et al. 2006; Dinerstein and Irvin, 2005). This is the strategy used at Knepp Estate where the traditional grazing animals being reintroduced to the site include Old English Longhorn cattle, Tamworth Pigs and Fallow Deer.

2.1.3 Knepp as a unique research site

Knepp is unique from the sites discussed due to using a naturalistic approach based on native breeds which are not extinct, and so surrogate species are not used. The large herbivorous animals were instead sourced from other sites in the United Kingdom. Knepp Estate also follows the practice used at Oostvaardersplassen, and differs from many other naturalistic conservation sites in the minimal human intervention to animal grazing at the site. Other grazing strategies often involve the careful management towards specific habitat and species composition (Hodder and Bullock 2005). The sensitivity of certain plant species to specific grazing densities is used to make decisions on cattle numbers (van Teeffelen *et al.*, 2008), to ensure that certain habitats are allowed to flourish. The aim of Knepp is to create as near-natural grazing regime as possible, within the limits required by animal welfare laws. Studies have been carried out on the re-wilding of North American landscapes (Caro, 2007; Donlan *et al.*, 2006) but there has been very little research on re-wilding strategies within Britain. Knepp offers unique opportunities to investigate further the effect of herbivorous grazing on the natural landscape of Britain.

The unique nature of Knepp Estate re-wilding strategy can create difficulties in the management of the site as there are few platforms on which to inform decision making. There are limitations and restrictions to how natural the project can be and these have been recognised and taken into consideration (see "Creating Naturalistic Grazing in Lowland England", 2007). These include recognising that historic breeds of grazing animal in Britain as domesticated animals, are not identical with extinct forms, although their grazing pressure is anticipated to be similar. In addition a degree of human intervention is required to comply with animal welfare laws. It is hoped that the Knepp Castle work can be used to inform similar projects.

Irrespective of the debate over what the natural landscape of Britain would be like without human intervention, re-wilding strategies with minimal human intervention are growing in popularity at conservation sites due to claims of numerous benefits and their relative cheapness. Through the Knepp Wildland Project it is hoped to return the biodiversity and land quality to how it was before the impacts of intensive farming at the site. It is also seen as an opportunity to investigate the impacts of large herbivorous grazers on the natural landscape, and to monitor habitat changes as the site reverts to a more natural state.

2.2 Dung Beetles

2.2.1 Using a single species as an ecological indicator

Invertebrates offer a rich source of information for conservation studies due to their large number of species, and the wide range of niches that species occupy (Spector, 2006). However, due to their diversity, comprehensive studies of invertebrates across a site are often not feasible due to limited time and expertise, requiring specialist taxonomic knowledge (Lovell et al. 2009). Instead it has been suggested that research is better carried out on specific focal taxa. When using focal taxa in research, the enquiry will signal that something is going on within a particular target species. From this one may speculate what is going on with other species or ecological processes (Feinsinger, 2001). There are certain criteria that need to be met to provide an efficient target species.

2.2.2 Why use dung beetles?

The focus of this research is on dung fauna as an index of the impacts of the naturalistic grazing strategy at Knepp Estate, it is important to understand the role of dung beetles (family Scarabaeidae) in grassland and grazing ecosystems. Spector (2006) discusses how Scarabaeidae are a suitable focal taxon and points to their abundance, their suitability for sampling, their habitat specialisation and the importance of their role in grazing ecosystem functions. The latter is seen in their involvement in the breakdown of dung and nutrient cycling. Dung beetles also have a high sensitivity to habitat modification and changing dung resources (Nichols *et al.*, 2008). In terms of agricultural grazing systems this includes sensitivity to biocide use, and changes in agricultural practices (Hutton and Giller, 2003). Dung fauna are also a suitable focal taxon due to methodological reasons. Dung beetles are often very abundant and it is feasible to get sufficient amounts of data in short periods of time and with minimal costs (Ausden, 1996). Once the samples have been collected, the taxonomy of Scarabaeinae is well known and understood, allowing for accurate identification through the use of keys such as Skidmore (1991) and Jessop (1986). The sensitivity of dung beetles to their environment makes them an ideal focal taxon for examining the possible impacts of the habitat changes at Knepp Estate during the Wildland Project.

2.2.3 Dung fauna and biocide use

Looking at dung fauna is particularly significant at Knepp Estate due to the effect of agricultural biocide use on invertebrate biodiversity. Avermectins are broad-spectrum biocides used to reduce both ecto- and endoparasite infection in cattle. Many previous studies on the impacts of biocides on dung fauna ecosystems have focussed in particular on the impacts of ivermectin, an anti-parasitic administered for the treatment of pasture animals (Dadour *et al.*, 1999; Madsen *et al.*, 1990; Kryger *et al.*, 2005). These studies have shown how such biocides can have unintentional effects on non-target species such as dung beetles, due to active parts of the drugs being excreted in cattle dung (Chiu *et al.*, 1999). This has been shown to decrease the survival rate of the larvae of dung-breeding Diptera and dung beetles (King 1993). This can result in decreased dung fauna biodiversity and therefore decreased rates of dung degradation (Herd, 1995). The dung fauna helps with the break down of faecal material and so accelerates nutrient cycling rates, preventing the loss of nutrients such as nitrogen from grasslands due to volatilisation (Nielsen, 2007). It has been shown that ivermectin can impair some of the biological processes which are important in nutrient cycling and have a detrimental effect on land quality (King, 1993). Slower breakdown rates of dung also result in a decreased grazing area as cattle avoid eating around the dung which can result in economic losses (Iglesias *et al.*, 2006). One of the first stages of the Wildland Project at Knepp Estate was to stop the use of chemicals and fertilizers on the land so the site complies with organic standards. This offers an opportunity to examine the possible impacts that previous biocide use at the site had on dung fauna ecosystems.

3. Study Methods

3.1. Study site

Knepp Castle Estate is located 8 km south of Horsham in West Sussex (Figure 3.1).

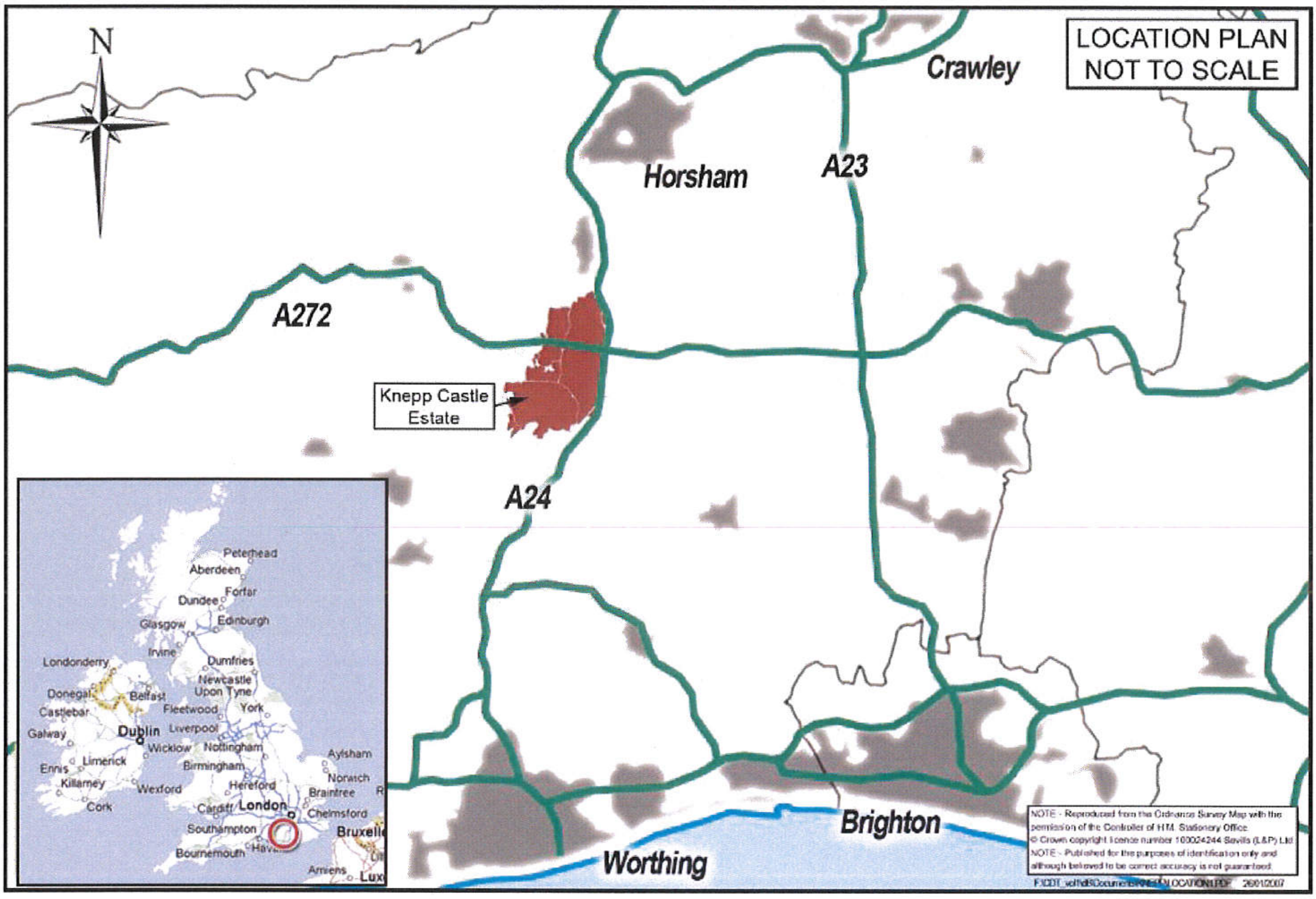


Figure 3.1 A map showing the location of Knepp within the UK, circled in red, and in relation to local towns. Source: Multimap (2009) and Knepp Feasibility Assessment (2007)

The Rewilding Project covers approximately 3,500 acres of land at Knepp Estate. This research focused on the southern block of the site, as shown in appendix 1. The samples were collected from dung from English Longhorn cattle which had recently been introduced to the site. The cattle were initially kept for two weeks in neighbouring fields to remove any traces of ivermectin or other biocides that may still remain in the cattle before being released into the Rewilding site. Land in the study area had initially begun being set-aside in the early 2000s. The flora varied across the site but the dominant landscape and vegetation was that of pastoral grassland, with areas of woodland and hedgerows and shrubbery separating the different fields (figure 3.2). A map of the dates which the different fields were set aside and of the wooded areas at the site can be seen in appendix 2.

Figure 3.2 A photograph illustrating typical landscape and vegetation on the southern block of the Rewilding site, from which the samples were collected. The image was taken in June, on the second date of data collection.

3.2. Experimental methods

The samples were collected directly from the dung through wet sieving as beetles will float in water (Sutherst *et al*, 1987). The dung was shovelled into a bucket of water and the beetles were left to float to the surface where they were skimmed off using a sieve or picked out using a paint brush or forceps. The beetles were separated from the dung by stirring it in the bucket to unsettle any specimens that may remain in it. After all the beetles had been extracted from the water, the contents of the bucket were then emptied across the ground and examined for any beetles which may have been missed. On all occasions no beetles were found in the emptied contents, showing the efficiency of the method used. Once collected the specimens were killed and stored in alcohol which acts as a preservative (Greendale and Greendale, 1971). Each sample taken represents one dung pat and on each day the site was visited, at least three samples were taken. A total of 14 samples were collected. The samples were labelled A-N and notes were taken of the age of dung from which the sample was collected, the surrounding habitat and vegetation and any other information considered important.

Samples were collected from the site on four different dates during spring-summer 2009. The first samples were collected in early May whilst the cattle were still being kept in the initial fields before being released into the Rewilding site. Samples were then collected once a month after this. To ensure that a good representation of the dung fauna was collected and to provide further information of why particular species may be found, a grading system was used for the age of the dung sampled, where 1 was fresh dung without a crust, 2 was dung which has started to crust on the surface, and 3 was dung which was crusted. This would ensure a sample of fauna living in dung of various ages. By taking samples once a month over a four month period I hoped to take into account seasonal dung changes in dung fauna.

Samples were taken from both the fields where the cattle were initially kept when they first arrived at Knepp Estate, and also from the south-western part of the estate which constitutes a large part of the Rewilding site. The fields in which the cattle were stored when they first arrived at the site are also in the process of being converted to certified organic land and although the fields are neighbouring land, they are included as part of the Rewilding Project. The initial movement patterns of the cattle meant that at first they kept returning to the original storage fields. These fields were therefore subject to high grazing pressures and would provide an ideal opportunity to see the impacts of herbivorous grazing on dung fauna. It is therefore relevant and important to include samples from these fields. The data collection points are marked on a map of the estate in appendix 1. The data I collected would give me data over a temporal scale as the cattle spread further around the land and the vegetation altered, whilst giving me a feasible amount of data to identify.

Once collected, the specimens were identified with the use of a stereomicroscope, which allowed magnification of the specimens. The magnified beetles were then identified down to species through the use of identification keys such as Skidmore (1991) and Jessop (1986). The samples were referenced to specimens in the Osborne Collection to aid identification.

3.3 Data analysis

3.3.1 BugsCEP

Once the samples had been collected and the specimens identified the data was used with BugsCEP (Buckland and Buckland, 2006), a computer software programme for coleopteran ecological studies designed to aid climate and environmental reconstruction but also for the storage and analysis of fossil and modern site data. BugsCEP was used to create count sheets for each sample and to produce abundance and species richness graphs. Baseline surveys were carried out at Knepp Estate in the summer of 2005 involving the collection of invertebrates through pit-fall traps. This data is stored in BugsCEP and can be used to provide comparisons.

3.3.2 Diversity indices

To analyse the diversity of the samples, diversity indices were used. Diversity indices allow the quantification of the diversity of samples of different sizes. When selecting appropriate indices to use, the scale of the research needs to be considered (Whittaker *et al,* 2001). Whittaker (1972) defines the α diversity as the diversity of species within a community or habitat. This is also otherwise known as local species richness (Bergon et al, 2006). As dung fauna belong to a specific and discrete ecosystem the alpha diversity of the samples can be calculated. This was quantified through the use of the Simpson Diversity Index and the Shannon-Wiener Index.

BugsCEP was also used to run a modified Sørensen Test. The Sørensen Coefficient is a measure of beta diversity and is used to measure the similarities in species composition between the different samples collected (Koleff *et al.* 2003).

4. Results

4.1 Variations in species abundance and richness

BugsCEP uses habitat codes assigned to species to signify the presence of taxa into the environments that they most likely represent. Output graphs are then produced showing the abundance of species in each sample common to the different habitat codes in each sample. Graphs are also produced comparing the total abundance and species richness for each sample. Figure 4.1 shows the abundance and number of species graphs for the samples, as well as the sample environmental representation sums (sumrep). These have been expressed as a percentage sum of the environmental representation for each sample (sumrep). Appendix 3 shows the full BugsCEP graphs produced, with each sample broken down into the different habitat codes occupied by the specimens.

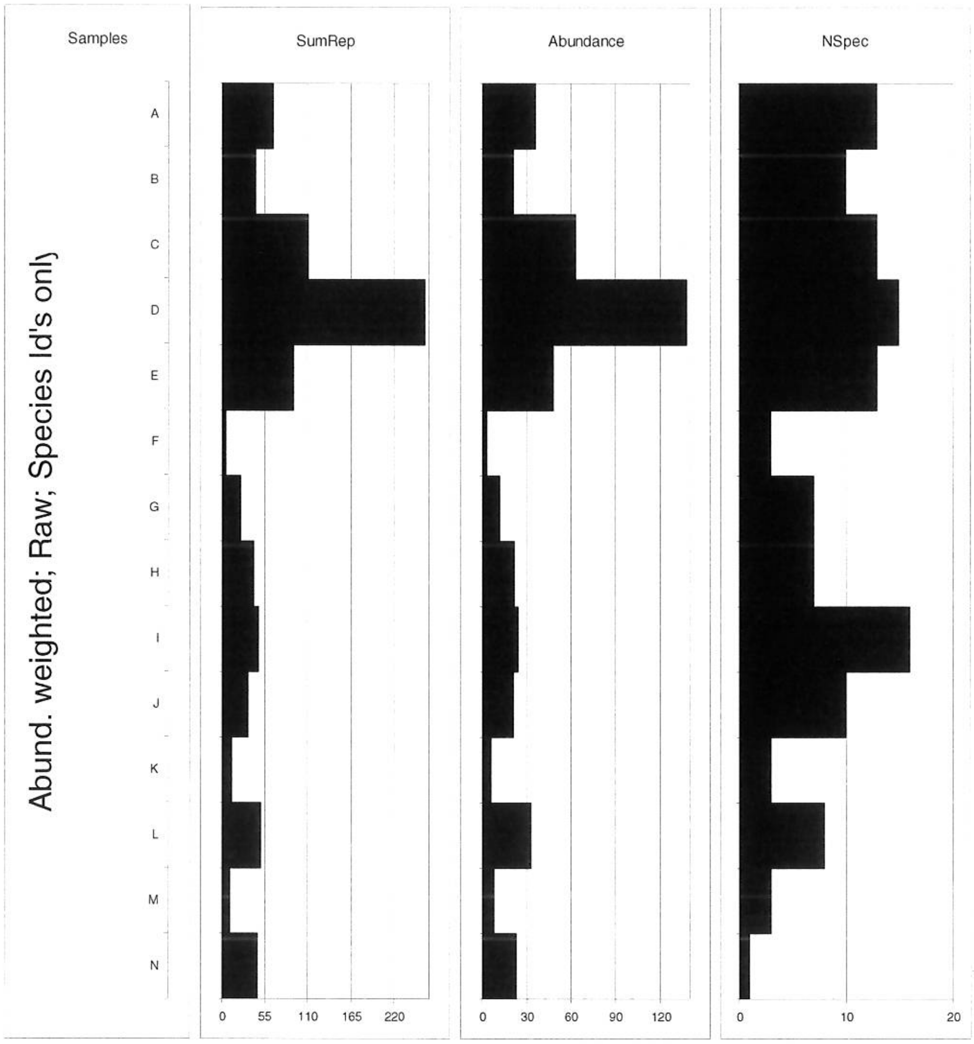


Figure 4.1 Graphs produced in BugsCEP showing the environmental representation sums (sum rep), abundance and number of species for each sample.

The graphs separating the samples into habitat codes (appendix 3) show that the most common habitat occupied by the beetles collected was dung, which is expected. It also shows some of the other habitats where the beetles are commonly found, such as woodland or meadowland/pasture. Variations in the variety of habitat codes covered by the specimens can be seen between the different samples. Large variations can also be seen between the samples when looking at the total abundance and total number of species (figure 4.1). These variations could be due to a variety of reasons such as changes in vegetation across the site, changes in the age of the dung or seasonal changes in the dung fauna composition. These reasons will be discussed in further detail later.

4.2 Measuring the biodiversity of the samples

Biodiversity can be a difficult term to define and is often dependant on the scale of the research being carried out (Bergon et al, 2006). At a simple level it could be considered "a measure of the total genetic and ecological diversity" (Southwood and Henderson, 2000 pp.462). The diversity of the samples could be expressed as species richness, otherwise defined as the variety of different species. However, the amount of information this actually tells us about the diversity of a sample is limited. Diversity is difficult to quantify as species abundance needs to be considered as well as species richness. When analysing species richness and abundance, there is a need to take into consideration rare species in the samples. Samples where there is only one individual of particular species can have their species richness value skewed by these specimens. This can be illustrated through looking at the rank abundance graphs of the data. Feinsinger (2001) recommends the use of rank abundance graphs to show the distribution of diversity data, as using species richness and species abundance values alone can produce misleading results. If the abundance of the species was evenly distributed the graphs would be a straight line. Figure 4.2 shows a rank-abundance graph, used to illustrate how the relative abundances of the different species in the samples vary. If species richness was used as a measure of diversity, the species of rank abundance 1 and the species of the lowest rank abundances on the graph would be given equal weighting. Species richness and species abundance are also difficult to compare when the samples are of different sizes, as a larger sample will have a larger abundance and is therefore likely to have greater species richness (Magurran, 1988).

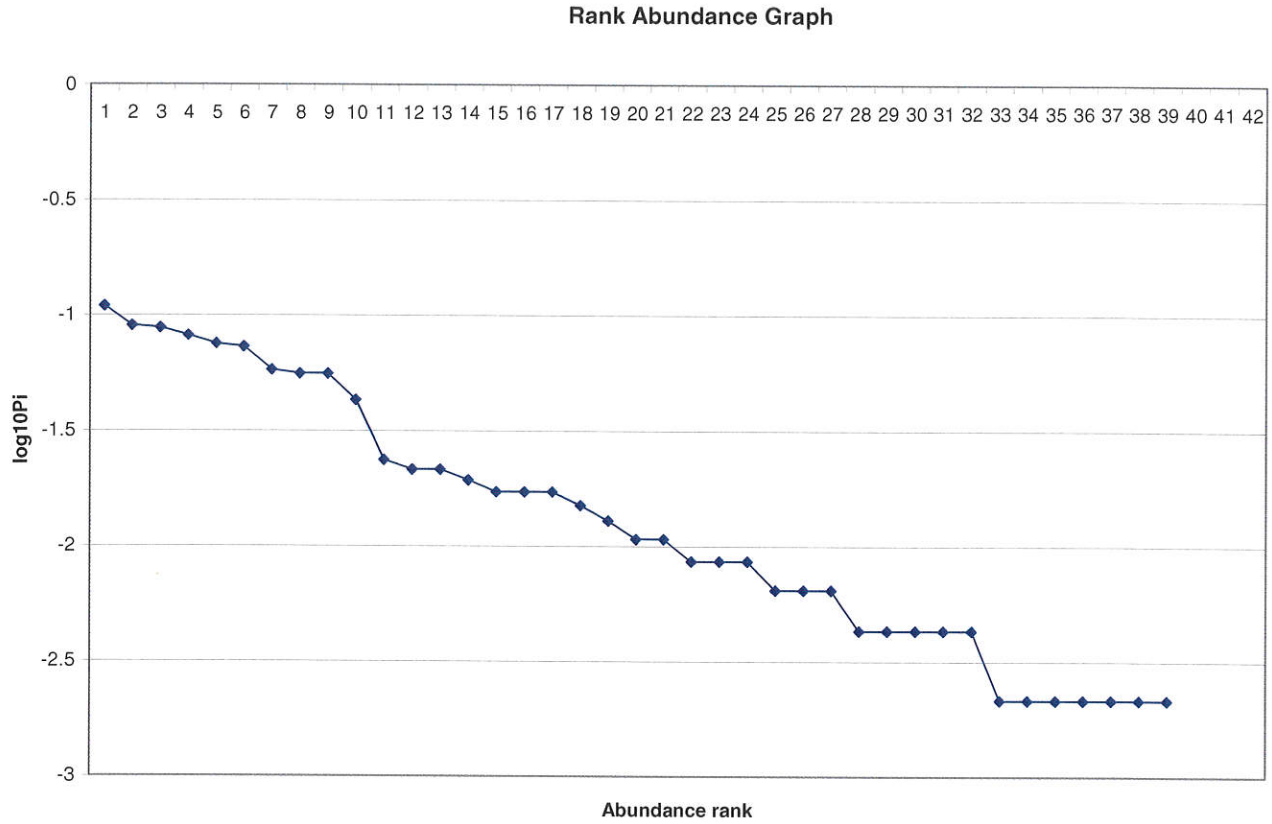


Figure 4.2 Rank-abundance curve of the species. The graph illustrates how the abundance of the different species in the samples varies. The length of the horizontal "tail" at the bottom of the graph represents the number of species with an abundance of 1. These are the species which can skew species richness values as they are given equal rating to species of abundance rank 1 despite being relatively uncommon.

As species richness and species abundance can be misleading values, diversity can instead be quantified through the use of diversity indices. Indices quantify the diversity of samples taking into account relative species abundances as well as species richness. Diversity indices allow the comparison of samples of different sizes. Different indices have different advantages and disadvantages associated with them and these need to be taken into consideration when interpreting the values produced.

Several indices were used when analysing the results to take this into account and to provide a thorough analysis of the results.

4.3 Quantification of dung fauna diversity with indices

4.3.1 The Simpson Diversity Index

The Simpson Diversity Index measures the probability that any two individuals drawn from a population will be the same (Southwood and Henderson, 2000). The index is a measure of dominance and is weighted by the most abundant species. The index is calculated using the following equation:

$$D = \frac{\sum_{i=1}^{S} n_i(n_i - 1)}{N(N-1)}$$

Where n_i is equal to the number of individuals in the *i*th species and N is equal to the total abundance.

The Simpson value produces a value between 0 and 1 where a 0 indicates high diversity and a value of 1 indicates low diversity. When the Simpson Index was calculated for the samples, a D value of **0.06** was produced. As this number is very low it indicates a high level of diversity of species collected.

4.3.2 The Shannon-Wiener Index

The Shannon- Wiener Index is a general diversity index that is positively correlated with species richness and evenness (Whittaker, 1972). The index is calculated using the proportion of each species to the total abundance using the following equation:

$$H_{\text{Sh}} = -\sum_{i=1}^{S} p_i \log p_i,$$

Where P_i is the proportion of individuals in the *i*th species as calculated by $\frac{n_i}{N}$

Where n_i is the abundance of the species and N is the total abundance.

The Shannon-Wiener Index is usually found to be between 1.5 and 3.5 and rarely exceeds 4.5 (Magurran, 1988). When the Index was used with the species identified in the samples collected from Knepp Estate, a H value of **3.03** was produced.

4.3.3 The Sørensen Coefficient of dissimilarity

The Sørensen Index is a measure of beta diversity. Beta diversity is the change in species composition between two or more populations (Koleff et al, 2003). The Sørensen coefficient of dissimilarity produces a value between 0 and 1 where 1 indicates that every species found in one plot is found the other, and 0 indicating that there are no species in common (Magurran, 1988). The Sørensen test is based on presence-absence data and so does not take into account species abundance and is therefore limited in the information it can provide as a measure of species diversity (Chao *et al,* 2005). Instead BugsCEP can be used to compare the different samples using a modified Sørensen test which takes into consideration the abundance of the samples. The correlation matrix from the modified Sørensen test can be seen below (figure 4.3).

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
A														
B	0.18													
C	0.12	0.23												
D	0.22	0.16	0.29											
E	0.12	0.41	0.32	0.18										
F	0.00	0.17	0.06	0.01	0.08									
G	0.29	0.12	0.15	0.12	0.13	0.00								
H	0.14	0.51	0.27	0.11	0.60	0.16	0.06							
I	0.17	0.31	0.11	0.13	0.39	0.07	0.22	0.22						
J	0.49	0.14	0.11	0.15	0.09	0.00	0.36	0.09	0.18					
K	0.09	0.00	0.08	0.03	0.00	0.18	0.20	0.00	0.00	0.14				
L	0.17	0.18	0.20	0.25	0.10	0.00	0.22	0.07	0.07	0.25	0.24			
M	0.09	0.21	0.22	0.08	0.18	0.36	0.10	0.20	0.13	0.07	0.00	0.00		
N	0.44	0.18	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.11	0.00	

Figure 4.3 A modified Sørensen correlation matrix produced using BugsCEP. The matrix compares the similarity of the samples. Values of over 0.4 have been highlighted as showing a significance similarity.

When analysing the results of the modified Sørensen test, a significance value of 0.4 was used to determine which samples could be considered significantly similar. It is difficult to use other research on dung fauna diversity to determine a suitable significance value as different research themes and sample sizes will produce different results. For this research it was decided that values above 0.4, meaning that the similarity in species composition is greater than 40%, could be considered significantly similar. Samples above this value in the table are highlighted in red. When this value was used only 4 of the results in the table are considered to be significantly similar. The matrix therefore shows the low correlation of species between the different samples. This indicates that there is wide dung beetle diversity at the site.

5. Discussion

5.1. Review of original aims and objectives

The samples collected have shown large variations in species richness and species abundance, as shown in figure 4.1. I will begin the discussion by offering explanations for these variations and will relate these back to the impacts of the Rewilding Project. I will then discuss the quantification of the diversity of the samples, and as dung fauna are being used as a focal taxon, I will discuss what implications these values have for the broader environmental impacts of the Rewilding Project. Some general comparisons are made with the results from the 2005 baseline survey. The chapter is then concluded by discussing the significance of the results for not only wider environmental conditions at Knepp Estate, but also for the use of naturalistic grazing as a conservation strategy.

5.2 Reasons for variations in species richness and abundances across the samples

The results have shown that there is a wide range of species richness and abundance values across the samples. Possible causes of this variation in sample diversity need to be taken into consideration when discussing how naturalistic grazing can affect dung beetle biodiversity at the site.

5.2.1 Changes in vegetation cover

Although dung is a specialised ecosystem, certain dung beetle species still show niche specialisation between different habitats, for example open field, pine forest and spruce forest (Hanksi and Koskela, 1977). Changes in vegetation can therefore influence which dung beetles are found at particular sites.

When the samples were collected the field from which they were taken was noted, as marked in appendix 2. This could provide an opportunity to look at changes between the different fields which were set aside at different times. However, the vegetation still showed large variation across single fields, and so changes may not be due to the time at which the fields were set aside or the field location, but simply due to the grazing habits of the cattle and the impacts of this on vegetation. For example if a sample was taken at the edge of a field near the shade of neighbouring woodland or shrubbery, this could affect the moisture of the dung and therefore dung fauna diversity compared to the middle of the field. Instead the samples taken from the Rewilding Project site and those taken from the site where the cattle were originally stored when they arrived at Knepp Estate were compared (figure 5.1). These sites were compared because although the original storage site is now considered part of the project and the area was clear of biocides when the cattle were moved in, it is possible there may be differences in dung fauna diversity compared with the rest of the Rewilding site. Due to the grazing habits of the cattle, they regularly return to the area where they were first introduced to the site and so the fields are subject to high grazing pressure compared to other fields, which has been shown to impact on dung fauna diversity (Jay-Robert *et al,* 2008). The cattle were originally stored in the fields to ensure any traces of avermectins were removed from them before they were introduced into the Rewilding Project. It is possible that if any biocides were excreted by the cattle that these may have an impact on the dung fauna found in the samples.

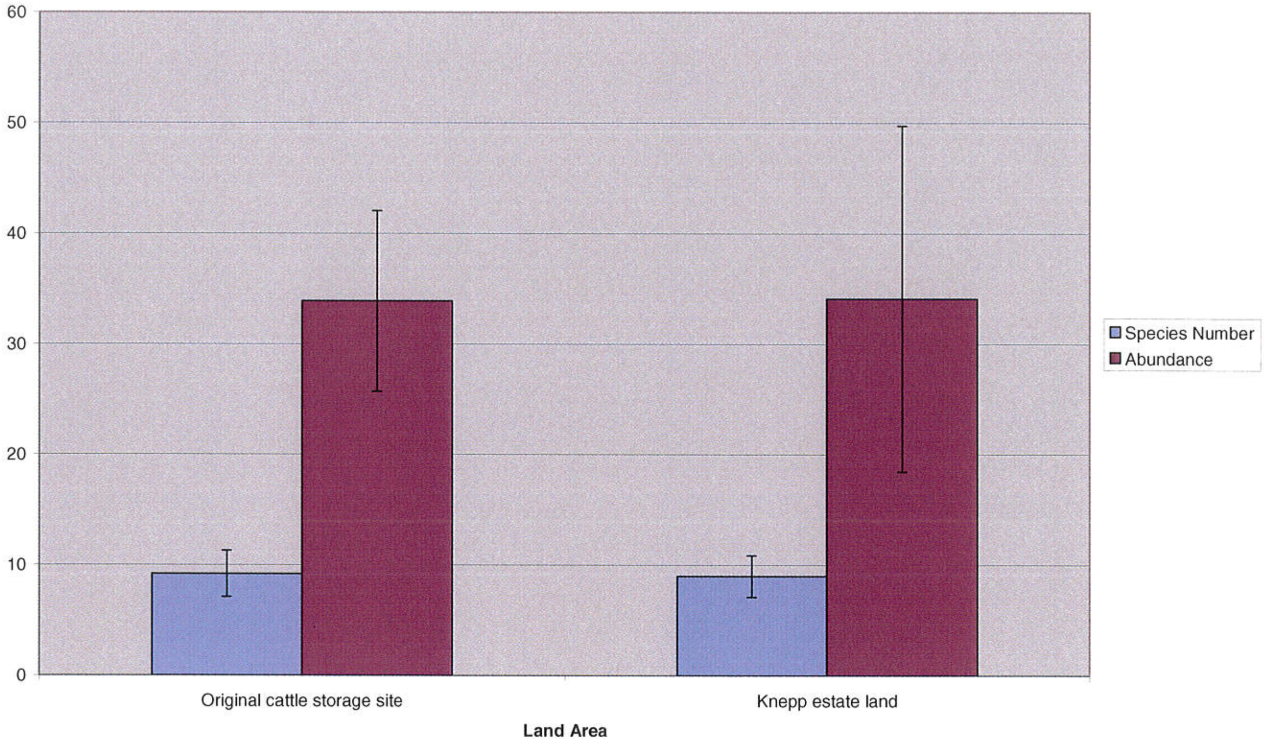


Figure 5.1 A graph comparing average abundance and number of species from samples from the original site at Knepp where the cattle were stored with samples from land including in the Rewilding Project. Bars representing the standard error of the means are included.

The graphs show that the average results are very similar and the error bars suggest a large deal of variation and overlap of the results from the samples from each area. This would indicate that there is little difference in the species abundance and species richness between the original cattle storage site and the Rewilding site. The differences between the sites could be lower that expected because both areas are included in the Rewilding Project and so there is no biocide use at either location. Ivermectin affects dung fauna diversity due to active compounds being excreted in cattle dung (Iglesias *et al*, 2006). This means that once the cattle were clear of all traces of ivermectin, there would be no differences in biocide concentration in the dung between the sites and so negligible impact on dung fauna diversity. The cattle were originally stored separately from the rest if the Rewilding site as a precaution to ensure no biocides contaminated the site. Unless the cattle had been recently treated with an avermectin, biocide concentration in the cattle dung was likely to be low or negligible and so would not have an effect on dung fauna diversity. Another possible reason that there are no significant differences in dung fauna abundance and species richness between the sites could be that although there was likely to be differences in grazing pressures, all the samples were taken from sites of pastoral grassland. Although there were slight differences in vegetation, with the site where the cattle were originally stored having shorter grass due to grazing, no samples were taken from areas of woodland. This means that a similar composition of dung fauna could be expected between the different sites.

As the amount of information supplied by comparing the original cattle storage site with the Rewilding Project site is limited, samples with particularly high and particularly low abundance could instead be looked at to see if the species composition could be related to landscape. The graphs produced by BugsCEP shown in figure 4.1 can be used to compare the abundance and species richness of the samples. The graph shows that sample D clearly has a higher abundance relative to the other samples. Sample D was taken from New Barn 4 field in June, the second date samples were collected. The field consisted of pastoral grassland vegetation and the sample was taken from the periphery of the field where the grass was slightly longer and a broader range of plant species were growing. The dung was categorised as age 2 and the weather on the day the sample was taken was mild and cloudy. It is possible the high abundance and species richness of sample D is a result of being collected from a site where the grass was longer and there was a wider variety of surrounding vegetation, as the sample was collected from near a hedgerow at the periphery of the field. It is also likely that the microclimate had an affect on the abundance and species richness as the sample was collected on the second date when it was cooler and wetter than the two later dates when samples were collected.

In comparison, samples F, K and M all show the lowest abundances. Samples F and K were taken from New Barn 5 field and sample M was collected from Bentons field and they were collected on the third and fourth dates the site was visited, when the weather was warmer and drier than the earlier dates. The dung ages which the samples were collected from were categorised as 2, 3 and 1 respectively. This would suggest that the age of the dung is not the cause for the low abundances in these samples. The surrounding vegetation from which the samples were taken could be a cause of the low abundances. Sample F was taken from a dirt track cutting across the field. Due to the hot, dry weather the ground had solidified and so would make burrowing difficult for the dung fauna (figure 5.2). As many dung beetle species such as Scarabaeidae and Geotrupidae species rely on burrowing in to the ground to lay eggs or to feed (Hanksi, 1991), prevention of doing so could be a cause of decreased abundance. The low abundances could be also attributed to changes in the weather, as the two later dates which the site visited were warmer and drier. This can affect dung fauna abundance as certain species such as *Aphodius sticticus* are shade specialists (Hutton and Giller, 2003), or show preference to dung with a higher moisture content, such as *Sphaeridium* species (Anderson *et al,* 1984).

Figure 5.2 Images of the dung which sample (left) and sample F (right) were collected from. The two samples show a large difference in species abundance and species richness, illustrating how the surrounding habitat can affect dung fauna diversity.

This shows that vegetation type influences dung fauna diversity which is important when analysing the impacts of the Rewilding Project. As dung fauna have been shown to show preferences to particular habitats, an area which covers both woodland and pastoral habitats will be most beneficial to broadening dung fauna diversity (Barbero *et al,* 1999). The results which showed the greatest average abundance and species richness were samples taken from the periphery of grassland fields. The vegetation in these locations tended to have not been grazed as short and on the later dates these locations offered greater shade than samples taken from the middle of fields. It is likely that such distinct differences between the middle and periphery of fields will decrease as the natural vegetation successions continue to develop across the fields.

5.2.2 Seasonal changes in dung fauna

It has been shown that seasonal changes can affect the species composition of dung fauna ecosystems (Roslin, 2001). Some dung fauna such as *Aphodius* species have been shown to be more common in spring and early summer, whilst some are autumnal species and may become more abundant in September (Hanski, 1991). Previous research in south west England over a similar seasonal period by Lee and Wall (2006) has suggested that Coleoptera abundance of dung shows seasonal variations, with certain species appearing to show peak abundance in the earlier months of the study. The average species abundance and species richness from the different dates the site was visited were therefore compared (figure 5.3).

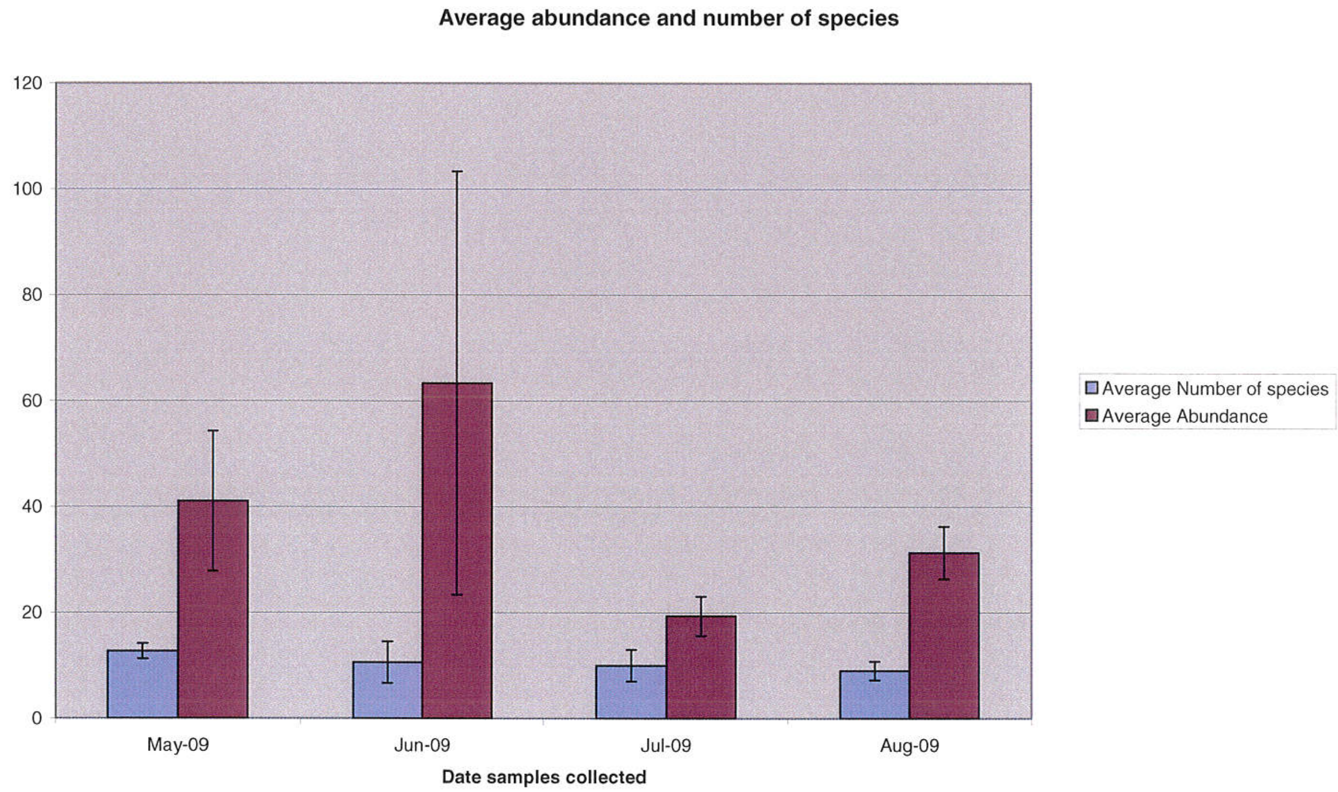


Figure 5.3 A chart showing changes in the average number of species and average abundance on the different dates the site was visited. The standard error of each mean is shown.

The graph shows no significant changes in average species richness, although there are notable differences in the average species abundance on the different dates. As the average abundances are greater in the earlier dates, this could suggest that seasonal change may be a factor influencing species composition of dung beetles at the site. The error bars show the standard error of the mean and indicate there is greater variety in the samples on the earlier dates. This would suggest that the mean values produced are less significant. However, there is still a notable difference between the species abundance on the later two dates compared to the earlier dates. The later two dates which the sites were visited were considerably warmer and drier than the first two dates, resulting in the rapid drying out of the surface of the dung. It is possible this could affect dung fauna diversity as it has been shown that earlier formation of a crust can decrease the "findability" of the dung as it prevents odour dispersal and dung beetles rely on their olfactory senses to locate the resource (Gittings and Giller, 1998). Research has shown that during particularly hot and dry periods of weather *Aphodius* species have shown preference to shaded dung over dung in open habitats (Landin, 1961). These changes in climate between the different dates could offer an explanation for changes in species richness and abundance on the different dates. As the results show seasonal changes in dung fauna population, it is important to consider these when analysing sample diversity in relation to the Rewilding Project.

5.2.3 Age of dung

The average number of different species and average abundance per sample was calculated for the different age categories of the dung (1, 2, or 3). These averages show that the highest average abundance and the largest average number of different species were found in dung in the age category of 2, a few hours old and beginning to form a crust (figure 5.4). This could offer an explanation for the variations in abundance and species variety. Fresh dung categorised as 1 showed the lowest average abundance and species richness. This may be due to the samples being taken before the dung had been left long enough to be fully colonised. Dung categorised as age 3 showed higher average values than dung categorised in group 1 but lower than the average species richness and abundance for dung categorised as 2. This could be due to the formation of the crust by samples of age 3 which prevents further beetles from entering the dung (Lee and Wall, 2006). Some northern temperate species of dung beetles such as Scarabaeidae are burrowers and may have burrowed to form nests to lay eggs by the time dung reaches an age category of 3. These would therefore not be collected due to the wet-sieving sampling method used. It is also possible that other species such as *Aphodius* species which do not burrow to form nests but are instead dung dwellers may have bred and left the dung by this point (Cambefort and Hanski 1991). This is supported by presence of larvae in samples from older dung, however, although the presence of larvae in samples was noted, they were not identified or counted. These factors could therefore explain changes in species richness and abundance in dung of different ages.

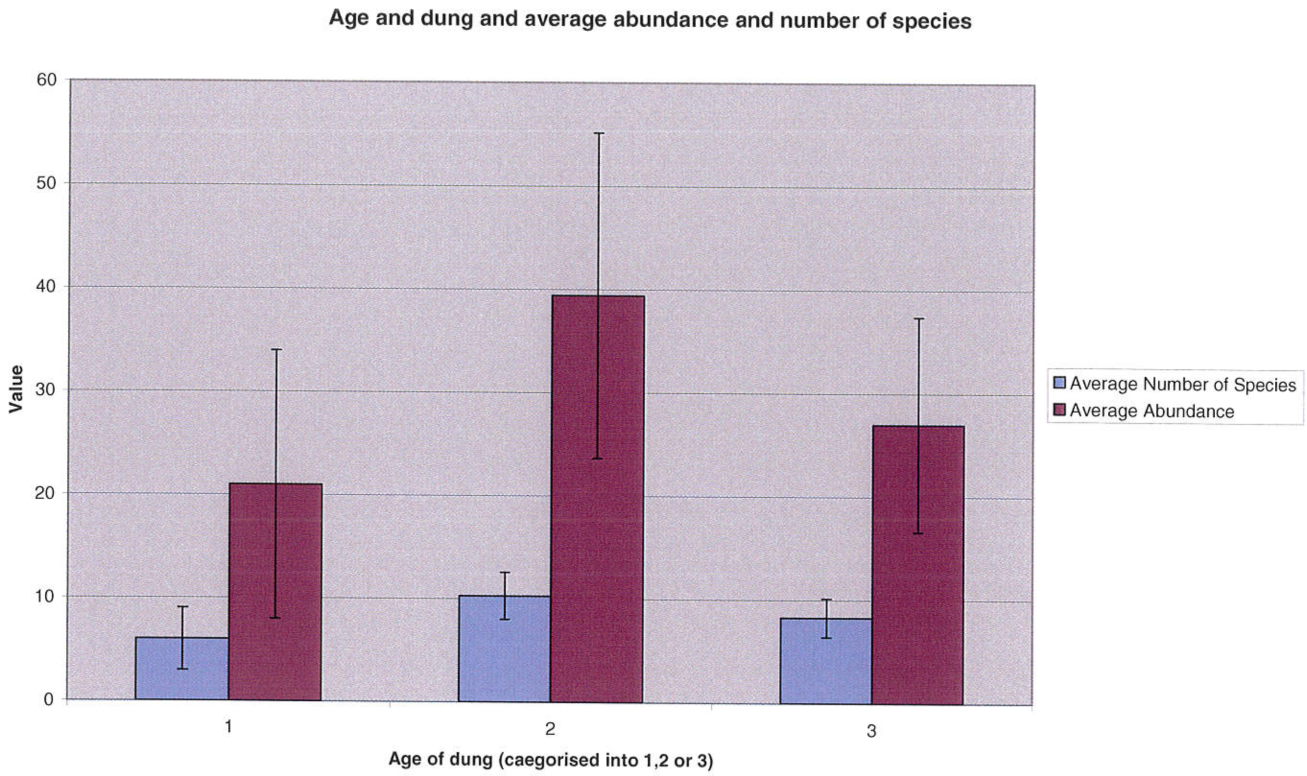


Figure 5.4 A graph comparing the average species abundance and species richness from dung of different ages. The standard error of each mean is shown.

Although the averages would suggest that age may influence dung fauna diversity, the error bars show a large spread of standard error from the mean. It also needs to be considered that when looking at samples with particularly high and low abundances, age appeared not to be a factor affecting the diversity. This suggests that when analysing the results, further consideration can be given to the impacts of the surrounding environment and seasonal changes.

Looking at variations in the species found in the different samples has allowed for investigation into some of the impacts of the Rewilding Project on dung fauna diversity. The differences between the samples have shown that changes in surrounding habitats and changes in microclimate have significant influences on the dung beetle diversity of the samples. The samples with the highest abundances and species richness were collected on the earlier dates when the weather was cooler and wetter. The samples also showed variations with different vegetation types. Samples collected from dung with surrounding grassland vegetation which had begun to grow out and diversify showed the highest abundances. The results have shown that different dung beetles show preferences to different surrounding habitats, supporting previous research such as that by Davis *et al* (2001) and Kanda *et al* (2005). This is a positive sign for dung fauna biodiversity as it believed that a naturalistic conservation strategy driven by herbivorous grazing will result in a mosaic of different landscapes (Kirby, 2004) which will support a wide range of dung beetles species.

5.3 Quantification of dung fauna diversity

As discussed, biodiversity covers more than the number of different species. Species richness can be misleading as a measure of diversity as it can be swayed by rare species or species where there are only single specimens in the sample (Feinsinger, 2001). Species richness should be given greater consideration when the species are about equally common than when wide disparities occur in their abundances.

5.3.1 What is shown by the diversity indices?

The Simpson Index produced a D value of **0.06**. This value is very close to 0 and so indicates a high level of diversity. As the Simpson index is a measure of the likelihood of any two individuals selected from the samples being the same, this would indicate there is a wide variety of species.

The Shannon-Wiener Index produced a H value of **3.03305**. The index usually falls between 1.5 and 3.5 (Magurran, 1988) and the larger the value, the greater the diversity of the sample. The Shannon-Weiner index is related to species richness and evenness and as the value produced is at the top end of the expected range of values, this suggests a high level of diversity. To provide further indication of the relative value of this diversity index, comparisons can be made with other research on dung fauna diversity to provide further indication of what the value represents. Hanski and Koskela (1978) used the Shannon-Wiener Index to quantify and compare dung fauna diversity of different dung beetle communities and all but one of the results produced fell between 2.084 and 2.894. Kanda *et al* (2005) also used the Shannon-Wiener index to quantify and compare dung fauna diversity. The values produced from both forest and grassland areas ranged between 1.511-2.348. Although these values can not be used in direct comparison with this research due to differences in research themes and sampling methods, it does provide an indication of the high H value produced from the dung beetle samples from Knepp Castle Estate.

The Sørensen Coefficient of Dissimilarity shows that there is low similarity between the samples. Values of 1 show complete similarity and values of 0 show no similarity. Values of over 0.4 were highlighted as showing significant similarity. Using this value, the correlation matrix shows that only four of the values show significant similarity to each other (figure 4.3). The low similarity between the samples suggests a high diversity of dung beetles at the site. The values also support the theory that various factors can influence dung fauna diversity within the site, as previously discussed.

5.3.2 Implications of diversity indices results

All three diversity indices have indicated a high level of diversity within the samples collected. This is an indication of the positive impacts of the Rewilding Project on dung fauna at the site. There are various possible ways in which the Rewilding Project could have resulted in high levels of dung fauna diversity as indicated by the diversity indices results. One reason, which is an important topic of environmental concern due to intensive agricultural practices, is changes in biocide use at the site. Biocide use in agriculture has been shown to decrease the species richness and abundance of dung fauna (Wall and Strong, 1987; Strong and Brown, 1987). It is therefore likely that the conversion of Knepp Estate to an organic site as part of the Rewilding Project has allowed for high levels of dung beetle diversity at the site. Dung fauna diversity is also likely to have increased due to vegetation changes as the project is implemented and the vegetation cycles begin to develop. As discussed, different dung beetles species show preferences to different habitat types. It is believed that the impacts of grazing by large mammals at the site will result in a mosaic of habitats as herbivorous grazing will interrupt some areas of natural succession, resulting in woodland, shrubbery and open grassland areas (Vera, 2000). These vegetation successions will take a while to fully develop, although the variety of habitats and diversity of vegetation at Knepp Estate has already broadened from that of intensive pastoral agricultural systems (Greenaway, 2007). These vegetation changes will have resulted in a wider range of habitats suitable for a broader diversity of dung beetle species.

5.4 Dung beetle species and ecosystem functioning

Different dung beetle species contribute unevenly to overall ecosystem functioning (Rosenlew and Roslin, 2008). This needs to be taken into consideration when examining the species found in the samples. As they contribute unevenly some species may be more important to the ecosystem and so particular interest should be paid to their presence or absence in the samples collected. Figure 5.5 compares the abundance and species richness of the different genera found in the samples.

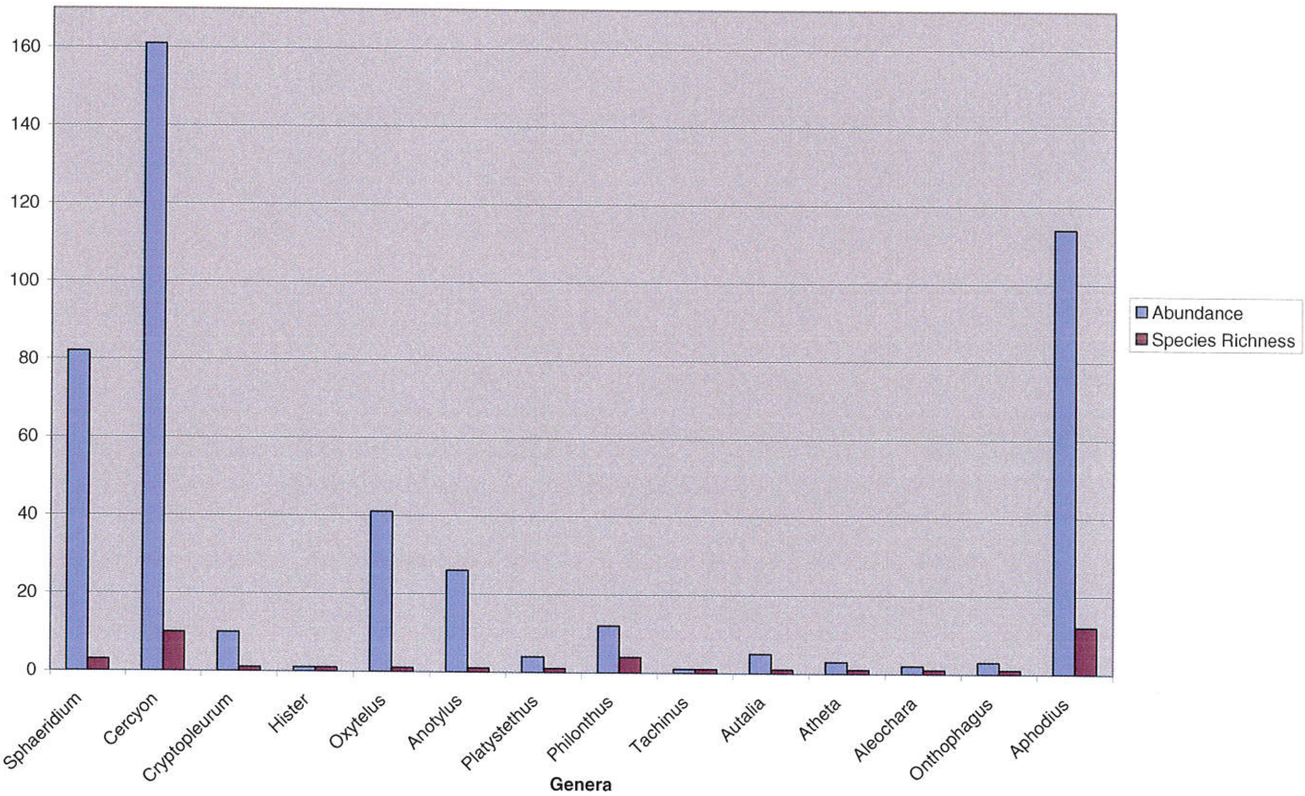


Figure 5.5 A graph showing the abundances and species richness of the different genera found in the samples collected

The results show that numerically *Cercyon* was the dominant genera, accounting for 34.6% of the total samples taken. *Cercyon* are from the family Hydrophilidae, a family of mainly aquatic beetles, although *Cercyon* species are commonly found in dung (Skidmore, 1991). The abundance of *Aphodius* species found is also high, with 24.5% of the samples being from the genus. *Aphodius sticticus* was also the most common species found in the samples. When looking at the species richness *Aphodius* and *Cercyon* were again the dominant genera, accounting for 30.8% and 25.6% of the different species respectively. The high abundance of these genera can be expected as many of their species are common to dung, and as *Aphodius* form the most common genera of coprophagous beetles in northern Europe (Hanski, 1991). However, it is also important that these genera were found in high proportions due to the role that they play in dung ecosystems. Where as predatory species such as those from the family staphylinidae are merely casual marauders of dung habitats, genera such as *Aphodius* rely exclusively on dung as their primary habitat. It is therefore important to consider their abundance due to their reliance on dung ecosystems for feeding and breeding (Gittings and Giller, 1997). *Aphodius* species also offer important contributions to dung ecosystems. The importance of the role of *Aphodius* in dung dispersal in northern temperate grassland ecosystems through direct metabolisation, dung burial and microbial stimulation has been identified by Holter (1979). The contribution of *Aphodius* to dung dispersal is also related to nutrient cycling as fast rates of dung dispersal will result in improved nutrient cycling and enhanced land quality (Nichols *et al.*, 2008). *Aphoidus* species further contribute to ecosystem functioning through decreasing the occurrence of endoparasitic species in cattle (Bergstrom, 1983). Their high abundance and species richness at Knepp estate is therefore a positive indication for the quality of the grassland ecosystems at the site.

Aphodius species differ in their habitat preferences with some species more common in open pasture, such as *Aphodius fossor,* and others preferring woodland (Roslin, 2000). The high abundance of *Aphodius* in the samples collected can be expected due to the varying nature of the vegetation at the site. As the vegetation cycles and patches of woodland continue to develop then the diversity of *Aphodius* and other dung fauna species can be expected to increase as a wider range of habitats becomes available for utilization. Coprophages such as *Aphodius* have also been shown to show greater habitat specialization compared to carnivorous dung beetles. A wide variety of coprophage species is therefore a greater indication of wider diversity (Hanski and Koskela, 1978).

5.5 Comparisons with 2005 Coleopteran Baseline Survey

To further analyse the impact of the Rewilding Project on dung fauna at the site, comparisons can be made against the Invertebrate Baseline Survey carried out at Knepp Estate in 2005. Pit-fall traps were used to conduct the 2005 survey and the differences in the methods used compared to this research could affect the results obtained. The Baseline Survey did not have a particular focus on dung fauna and so will include a wider diversity of Coleoptera. It is therefore unsuitable to make detailed comparisons of the two studies, however certain general comparisons can still be made. The first important comparison is that there were no dung occupying beetles found in the 2005 survey which were considered of notable conservation interest according the UK Red Data Books (Hyman, 1992). However in the 2009 samples, two notable species were found. These were *Cercyon obsoletus* which is classified as N, notable, and *Cercyon atricapillis* which is classified as NB, notable B. Whilst it is incorrect to assume that the absence of these species in the 2005 Baseline Survey means they were not present at the site, their presence in the 2009 data is a positive sign on the impacts of the Rewilding Project on dung fauna diversity at the site.

5.6 Wider Implications of dung fauna diversity

As dung fauna are being used as a focal taxon, high diversity in the samples could indicate that wider diversity at the site is high. As discussed, the landscape is expected to develop through vegetation cycles as the Rewilding Project progresses. As the cycles progress and are interrupted by herbivorous grazing a mosaic of different habitats is created and dung fauna common to different habitats will be found. When used with BugsCEP the results signify the presence of beetles classified in several different ecocodes (appendix 3). As the samples show a variety of dung beetle species which demonstrate specialisation to a range of different habitats this would suggest that there is already a variety of different grazing habitats and vegetation at the site. This is supportive of the Vera hypothesis (2000) that the effects of large herbivorous grazing animals will increase biodiversity through creating a mosaic of different habitats.

The important role of dung beetles in grassland ecosystems and their sensitivity to habitat change has been discussed. Increased dung beetle abundance would result in increased rates of dung breakdown. This will increase the grazing area available to the cattle as grazing animals avoid feeding near dung (Iglesias *et al.*, 2006). High rates of dung breakdown would also indicate fast rates of nutrient cycling, resulting in improved land quality. The actions of dung beetles improves he nutrient quality of soils by reducing denitrification losses by incorporating faecal matter into the soil and through the elimination of anaerobic zones within dung piles (Dubeux *et al.,* 2007) . This in turn has been shown to stimulate primary production and vegetation growth (Bang *et al.*, 2005).

As discussed different dung fauna species contribute differently to dung ecosystem functioning. The results have shown high levels of *Aphodius* species, which are particularly important to dung ecosystems due to their reliance on the resource for breeding and feeding but also due to their contribution to grassland ecosystem functioning. The high abundance and species richness of these dung beetles therefore has positive implications for Knepp Estate. As the mosaic of different habitats created through herbivorous grazing continues to develop, this will provide habitats suitable for a wide range of dung beetle species which offer different contributions to grazing ecosystem functioning.

This research, along with other environmental monitoring at the site, has illustrated how environmental quality has improved at the site since the Rewilding Project was implemented. This would suggest that naturalistic conservation strategies are a successful method of improving environmental quality in the UK. Although the predicted vegetation cycles have not had time to fully develop, wildlife diversity at the site is already growing considerably compared to the monoculture of intensive agricultural systems. As the Knepp Estate Rewilding Project is a unique conservation strategy in the UK, the results of the project offer a platform inform decision making for similar strategies in the UK.

5.7 Further Research

This research focused on an area of Knepp Estate where English longhorn cattle were roaming and all the samples were collected from dung from the herd. Collecting samples from a specific grazing species could influence the results as dung beetles show preferences to dung from different herbivorous animals (Finn and Giller, 2002). Investigation into the impacts of the Rewilding Project on dung fauna could be furthered by covering areas frequented by different species of grazing animals. It is also likely that different herbivores will exert different grazing pressures on the landscape and so create different habitats suitable for different dung beetle species. As the cattle had only recently been introduced to the site when the samples were collected, they had not shown much interaction with other grazing species. It has been shown that areas of mixed livestock tend to have greater beetle diversity (Hutton and Giller, 2003; Barbero *et al,* 1999) and so when the species do begin to interact more dung beetle diversity may further improve.

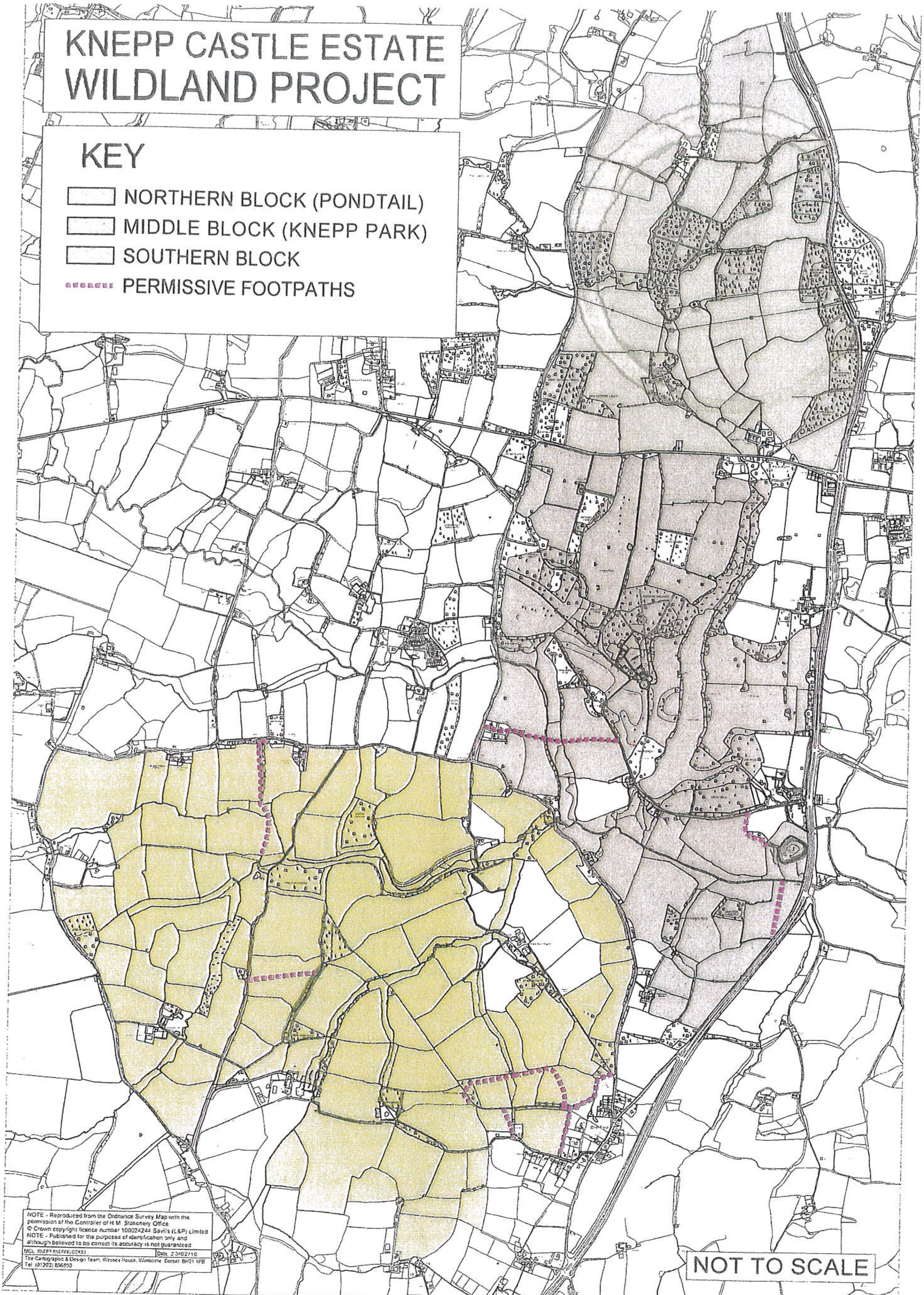
The results have also shown how changes in vegetation can affect dung fauna diversity. Dung beetles show specialisation and preferences to different surrounding habitats. A high diversity of dung beetle species could indicate a wide range of suitable habitats. When analysing the results, the samples with the highest abundance and species richness were those which were collected from fields where the grassland vegetation had begun to grow out and the variety of plant species broaden. The natural vegetation cycles proposed by Vera (2000) consist of three phases, open, park and scrub. It is predicted that one cycle through these phases, producing the predicted mosaic of habitats as described by the hypothesis, would take approximately 500 years (Kirby, 2004). As the Rewilding Project only began being implemented in 2001, the full impacts of the grazing scheme on the environment will not have fully developed. It is therefore likely that further development of the cycles may yet result in a wider diversity of habitats at the site, resulting in an increase in the diversity of dung beetle species. This could be further investigated through collecting samples along a vegetation transect at the site, ranging from densely grazed grassland to wooded areas and seeing if there is differences in diversity.

6. Conclusions

The results from this research have shown high levels of dung fauna diversity at the site. This is supported by the α-diversity index values, the Sørensen index indicating low similarity of species between the samples and also due to the presence of two species of notable conservation interest. As dung fauna were used as a focal taxon this can be related to broader ecological trends at the site. Dung fauna species are sensitive to changes in their environment. Due to their sensitivity to environmental changes, the high diversity of dung beetles is in indicator of high environmental quality. This can be particularly related to changes in biocide use at the Knepp Castle Estate. Many studies have illustrated the negative impacts biocides, and in particular avermectins, can have on dung fauna diversity. It is therefore likely that the conversion of Knepp to an organic site as part of the Rewilding Project has been an important factor in increasing dung fauna diversity.

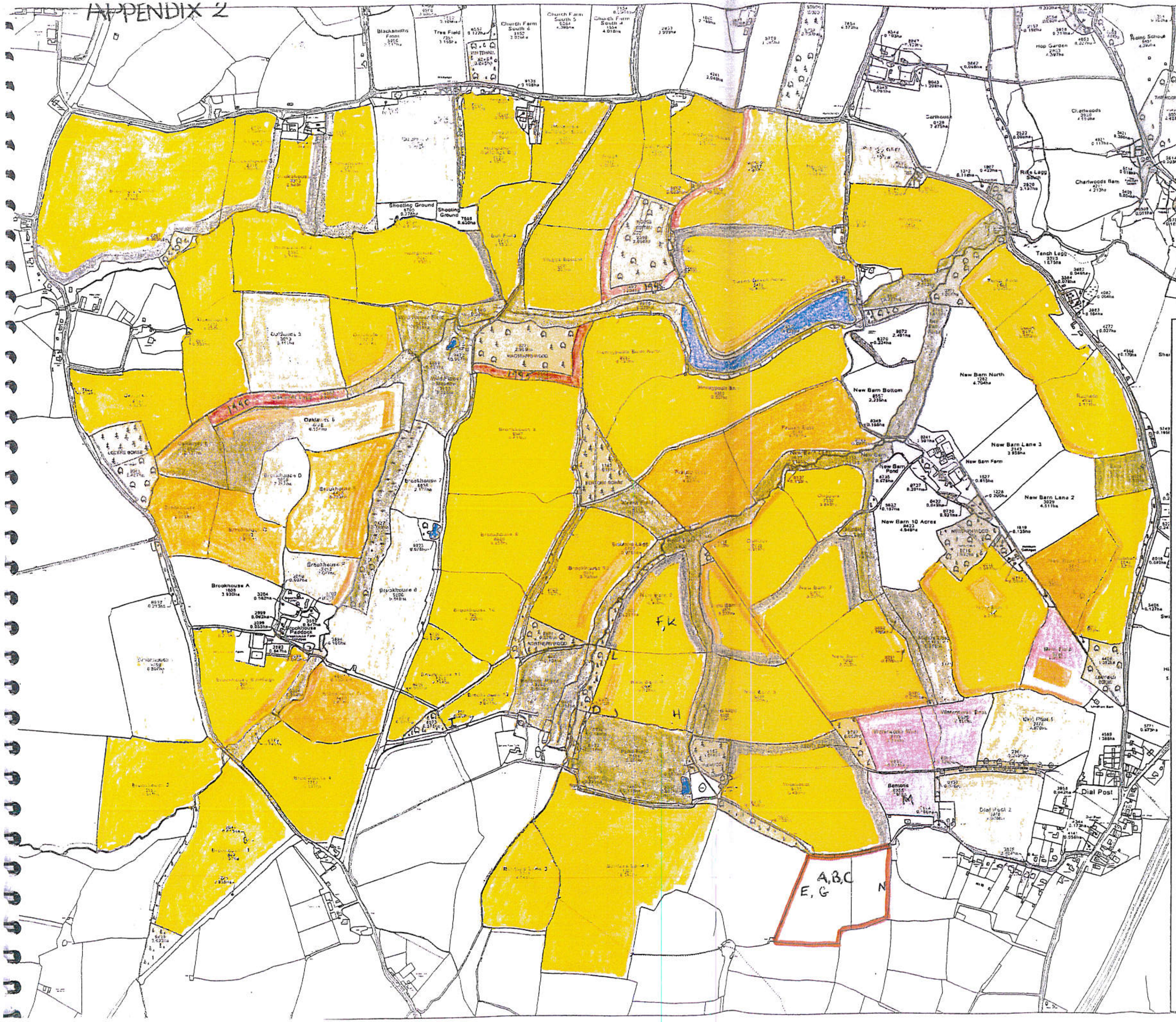
A high diversity of dung beetles would also suggest improved environmental quality due to the importance of their role in grassland ecosystems. In particular *Aphodius* species, which were found in high abundance at Knepp Estate, have been noted for their important role in dung breakdown and the associated recycling of organic matter and nutrients in northern temperate regions (Hutton and Giller, 2003). Abundant and varied dung beetle assemblages also offer improvements in vegetation growth, secondary seed dispersal and parasite control (Nichols *et al.,* 2008).

The Rewilding Project at Knepp Estate is a unique conservation strategy in the United Kingdom. Often conservation strategies are carefully managed in order to create a desired landscape for conservation. Leaving herbivorous animals to roam freely with minimum human intervention is an unusual method as there is no defined goal to the conservation strategy. This dissertation has aimed to show the positive implications that high dung fauna diversity has for wider biodiversity and environmental quality at Knepp Estate. Although the vegetation cycles and eventual landscape which will be created by the strategy are still uncertain, the project has so far had positive implications for the use of naturalistic grazing as a conservation strategy. Due to its unique nature Knepp Estate sets an example for similar potential conservation strategies in the United Kingdom, but also offers a unique and fascinating site for scientific research on the impacts of large herbivorous grazing on the natural landscape of Britain. This study offers a baseline focussed specifically on dung fauna at the site, allowing for further comparisons of diversity, and its implications to wider diversity at the site, as the vegetations cycles fully develop and progress.



APPENDIX 1 - A MAP OF KNEPP ESTATE SHOWING THE SOUTHERN BLOCK, WHERE THE SAMPLING WAS CARRIED OUT

APPENDIX 2



Historical Cropping - New Barn and Brookhouse Farms, Knepp Estate

Showing the year each field went into either Set-aside or into fallow, following the previous year's harvest.

- Set-aside in 1999 (or before)
- Set-aside in 2000
- Set-aside in 2001
- Set-aside in 2002
- Set-aside in 2003
- Set-aside in 2004
- Fallow in 2005
- Fallow in 2006
- Wild Bird Seed Crop 2005 (put in)
- Wild Bird Seed Crop 2006 (put in)
- Permanent Pasture

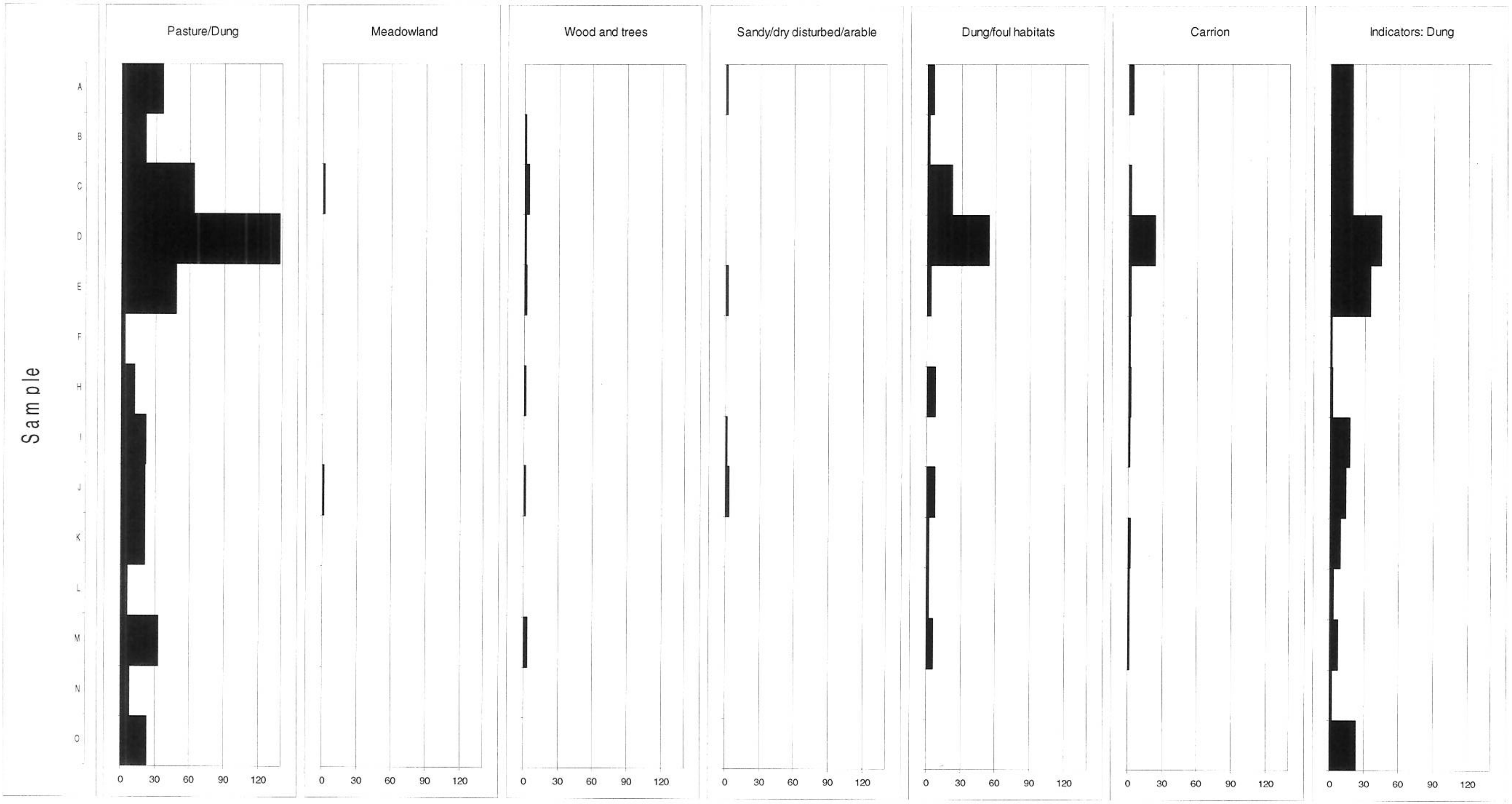
In 2005, land taken out of arable production was able to become fallow under SPS rules. This land has to be cut at least every 4th year to stop scrubbing up, to meet cross compliance regulations.

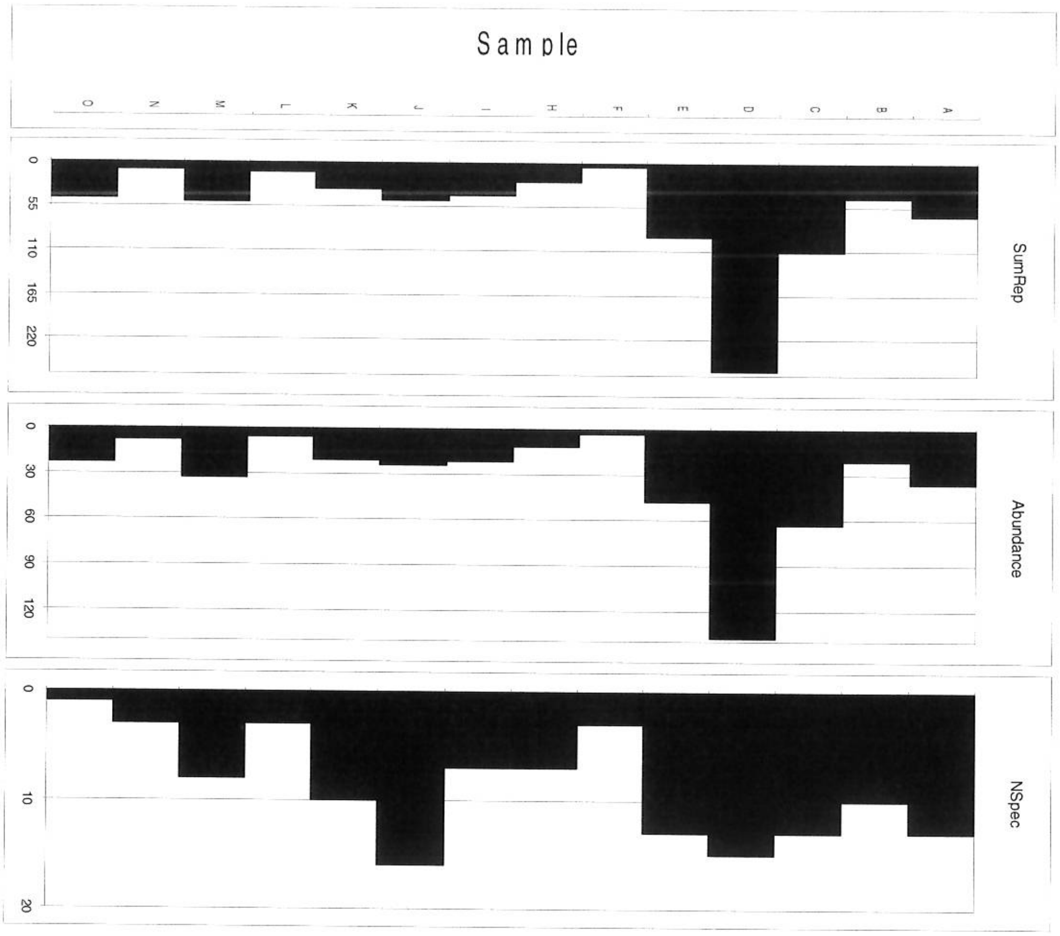
Land around buildings is cut about 100m from properties each summer.

July 2007

— ORIGINAL STORAGE SITE

Appendix 3- BugsCEP graphs showing the breakdown of the samples into different Ecocodes occupied by the specimens





Sample
O N M L K J I H F E D C B A
SumRep
0 55 110 165 220
Abundance
0 30 60 90 120
NSpec
0 10 20

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