

STRIVE

Report Series No.67

The CréBeo Soil Biodiversity Project

STRIVE

Environmental Protection
Agency Programme

2007-2013

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EPA STRIVE Programme 2007–2013

The CréBeo Soil Biodiversity Project

**CréBeo – Baseline Data, Response to Pressures, Functions and
Conservation of Keystone Micro- and Macro-Organisms in Irish Soils**

(2005-S-LS-8)

STRIVE Report

End of Project Report available for download on <http://erc.epa.ie/safer/reports>

Prepared for the Environmental Protection Agency

by

University College Dublin

Authors:

**Olaf Schmidt, Aidan M. Keith, Julio Arroyo, Tom Bolger, Bas Boots, John Breen,
Nicholas Clipson, Fiona M. Doohan, Christine T. Griffin, Christina Hazard and Robin Niechoj**

ENVIRONMENTAL PROTECTION AGENCY

An Ghníomhaireacht um Chaomhnú Comhshaoil
PO Box 3000, Johnstown Castle, Co. Wexford, Ireland

Telephone: +353 53 916 0600 Fax: +353 53 916 0699

Email: info@epa.ie Website: www.epa.ie

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The EPA STRIVE Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

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Details of Project Partners

Olaf Schmidt

School of Agriculture, Food Science and
Veterinary Medicine
Agriculture and Food Science Centre
University College Dublin
Belfield
Dublin 4
Ireland
Tel.: +353 1 7167076
Email: olaf.schmidt@ucd.ie

Tom Bolger

School of Biology and Environmental Science
Science Centre (West)
University College Dublin
Belfield
Dublin 4
Ireland
Tel.: +353 1 7162330
Email: tom.bolger@ucd.ie

Christine T. Griffin

Institute of Bioengineering and Agroecology
Department of Biology
National University of Ireland
Maynooth
Co. Kildare
Ireland
Tel.: +353 1 7083841
Email: christine.griffin@nuim.ie

John Breen

Department of Life Sciences
University of Limerick
Limerick
Ireland
Tel.: +353 61 202853
Email: john.breen@ul.ie

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Executive Summary

European and national policy developments on soil protection and conservation of biological diversity (biodiversity) have exposed knowledge gaps that need to be addressed by research. Soils are among the most biodiverse ecosystems on earth and, in turn, many ecosystem services provided by soils (such as nutrient cycling, waste degradation, pest and disease suppression, carbon storage) depend on the activity of these diverse organisms. However, systematic and specific information is limited on the organisms that live in Irish soils, their response to environmental pressures and their roles in soil processes.

The project had four specific scientific objectives:

1. To provide baseline data on the distribution and diversity of a range of important soil organisms in major land uses and soil types in Ireland;
2. To establish the need for protecting specific habitats where soil-dwelling ant species occur;
3. To investigate under field conditions the response of important organisms to pressures caused by land-spreading of organic waste materials; and
4. To conduct innovative ecological experiments that examined the link between biodiversity and functions in soils.

In relation to these objectives, the key achievements of the project are:

- A survey was conducted of the diversity of micro-organisms (bacteria and fungi), root-associated fungi (mycorrhizas), nematodes (microscopic worms), earthworms, micro-arthropods (mites) and ants at 61 sites representing five dominant land uses and eight major soil groups in Ireland. The survey produced a wealth of new data on the occurrence, abundance and diversity of these organisms; it showed that patterns of biodiversity across land-use classes varied for different groups of organisms, that soil type had limited effects on biodiversity, but soil properties were related to the

diversity of many soil organism groups. Differences across classes suggest that the usefulness of particular taxa/groups as biodiversity indicators may be land-use specific, while variation within land uses suggests that this classification could be refined. Previously unrecorded species include 13 predatory nematodes, an earthworm endemic to southern France and a mite species potentially new to science. These findings highlight the lack of inventory data on soil organisms in Ireland; increasing the number of sites would likely lead to further discoveries. This survey provides the first systematic baseline data for future monitoring and reporting on biodiversity in Ireland ([Chapter 2](#)).

- Eighty field sites in 10 habitat types were surveyed and characterised in terms of their conservation value for rare ant species and other vulnerable organisms that are associated with ants ([Chapter 3](#)).
- The biodiversity of key functional groups in agricultural soils was shown to be resilient to the application of a common soil management pressure. In two replicated field experiments, annual land-spreading for 2 years of two types of biosolids (treated sewage sludge) at permitted rates (~5 t dry matter/ha) had few measurable effects on soil micro-organisms, mycorrhizal fungi or nematode worms, and had positive effects on earthworm abundance in an arable soil. Temporal variability was generally greater than treatment effects for all soil organism groups ([Chapter 4](#)).
- New molecular biology and isotopic tools were used to investigate the interrelationships of important soil species and ecological functions. Grassland ants were shown to alter the properties of soil and to harbour (in their nests and abdomens) different micro-organisms and functional genes related to nitrogen cycling than occur in soil. Earthworm species that feed on plant residues were shown to contribute to the recycling

of nitrogen and carbon; any loss of such species (e.g. through predation by exotic flatworms) would have impacts on ecosystem functions such as decomposition and nutrient cycling ([Chapter 5](#)).

The recommendations for soil biological monitoring in Ireland include:

- To revise and differentiate more land-use classes;
- To identify benchmark sites;
- To use a tiered structure of core and specific indicators;
- To include measurements of soil processes;
- To establish a working group to oversee the development of a monitoring scheme; and

- Relating to pressures on and functions of soil organisms, further research should be conducted on the long-term effects of biosolids on soil biota, and the relationships between temperate ants and microbes.

By increasing the scientific knowledge and research capability in soil biodiversity in Ireland, this project has:

- Informed sustainable soil protection strategies; and
- Enhanced our understanding of biological diversity in Irish soils, a priority under the National Biodiversity Plan.

Full technical details of this project, including method descriptions, statistical analyses, results and a comprehensive list of references, are contained in the Final Technical Report.

1 General Introduction

1.1 Background

The European Commission's initiative *Towards a Thematic Strategy for Soil Protection* is intended to lead to the establishment of protection strategies and quality objectives for the 'forgotten' environmental medium, soil. Soil science has moved centre stage in current thinking about broader environmental issues, including climate change, ecosystem health, sustainability and biodiversity (Wardle et al., 2004; Foley et al., 2005; DEFRA, 2009). Central to all considerations of soils, their functions and protection is the concept that soils (the 'pedosphere') are living, complex, dynamic and interactive entities (Bardgett, 2005).

Soils and soil organisms are essential components of terrestrial ecosystems. There is universal agreement among both scientists and policy makers at international (Francaviglia, 2004), European (Andr n et al., 2004; Gardi et al., 2009) and national (Barr, 2008; Brogan, 2008; NBDC, 2010) levels that significant research efforts are required to provide knowledge on soil biodiversity, its drivers, functions and contributions to ecosystem services. Such knowledge can inform the development of management strategies that will use soils in a sustainable manner, both in the environmental and economic senses. Indeed, there is an increasing awareness of the multiple roles of soils and the range of services they provide (Gardi et al., 2009; Turb  et al., 2010). Knowledge of biological soil functioning gains even greater importance for the sustainable use of land under future scenarios for urbanisation, agriculture Common Agricultural Policy reform and climate change. The latter scenario in particular will affect *all* soils, including 'non-productive' soils, and the biodiversity they sustain.

Soils have of late been recognised as one of the last great frontiers of biodiversity research (e.g. Wardle et al., 2004; Foley et al., 2005). Knowledge gaps and research priorities in soil biodiversity have been identified by the scientific community at the highest

organisational level (Brussaard et al., 1997; Wolters, 1997). These include, inter alia, the identification of key taxa in ecosystem processes, standardising methods, species redundancy in relation to soil functions, responses of biodiversity to perturbations, and above/below-ground linkages. Existing research needs to span an enormous range of tasks and scientific endeavours, from taxonomy, species inventories and natural history to process quantification, ecological theory and evolutionary mechanisms.

In Ireland, all of these tasks require research efforts; for example, we do not yet even have comprehensive species lists for most soil invertebrate groups (Bolger et al., 2002; NBDC, 2010). Faced with such a catalogue of tasks, it was essential for a national project to identify priority knowledge gaps and focus on restricted, realistic research questions that are based on well-defined ecological concepts, such as the keystone species concept. Bolger (2001, p. 216) defines keystone species as "*those species whose direct or indirect effects on the survival of other species or on ecosystem function are disproportionately large in relation to their abundance or biomass*". As with most conceptual models, the keystone species concept in ecology has its critics as well as supporters. In soil ecology, some authors ignore the concept (e.g. Bardgett, 2005), but most use it in some fashion, even be it under different terminology such as species with key roles or key taxa. Bengtsson (1998) proposed the term 'keystone process species' and argued emphatically that the identification of these species and the quantification of their functions in ecosystems are the most urgent tasks faced by soil biodiversity research. This fundamental premise formed one basis of the present project.

Knowledge of keystone species in soils has been described as being 'minimal' (Freckman et al., 1997). There is no agreement in the soil ecological literature on which soil organisms are keystone species, or on how they should be recognised. It is also clear that a rigid keystone species concept is not applicable

equally to all soil organisms. For example, earthworms have often been called keystone species or ecosystem engineers, but they are – unlike most other soil organisms – a taxonomically well-defined, species-poor, mega-faunal group. In this project, 'keystone' was understood to be applicable to species, guilds, or functional groups of soil organisms. The project investigated a range of biologically dissimilar soil macro- and micro-organisms which potentially have keystone status, are known to have important functions, are likely to be impacted by soil management pressures, and for which expertise exists.

Given its size, Ireland has a distinguished record of internationally recognised research on the distribution, taxonomy and biology of certain soil organisms (Bolger et al., 2002), for example micro-arthropods, springtails, enchytraeid and lumbricid worms, and plant pests and pathogens. However, Ireland never had a sustained, systematic or large-scale multidisciplinary research programme in soil biology comparable with those undertaken in other countries such as New Zealand (Sparling et al., 2002), Canada (Fox et al., 2003), France (Ranjard et al., 2010), Germany (Emmerling et al., 2002), the Netherlands (Rutgers et al., 2009) or the UK (Loveland and Thompson, 2002; Black et al., 2005; Fitter et al., 2005; Aalders et al., 2009). In particular, Ireland lacks baseline data for significant numbers and groups of organisms in a wide range of soils (NBDC, 2010).

This project tackled at least two areas in which significant scientific knowledge gaps exist in Ireland, namely **soil protection** and **soil biodiversity**. The project enhanced knowledge and understanding of the biodiversity in Irish soils, a research priority under the National Biodiversity Plan (Anonymous, 2002). The project also contributed to the development of a soil protection strategy which urgently requires information on biological properties of Irish soils (Brogan et al., 2002; Brogan, 2008).

1.2 Overall Project Aims

The overarching objective of the project was to generate knowledge and research capability in soil biodiversity in Ireland that will inform the development of policies and management guidelines compatible

with national and European Union (EU) soil protection strategies.

The project had the following **specific objectives** and **targets**:

- To provide baseline data on the distribution, diversity and indicator value of micro- and macro-organisms of potential keystone status (soil bacteria and fungi, mycorrhizal fungi, nematodes, micro-arthropods, earthworms, ants) in a subset of the National Soil Database reference sampling locations;
- To establish the need for protecting those specific habitats where soil-dwelling ant species are keystone species;
- To investigate under field conditions the response of these organisms to a relevant pressure, i.e. the application of exogenous organic materials to soil;
- To conduct innovative experiments testing hypotheses derived from ecological theory on the functions of selected keystone species and interactions between them (ants, bacteria and fungi, earthworms);
- To review and synthesise existing information on soil keystone species in Irish soils; and
- To analyse, synthesise and disseminate project results, and to provide recommendations for soil protection strategies that will sustain Ireland's soil biodiversity.

Summary results are reported here as follows:

- [Chapter 2](#) reports baseline data on soil organism distribution and diversity across land use and soil types in Ireland;
- [Chapter 3](#) is concerned with the protection of specific habitats for conserving rare soil organisms;
- [Chapter 4](#) details field experiments that investigated the effects of land management pressures on keystone soil organisms; and
- [Chapter 5](#) focuses on functions of different groups of keystone soil organisms.

2 Baseline Data: Current Patterns of Biodiversity across Irish Soils

2.1 Background and Aims

A central necessity of soil biodiversity research in the context of soil protection strategies is baseline knowledge, derived from the basic inventory of organisms under consideration. Similarly, the monitoring of soil biodiversity cannot commence without baseline data (Morvan et al., 2008). Unlike some other countries, no systematic baseline data are available in Ireland for any soil organism groups, apart from specific root pests and diseases.

The most important means of obtaining biodiversity baseline data is the establishment of permanent, long-term soil monitoring plots (Rutgers et al., 2009). To contribute to the development of a national soil monitoring network in Ireland, this soil biodiversity survey was linked with ongoing national initiatives in soil monitoring, most notably the National Soil Database (NSD) project (Fay et al., 2007) and the Soil-C Project (Kiely et al., 2009). Initiated in 2002, the NSD contains about 1,310 sample locations from the Republic of Ireland, based on a 10 km × 10 km sampling grid. The database contains mainly chemical soil measurements, geographic information system (GIS)-supported mapping and basic site information. The NSD grid approach conforms to the internationally defined 'Level 1' monitoring of soil organic matter and biodiversity at national scales within a less than or at least 5- to 10-year time interval (Robert et al., 2004).

Soils being so biologically diverse, there is no general agreement on which organism groups, or keystone species, should be monitored (Andrén et al., 2004) and even less agreement on which organism groups are best indicators of soil quality (Ritz et al., 2009; Wienhold et al., 2009). Consequently, a range of soil micro- and macro-organisms which fulfilled one or more of the following criteria was used:

- They are known to have important functions and potentially have keystone status;

- They are likely to be impacted by soil management pressures; and
- Studying them is feasible (expertise and methods exist to study them).

The overall objective of this research was to enhance knowledge and understanding of the biological diversity in Irish soils, a research priority under the National Biodiversity Plan (Anonymous, 2002) and to contribute to the biodiversity requirements of the EU's Environmental Action Programme (EEA, 2006). Specifically, the survey aimed at providing systematic baseline data for Ireland on the occurrence, distribution, diversity and indicator value of micro- and macro-organisms of potential keystone status (soil bacteria and fungi, mycorrhizal fungi, nematodes, micro-arthropods, earthworms and ants) in a representative subset of the NSD reference sampling locations. Soil biodiversity was characterised in relation to the most common representative land uses and soil types in Ireland, and relationships between different organism groups and between biodiversity and different soil properties were explored.

2.2 Baseline Survey Design and Methods

A protocol was developed for the selection of a subset of the NSD sites based on a number of criteria, including the inclusion of major vegetation/land-use classes and soil types in proportion to their known frequency in Ireland and geographical spread. The sites selected by this protocol were also used by a sister project, the Soil-C project, examining carbon stocks in Irish soils (Kiely et al., 2009). In total, 61 sites were sampled during the soil biodiversity baseline survey ([Fig. 2.1](#)). Fifty-two of the sites were sampled from late summer to autumn in 2006, and a further nine were sampled in autumn 2007. These included arable (n = 14), pasture (n = 21), forest (n = 10, five each of coniferous plantation and broadleaved forest), rough grazing (n = 8) and bog (n = 8) land-use classes ([Table 2.1](#); [Fig. 2.1](#)). In addition, 12 of those sites

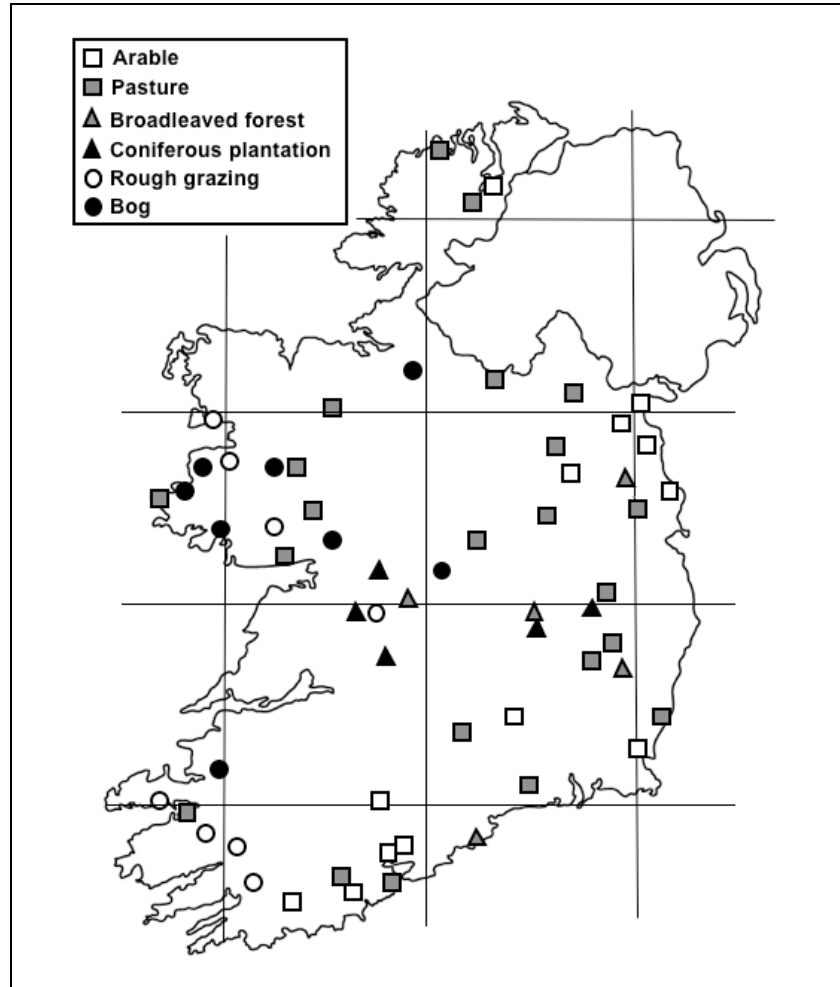


Figure 2.1. Distribution of National Soil Database sites sampled during the CréBeo soil biodiversity baseline survey, and their associated land-use classes. Adapted from Keith et al. (2009).

sampled in 2006 were re-sampled in 2007 to examine temporal variability. This repeat sampling included three sites each of the arable, pasture, forest and bog land-use classes. The major Irish soil types included were: acid brown earths ($n = 10$), shallow brown earths ($n = 3$), brown podzolics ($n = 9$), grey-brown podzolics ($n = 10$), podzolics ($n = 3$), gleys ($n = 10$), lithosols ($n = 3$) and peats ($n = 13$). This resulted in 20 land-use $\times$ soil-type combinations, 13 of which were replicated over at least three sites ([Table 2.1](#)).

Data held in the NSD were utilised to examine relationships between soil properties and the abundance, diversity and composition of the different groups of soil organisms. Many of these data were produced by the Soil-C project, which had 55 sites in

common with those sampled during the soil biodiversity baseline survey (Kiely et al., 2009).

The location of each site was determined using global positioning system (GPS) co-ordinates from the NSD (Fay et al., 2007) and a 20 m $\times$ 20 m plot was centred on the GPS co-ordinates at each site. Specific sampling protocols for the different groups of soil organisms were employed within this plot and are briefly outlined:

1. **Mycorrhizal fungi** were surveyed within 45 NSD locations in 2006: arbuscular mycorrhizal fungi (AMF) at all sites, ericoid mycorrhizal fungi (ERM) in all of the bog sites and some of the forest and rough grazing sites, and ectomycorrhizal fungi (ECM) in forest sites only. Soil samples were used for bioassays with *Trifolium repens* L. (white

Table 2.1. Final matrix of the number of sites in each land-use × soil-type combination sampled during the CréBeo soil biodiversity baseline survey.

Soil type	Land use					Total
	Arable	Pasture	Forest	Rough grazing	Bog	
Acid brown earth	5	5	–	–	–	10
Shallow brown earths	–	2	–	1	–	3
Brown podzolic	3	3	3	–	–	9
Grey–brown podzolic	3	4	3	–	–	10
Podzolic	–	1	–	2	–	3
Gley	3	3	4	–	–	10
Lithosol	–	2	–	1	–	3
Peat	–	1	–	4	8	13
Total	14	21	10	8	8	

clover), *Vaccinium macrocarpon* Ait. (cranberry) and *Picea sitchensis* Bong. Carr (Sitka spruce) as bait plants for AMF, ERM and ECM, respectively. Herbaceous roots and tree root tips were also extracted from field-collected soil cores and used for deoxyribonucleic acid (DNA) extraction. Molecular biology techniques were used to assess AMF, ERM and ECM diversity.

2. Soil bacteria and fungi were studied at all sites. Twenty soil cores (20 cm depth) were collected and bulked per plot, sieved (4 mm) and stored at –20°C for DNA extraction. Microbial DNA was extracted using a standard protocol.

3. Nematodes were extracted by sugar centrifugation from a 100 cm³ subsample of soil (20 soil cores pooled, 20 cm depth) from each site. Approximately 100 nematodes were identified for each site to at least genus level (with the exception of Rhabditidae and Neodiplogasteridae); predatory mononchid nematodes were identified to species level. Taxa were allocated to trophic groups and several indices were calculated to examine differences in diversity and community composition.

4. Earthworms were extracted in the field using two methods per site, hand-sorting of four soil blocks and, where feasible, by chemical expellant from

quadrats. Identification of mature individuals was to species level.

5. Micro-arthropods (Collembola and Acari) were extracted from four intact soil cores (5 cm diameter, 5 cm depth) per site. Oribatid (mainly detritivorous) and mesostigmatid (predatory) mites were sorted and identified to species level.

6. Soil-dwelling ants were assessed using a 20-m line of crumb baits to attract ant species that forage and by an active search (30 min to 1 h) within a 100-m radius of each plot, focusing on possible nesting sites. Collected ants were transferred into 70% alcohol and identified.

2.3 Summary Results and Discussion

2.3.1 Overview of recorded soil biodiversity

Across the whole survey, richness (number of ribotypes, i.e. fragments of target genes representing a species or group of microbes) of soil bacteria and fungi was 1,148 and 874, respectively; richness of bacteria ranged from 24 to 356 and fungi ranged from 6 to 159 at sites (Table 2.2). The overall number of AMF ‘species’ (measured as terminal restriction fragments (T-RFs)) recovered was 446, ERM with 266 and ECM with 41 species (Table 2.2). For all mycorrhizal types, there was a greater proportion of infrequent T-RFs/species than frequently occurring T-RFs/species.

Table 2.2. Summary of recorded soil diversity in the baseline survey. For some groups of soil organisms diversity has been shown separately for broadleaved (BL) and coniferous (CON) sites in the Forest land-use class. No data (ND) are available where the soil organisms were not sampled for practical reasons (e.g. Ectomycorrhizae are only found in association with woody plant species). Land-use data represent the total diversity recorded within each land-use class; numbers of sites differ between land-use classes.

Soil organisms		Recorded diversity								Diversity measure	
		Total	Minimum per site	Maximum per site	Arable	Pasture	Forest BL	Forest CON	Rough	Bog	
Microbes	Bacteria	1,148	24	356	851	985	707		615	569	Molecular: number of ribotypes
	Fungi	874	6	159	570	645	284		178	171	Molecular: number of ribotypes
	AMF	446 ¹	2 ²	78 ²	105 ²	160 ²	63 ²	42 ²	70 ²	68 ²	Molecular: number of T-RFs
	ERM	266 ³	35 ⁴	75 ⁴	ND	ND	ND	103 ⁴	84 ⁴	117 ⁴	Molecular: number of T-RFs
	ECM	41	3	13	ND	ND	21	21	ND	ND	Molecular: number of species
Micro/Mesofauna	Nematodes	94	5	25	49	63	44	40	45	31	Taxonomic: mainly genera
	Mites	108	0	27	26	68	52	64	11	46	Taxonomic: mainly species
Macrofauna	Earthworms	19	0	11	14	14	10	10	10	0	Taxonomic: species
	Ants	8	0	5	2	6	4		5	5	Taxonomic: species

¹Total diversity based on data from three plant types (field-collected *Trifolium repens* and *Lolium perenne*, and soil bioassay with *T. repens*).

²Numbers based on data from the soil bioassay with *T. repens* only.

³Total diversity based on data from two plant species (*Vaccinium macrocarpon* and *Calluna vulgaris*).

⁴Numbers based on *V. macrocarpon* data only.

AMF, arbuscular mycorrhizal fungi; ERM, ericoid mycorrhizal fungi; ECM, ectomycorrhizal fungi; T-RF, terminal restriction fragment.

Some AMF and ERM T-RFs and ECM species were unique to a site. The number of AMF and ERM T-RFs, and ECM species varied between sites with a range of 2 to 78 AMF, 35 to 75 ERM and 3 to 13 ECM (Table 2.2).

A total of 92 nematode taxa were recorded to at least genus level; a further two taxa were identified only to family (Rhabditidae and Neodiplogasteridae; Table 2.2). They included 31 bacterial feeding, 6 fungivorous, 11 plant associated (or root-hair feeding), 21 obligate plant parasitic, 9 omnivorous and 16 predatory genera. The most prevalent nematode taxa recorded in this survey (Rhabditidae, Plectus, Aphelenchoides, Filenchus, Helicotylenchus, and Aporcellaimellus) were generally found to be ubiquitous in a wide range of habitats and soils. Conversely, several of the less prevalent nematode taxa can be considered to have affinities to more specific substrates or micro-habitats; for example, Acrobeles and Wilsonema are more common in acidic sandy soils, Bunonema is usually abundant in the leaf litter layer and taxa in the Criconematidae are generally associated with the roots of woody plants.

The detailed examination of predatory mononchid nematodes resulted in 13 new nematode species records for Ireland – two of these being new records for both Ireland and the British Isles (Table 2.4; Keith et al., 2009). This study in just one family of nematodes highlights the general paucity of information that exists on soil biodiversity in Ireland. Clearly, given the relatively limited number of samples examined, further sampling would be expected to yield more predatory mononchid species, particularly in semi-natural habitats. For instance, in the Dutch monitoring network of 200 locations covering 10 different soil type/land-use combinations, 211 species and 141 genera of nematodes were recorded (Schouten et al., 2004). These predatory nematodes are not just of natural history interest, they are also important to the natural suppression of plant-parasitic nematodes in agricultural systems.

A total of 19 species of earthworm were recorded from the survey of 61 sites, including three anecic, seven epigeic and nine endogeic taxa (Table 2.5). The three most prevalent earthworm species (*Aporrectodea*

caliginosa, *Allolobophora chlorotica* and *Aporrectodea rosea*) are all endogeic. *Dendrobaena octaedra*, *Octolasion cyaneum* and *Proselodrilus amplisetosus* were recorded at only one site each (Table 2.5). Furthermore, the record of *Proselodrilus amplisetosus* is new for Ireland and the British Isles. This species (and most others in the genus) is endemic to Aquitaine in south-eastern France.

All earthworm records have been entered into the *Earthworms of Ireland* database by A.M. Keith (University College Dublin and Centre for Ecology & Hydrology, Lancaster), which contains published and unpublished earthworm species records, including this survey. This database has been submitted to the National Biodiversity Data Centre, Waterford, and is available via the online biodiversity database and mapping tool (see <http://maps.biodiversityireland.ie>).

A total of 108 mite taxa were recorded from 48 sites, with 65 oribatid and 43 mesostigmatid taxa (Table 2.2). The most prevalent oribatid and mesostigmatid taxa were *Heminothrus peltifer* and *Uropoda minima*, respectively. Although microarthropods are particularly well described for Ireland (Bolger et al., 2002), four soil mite taxa are new records to Ireland, and one may possibly be new to science, pending detailed confirmation (J. Arroyo, University College Dublin, unpublished data).

Ants were recorded from 35 (59%) of the 59 surveyed sites; no ant presence was recorded at the remaining 24 sites (41%). In total, 44 records of eight species (*Myrmica scabrinodis*, *Myrmica ruginodis*, *Myrmica rubra*, *Myrmica sabuleti*, *Lasius flavus*, *Lasius niger*, *Lasius platythorax* and *Formica lemani*) were confirmed (Fig. 2.2). *Myrmica scabrinodis* was recorded most often with 14 records, followed by *Myrmica ruginodis*, another member of the Myrmicinae, which had 13 records. Both species represent together over 50% of all records. *Formica lemani* was the most frequently recorded member of the Formicinae. The other species recorded were only found occasionally. Even though the main land-use types in Ireland (excluding dwelling and industrial use) were covered in this survey, only eight of the 18 ant species native to Ireland were found. However, a total of 14 species were recorded in a survey of a wider

Table 2.3. Ectomycorrhizal species and the number of conifer and broadleaf forest sites at which they were recorded. Ordered by number of sites, followed by taxa where number of sites is equal.

Fungal taxa	Conifer forest (n = 5)	Broadleaved forest (n = 3)	All forest (n = 8)
<i>Tylospora fibrillosa</i>	4		4
Thelephoraceae sp.1	3		3
<i>Amphinema byssoides</i>	2		2
Basidiomycete 1	2		2
Basidiomycete 5	2		2
<i>Laccaria montana</i>		2	2
Thelephoraceae sp. 2	1	1	2
<i>Thelephora terrestris</i>	2		2
<i>Tylospora asterophora</i>	2		2
<i>Wilcoxina</i> sp.	2		2
<i>Amanita rubescens</i>		1	1
Ascomycete	1		1
Basidiomycete 2	1		1
Basidiomycete 3	1		1
Basidiomycete 4	1		1
Basidiomycete 6	1		1
<i>Cenococcum geophilum</i>		1	1
<i>Clavulina cristata</i>	1		1
<i>Cortinarius alnetorum</i>		1	1
<i>Cortinarius sertipes</i>		1	1
<i>Cortinarius</i> sp.1		1	1
<i>Cortinarius</i> sp. 2		1	1
<i>Cortinarius</i> sp. 3		1	1
Helotiaceae sp.	1		1
<i>Inocybe lacera</i>		1	1
<i>Inocybe maculata</i>		1	1
<i>Inocybe napipes</i>		1	1
<i>Inocybe putilla</i>		1	1
<i>Inocybe</i> sp.		1	1
<i>Lactarius hepaticus</i>	1		1
<i>Lactarius necator</i>	1		1
<i>Lactarius quietus</i>		1	1
<i>Lactarius rufus</i>	1		1
<i>Naucoria escharoides</i>		1	1
<i>Russula betularum</i>	1		1
Thelephoraceae sp. 3	1		1
Thelephoraceae sp. 4		1	1
Thelephorales sp.		1	1
<i>Tomentella</i> sp.		1	1
<i>Tomentella</i> sp. 2		1	1
<i>Tomentella sublilacina</i>		1	1

Table 2.4. Predatory nematode species (Mononchida) recorded in the soil baseline survey and the number of sites in which they were recorded. Adapted from Keith et al. (2009).

Family/Species	No. sites recorded	New record for Ireland
Anatonchidae		
<i>Anatonchus sympathicus</i> (Andrássy, 1993) ¹	30	Yes
<i>Anatonchus tridentatus</i> (de Man, 1876)	1	Yes
<i>Tigronchoides ginglymodontus</i> (Mulvey, 1961) ¹	1	Yes
<i>Truxonchus dolichurus</i> (Ditlevsen, 1911)	5	Yes
Iotonchidae		
<i>Jensenonchus sphagni</i> (Brzeski, 1960)	3	Yes
Mononchidae		
<i>Clarkus papillatus</i> (Bastian, 1865)	21	No
<i>Coomansus parvus</i> (de Man, 1880)	3	Yes
<i>Mononchus aquaticus</i> (Coetzee, 1968)	3	Yes
<i>Mononchus truncatus</i> (Bastian, 1865)	1	No
<i>Prionchulus muscorum</i> (Dujardin, 1845)	1	Yes
<i>Prionchulus punctatus</i> (Cobb, 1917)	2	Yes
Mylonchulidae		
<i>Mylonchulus sigmaturus</i> (Cobb, 1917)	22	Yes
<i>Mylonchulus striatus</i> (Thorne, 1924)	3	Yes

¹Also new record for British Isles.

range of extensive habitats (see [Chapter 3](#)). The lesser number of species recorded in the baseline survey may be due to the relatively small numbers of sites which were covered, representing extensive use and conditions suitable to the thermophilic ecological requirements of ants. Shading and disturbance (compaction, tillage) are probably the main reasons for the relatively low number of sites where ants were present.

Together, these example results indicate how little is known about the distribution of soil organisms in Ireland. While there may be localised 'hot spots' of soil biodiversity records, for example in National Parks or research farms, there is clearly a need to expand and develop such systematic surveys of soil biodiversity. Such surveys will provide baseline data for future soil monitoring, ideally as a component of broader soil monitoring as is conducted elsewhere, for example in the UK (Black et al., 2005, 2008; Emmett et al., 2010),

France (Ranjard et al., 2010) and the Netherlands (Rutgers et al., 2009).

2.3.2 Characterising soil biodiversity in different land uses and soil types

2.3.2.1 Abundance of microfauna and macrofauna

Unlike microbes, it is relatively straightforward to estimate abundance of soil microfauna and macrofauna. The groups examined exhibited different patterns across both land-use and soil types, with land use having the clearest influence on abundance. Land use had a strong influence on nematode abundance, the latter being greatest for arable and pasture sites and least for bog sites ([Fig. 2.3A](#)). There was also a significant effect of land-use class on the relative abundance of bacterial feeders, plant associates or root-hair feeders, obligate plant parasites, omnivores and predators, but not on fungal feeders. In particular, the relative abundance of bacterial feeders was greatest in bog (47%) and also high in arable (37%)

Table 2.5. Overall earthworm composition by land-use class. Values are percentage occurrence (frequency) within a land-use class; lighter shading indicates presence in a land-use class.

Species	Functional group	Land-use class					
		Arable	Pasture	Forest BL	Forest Con	Rough	Bog
<i>Dendrobaena octaedra</i> (Savigny, 1826)	Epigeic	0.0	0.0	0.0	0.0	12.5	0.0
<i>Lumbricus eiseni</i> Levinsen, 1884	Epigeic	0.0	0.0	0.0	8.0	0.0	0.0
<i>Dendrodrilus rubidus</i> (Savigny, 1826)	Epigeic	0.0	0.0	50.0	20.0	25.0	0.0
<i>Aporrectodea caliginosa</i> (Savigny, 1826)	Endogeic	100.0	100.0	75.0	40.0	50.0	0.0
<i>Allolobophora chlorotica</i> (Savigny, 1826)	Endogeic	92.9	85.7	75.0	40.0	50.0	0.0
<i>Aporrectodea rosea</i> (Savigny, 1826)	Endogeic	78.6	90.5	50.0	40.0	50.0	0.0
<i>Lumbricus rubellus</i> Hoffmeister, 1843	Epigeic	28.6	57.1	50.0	40.0	50.0	0.0
<i>Lumbricus festivus</i> (Savigny, 1826)	Epigeic	64.3	85.7	50.0	0.0	12.5	0.0
<i>Lumbricus friendi</i> Cognetti, 1904	Anecic	21.4	14.3	0.0	20.0	12.5	0.0
<i>Octolasion tyrtaeum</i> (Savigny, 1826)	Endogeic	0.0	28.6	0.0	20.0	37.5	0.0
<i>Eiseniella tetraedra</i> (Savigny, 1826)	Endogeic	21.4	19.0	0.0	0.0	25.0	0.0
<i>Lumbricus castaneus</i> (Savigny, 1826)	Epigeic	42.9	52.4	75.0	40.0	0.0	0.0
<i>Satchellius mammalis</i> (Savigny, 1826)	Epigeic	7.1	47.6	0.0	20.0	0.0	0.0
<i>Lumbricus terrestris</i> Linnaeus, 1758	Anecic	35.7	66.7	25.0	0.0	0.0	0.0
<i>Aporrectodea longa</i> (Ude, 1885)	Anecic	71.4	47.6	25.0	0.0	0.0	0.0
<i>Murchieona minuscula</i> (Rosa, 1905)	Endogeic	21.4	0.0	25.0	0.0	0.0	0.0
<i>Aporrectodea limicola</i> (Michaelsen, 1890)	Endogeic	7.1	23.8	0.0	0.0	0.0	0.0
<i>Octolasion cyaneum</i> (Savigny, 1826)	Endogeic	0.0	4.8	0.0	0.0	0.0	0.0
<i>Proselodrilus amplisetosus</i> Bouché, 1972 ¹	Endogeic	7.1	0.0	0.0	0.0	0.0	0.0

¹Also new record for British Isles.
BL, broadleaf; Con, coniferous.

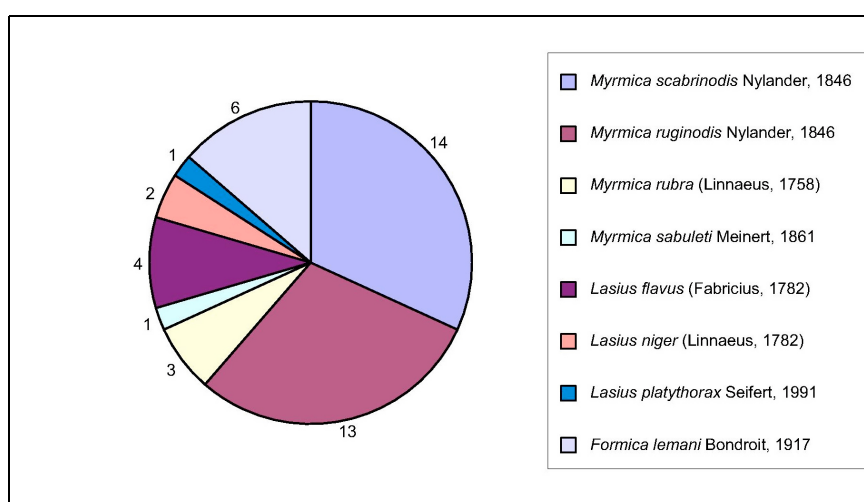


Figure 2.2. The proportion of species contributing to all 44 ant records in the baseline survey.

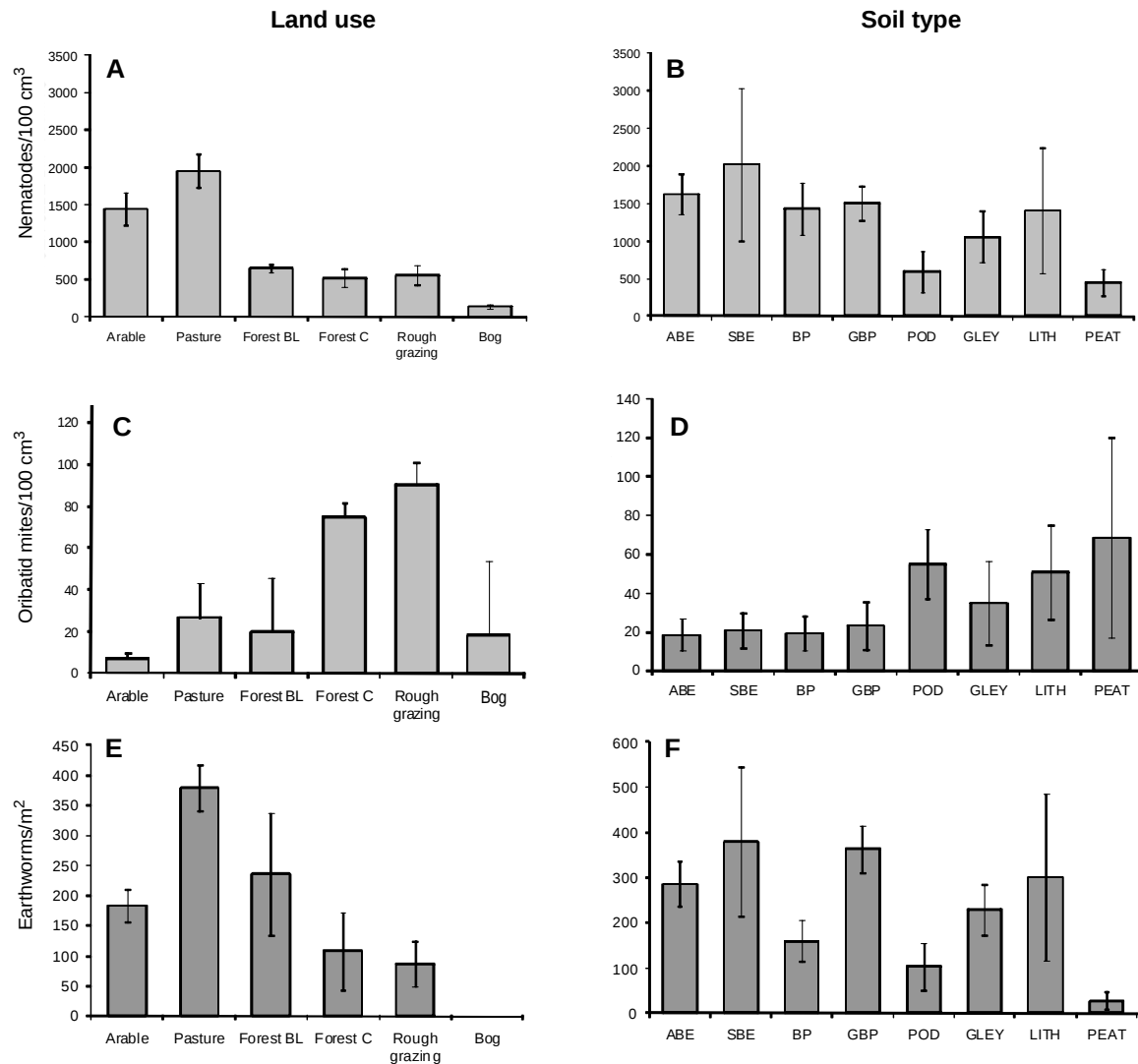


Figure 2.3. Abundance of soil micro- and macrofauna by land-use class (A, C, E) and soil type (B, D, F). Earthworm data from hand-sort sampling. BL, broadleaved forest; C, coniferous plantation. Soil types: ABE, acid brown earth; SBE, shallow brown earth; BP, brown podzolic; GBP, grey-brown podzolic; GLEY, Gley; LITH, Lithosol; PEAT, peat. Data are means $\pm$ standard error.

and rough grazing (37%). Relative abundance of obligate plant parasites was greatest in pasture (38%) and lowest in bog (18%), and predator relative abundance was greatest in arable (15%) and lowest in bog (2%). Soil type also had a significant influence on nematode abundance, largely because of lower abundances in podzolic and peat soils (Fig. 2.3B).

Land-use class also had a strong effect on the abundance of oribatid and mesostigmatid mites. Oribatid mites (predominantly detritivores) were most abundant in the coniferous plantation and rough

grazing land-use classes, and lowest in all other land-use classes (Fig. 2.3C). Mesostigmatid mites (predators) were most abundant in broadleaved woodland and were almost absent from bog sites. There was no significant influence of soil type on total mite abundance; neither was there a significant influence of soil type on oribatid or mesostigmatid abundance (Fig. 2.3D).

There were no earthworms recorded at any bog site. Pasture had the greatest earthworm abundance, and coniferous plantation and rough grazing land use, with

higher levels of organic matter and lower pH, had the lowest earthworm abundance (Fig. 2.3E). Earthworm biomass followed the same pattern as abundance across land-use classes and between extraction methods. There was no significant influence of soil type on earthworm abundance. However, abundance was generally lower in podzolic and peat soils (Fig. 2.3F). Further analysis showed that anecic earthworm biomass from hand-sorting was significantly different between soil types, but there were no differences in hand-sorted epigeic or endogeic biomass. The biomass of earthworms showed a similar pattern across soil types.

2.3.2.2 Richness of microbes, microfauna and macrofauna

Bacterial richness (assessed by genetic markers – intergenic spacer (IGS) regions) did not differ between land-use classes and soil types, presumably because variation within each broad land-use category can be associated with different management practices. In a previous study, 102 NSD sites were assessed for bacterial diversity (Fay et al., 2007). Using a different technique than here, it was concluded that soil type and associated soil characteristics were driving factors of soil bacterial diversity in Irish soils. Fungal assemblages (assessed by genetic markers – internal transcribed spacers (ITSs)), on the other hand, were different between land-use classes in the present survey (Fig. 2.4A). Land uses associated with organic soils generally differed from those on mineral soils and fewer fungal ribotypes were found than bacterial ribotypes. Total numbers of fungal ribotypes found in predominantly mineral soils (arable and pasture) were higher than those found in organic soils (forest, rough and bog). Overall, this indicates that fungal assemblages may be more responsive to soil abiotic variables than are bacterial assemblages, thus suggesting that fungal assemblages may be more useful as a soil indicator than bacterial assemblages.

Sites with different land uses and soil types did not differ significantly in the mean number of AMF mycorrhizal fungi or their community composition. The results suggest that the distribution of AMF is being driven by biotic and abiotic factors at the site level. In contrast, ERM communities were clearly separated by the land-use categories (Fig. 2.4B), suggesting that

land use does have an impact on particular mycorrhizal communities. The low diversity of ECM fungi in the forest sites sampled is in agreement with previous studies: plantation forests (monoculture plantations of exotic conifer tree species planted on peatlands, monocultures of broadleaf trees planted on old agricultural land and a semi-natural forest) can have a low diversity of ECM on tree roots.

There was a significant influence of land-use class on the number of nematode genera and the Shannon Evenness Index, with bog having the greatest evenness, but not on the Shannon Diversity Index or trophic diversity. However, there was a trend of greater trophic diversity in broadleaved forest and arable sites, and lower trophic diversity in bog. The number of genera was significantly different between soil types, being greatest in lithosols, with approximately 23 genera per sample and least in peat with 14 genera per sample. There was also a significant influence of soil type on the Shannon Evenness Index, Shannon Diversity Index and trophic diversity due to the large differences between peat and other soils.

Richness of mite taxa was also influenced by land use. Like oribatid abundance, mean oribatid taxa richness was greatest in coniferous plantations and rough grazing sites, with 12 and 11 taxa per soil core, respectively (Fig. 2.4C). However, the total number of oribatid taxa recorded in each land-use class was similar in the coniferous plantation, rough grazing and pasture. Mesostigmatid taxa richness was lowest in the arable and peat, and greater in all other land-use classes (Fig. 2.4C). The total number of mesostigmatid taxa recorded was similar in all land-use classes except peat where only one species was recorded. Likewise, there was no significant influence of soil type on the mean number of oribatid taxa and mesostigmatid taxa. The total number of oribatid taxa recorded across all sites was generally least in acid brown earth and shallow brown earth soil types, where arable land use predominates.

There was a clear effect of land use on earthworm species richness, with 14 species being recorded in both the arable and pasture land-use classes, and 10 species in the broadleaved woodland, coniferous plantation and rough grazing land-use classes

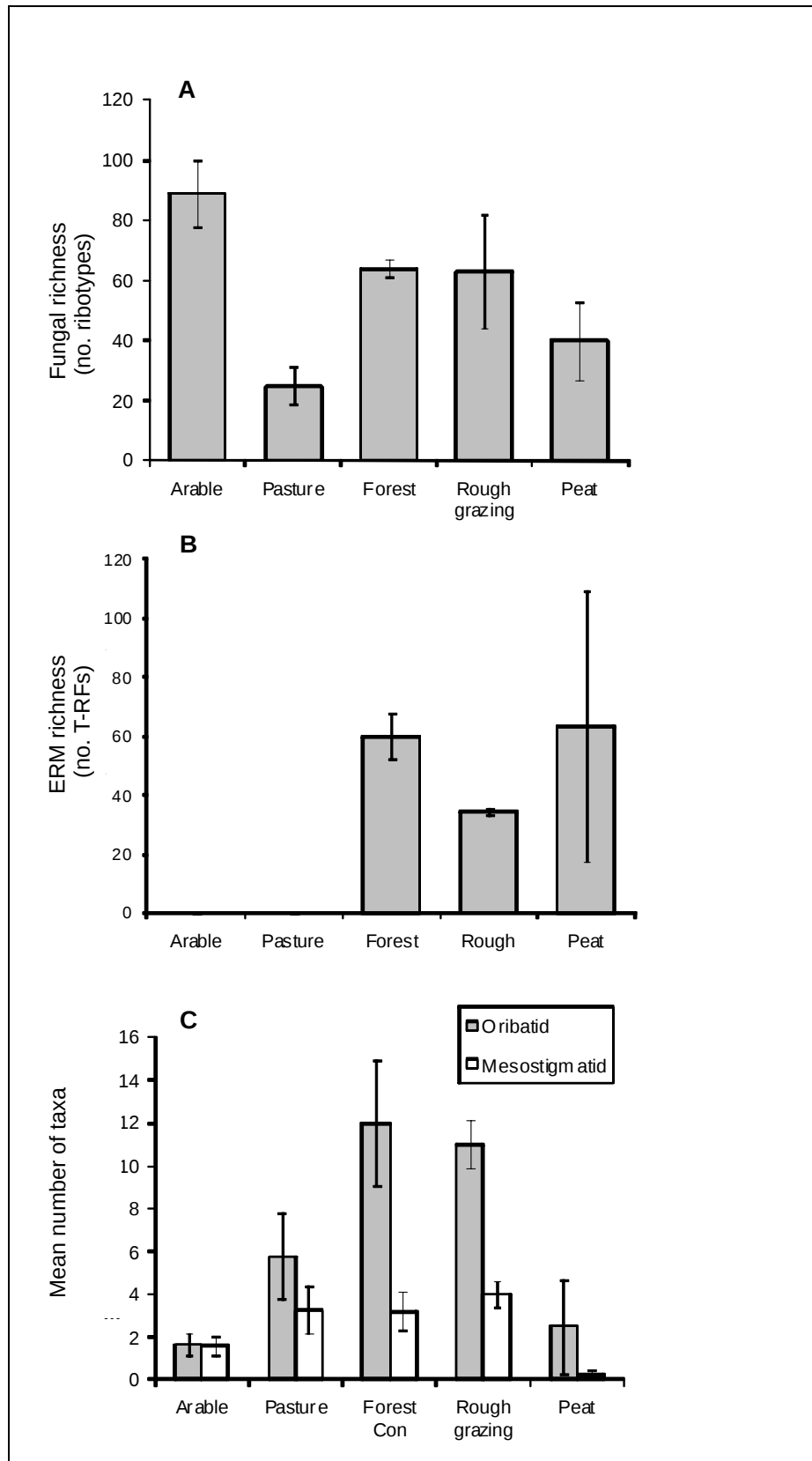


Figure 2.4. Richness of (A) soil fungi, (B) ericoid mycorrhizae (ERM) and (C) oribatid and mesostigmatid mites by land-use class. Ericoid richness based on soil bioassay with *Vaccinium macrocarpon*. Con, coniferous plantation. Data are means $\pm$ standard error. T-RF, terminal restriction fragment.

(Table 2.2). There was also a clear shift in the compositional ‘fingerprint’ of the earthworm community moving from extensive (i.e. rough grazing) to more intensive land-use classes (i.e. arable; Table 2.5).

The greatest number of ant species was recorded in pasture sites (six species), followed by equal numbers in both rough grazing and bogs (five species), and only two species recorded across arable sites (Table 2.2). The prevalence of individual ant species was also found to differ between land-use classes:

- *Myrmica scabrinodis* was most often recorded from bogs (five sites) but was not found on arable sites;
- *Myrmica ruginodis* was most often found in the pastures and rough grazing land-use classes (four sites each), with the lowest number of records for this species in forest and arable sites;
- *Myrmica rubra* was only recorded in two pasture sites and a forest site;
- *Myrmica sabuleti* was only recorded from one arable site;
- *Lasius flavus* was recorded in two rough grazing sites and one site each of pasture and bog;
- *Lasius niger* was recorded in a pasture and a rough grazing site;

- *Lasius platythorax* was found only on one bog site; and
- *Formica lemani* was found on two sites each of bog, forest and rough grazing but it was not found in arable or pasture sites.

2.3.2.3 Composition of microbes, microfauna and macrofauna

Composition can be very different between sites while abundance and richness effectively remain the same. Therefore, examining the composition of the different soil organism communities may provide a better characterisation of soil biodiversity at survey sites.

Analysis of similarity in the composition of microbes showed that there was no significant effect of land-use class or soil type on soil bacterial or fungal composition when including all sites in the analysis (Table 2.6). However, when only agricultural sites (pasture and arable) were included, there was a significant effect of soil type on the similarity of soil bacterial composition, and a significant effect of land-use class and soil type on the similarity of soil fungi (Table 2.6; Fig. 2.5). There were no significant effects of land-use class or soil type on similarity in the composition of AMF mycorrhizal composition (Table 2.6).

In contrast, there was a highly significant influence of land use on the similarity in nematode composition (Fig. 2.6A), and earthworm composition. Furthermore, the similarity of nematode community composition was

Table 2.6. The impact of land use and soil type on the similarity of soil community composition. The pseudo-F values shown are derived from permutational multivariate analysis of variance (PERMANOVA); higher F values (in bold) indicate a significant effect. ‘All’ includes arable, pasture, rough grazing and forest; ‘Agricultural’ includes arable and pasture only.

Soil organisms	All		Agricultural	
	Land use	Soil type	Land use	Soil type
Bacteria	1.02 ^{NS}	1.08 ^{NS}	1.06 ^{NS}	1.03*
Fungi	1.12 ^{NS}	1.09 ^{NS}	1.31*	1.12*
Arbuscular mycorrhizal fungi ¹	1.13 ^{NS}	0.81 ^{NS}	1.14 ^{NS}	0.85 ^{NS}
Nematodes	3.16**	1.20 ^{NS}	3.71**	1.10 ^{NS}
Micro-arthropods	1.39*	1.04 ^{NS}	1.77*	1.02 ^{NS}
Earthworms ²	2.79**	1.15 ^{NS}	2.37*	1.32 ^{NS}

*P < 0.05; **P < 0.01; NS, not significant.

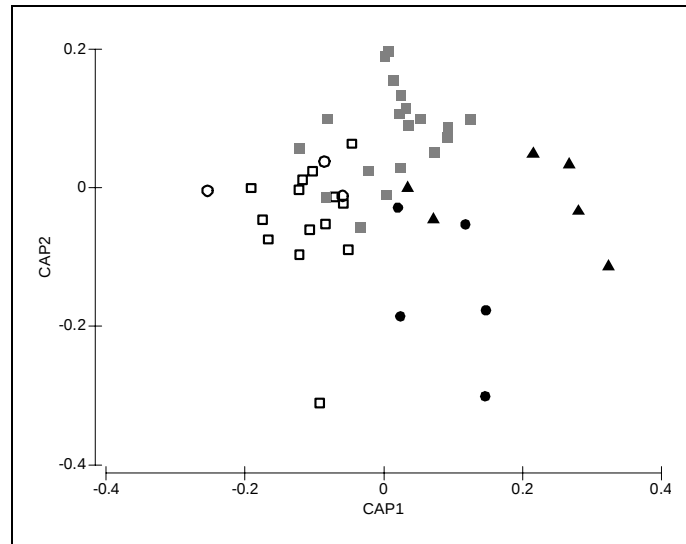


Figure 2.5. Canonical analysis of principal coordinates (CAP) of fungal internal transcribed spacer (ITS) assemblages for each type of land use (correlation of axes CAP1 $\delta^2 = 0.710$ $P = 0.035$; CAP2 $\delta^2 = 0.520$, classified correctly = 45%). Open square, arable; grey square, pasture; black triangle, forest; open circle, rough grazing; black circle, bog.

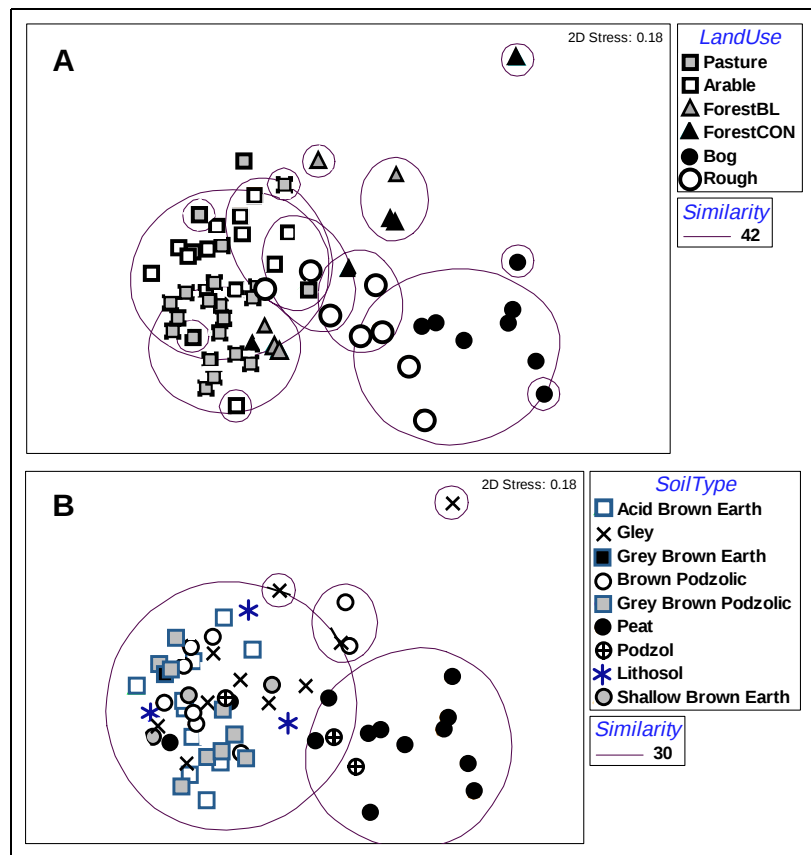


Figure 2.6. Non-metric multidimensional scaling (nMDS) ordination of nematode community composition classed by (A) land use and (B) soil type. Each data point represents a site; clusters (circled) represent similarity at indicated level (% similarity). BL, Broadleaved forest; CON, Coniferous plantation.

significantly different between all individual pairs of land-use class except between broadleaved woodland and coniferous plantation. However, there was no effect of soil type on the similarity of nematode, mite or earthworm composition (Table 2.6). Yet, similarity in the composition of the nematode communities was generally divided between peat/podzols and other soil types (Fig. 2.6B). The same pattern of significant effects was present for nematodes, micro-arthropods and earthworms when only agricultural sites (pasture and arable) were included in the analyses (Table 2.6).

All of these analyses are based on 'multivariate' statistical procedures, including permutational multivariate analysis of variance (PERMANOVA, testing the response of one or more variables to one or more factors), canonical analysis of principal coordinates (CAP, finding linear relationships among sets of variables), and non-metric multidimensional scaling (nMDS ordination, to order or cluster samples with several variables numerically and/or graphically).

2.3.3 Soil properties and soil biodiversity

The gradient of different soil properties measured across these sites is unavoidably confounded by the land-use classes. However, relationships between soil properties and the biodiversity of soil organisms may still be useful to understand and mitigate the effects of land-use change.

The richness of soil micro-organisms was significantly correlated with several environmental variables, e.g. soil moisture content and soil pH. However, measured environmental variables did not correlate with similarity in the composition of bacterial assemblages and, overall, redundancy analysis using soil properties poorly explained variance among microbial assemblages. Interestingly, the number of T-RFs from the *Trifolium repens* bioassay was correlated with soil phosphorus, showing that sites with high levels of phosphorus had a lower number of T-RFs (Fig. 2.7A).

Across all sites, soil bulk density and pH were significantly positively correlated with both nematode abundance and mean taxa richness (number of genera), whereas soil organic matter, nitrogen and the carbon to nitrogen ratio were all significantly negatively correlated with these (see Fig. 2.7B). Overall, similarity in the composition of the nematode community was explained best by a combination of bulk density, organic matter and the carbon to nitrogen ratio. Nematode taxa richness also plateaued with both increasing bulk density and pH. In contrast to nematodes, both total mite abundance and taxa richness were significantly negatively correlated with bulk density and soil pH, and significantly positively correlated with organic matter and nitrogen. This pattern was largely due to the oribatid mites, whose abundance and taxa richness followed the same

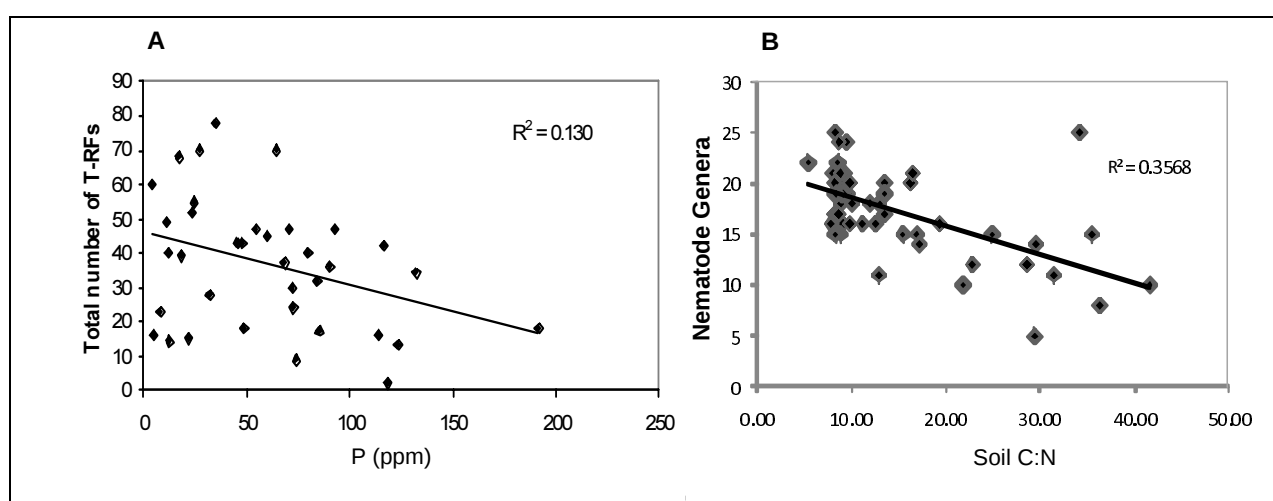


Figure 2.7. Relationships between (A) soil phosphorus concentration (ppm here is mg/kg) and the total number of terminal restriction fragments (T-RFs) of bioassay *Trifolium repens* and (B) soil carbon to nitrogen ratio and number of nematode genera.

pattern; mesostigmatid abundance or taxa richness was not significantly correlated with any of the selected soil properties.

Hand-sorted earthworm abundance was significantly positively correlated with bulk density and pH, and significantly negatively correlated with organic matter, soil nitrogen and the carbon to nitrogen ratio (Table 2.7). Hand-sorted taxa richness and total taxa richness (which includes expellant extraction where it was possible) followed the same pattern (Table 2.7).

2.3.4 Potential indicator value of the biodiversity of different soil organisms

While evidence of a positive relationship between below-ground diversity and functioning in soils is not always clear (Bardgett, 2005), it has long been appreciated that the functional activities of a diverse soil community play a crucial role (Brussaard et al., 1997). Therefore, greater biodiversity in soil is generally linked to desired ecological status and, ideally, this biodiversity is measurable with indicators (Turbé et al., 2010). Bioindicators need to be simple to measure and cost-effective, interpretable, sensitive and transferable, and acceptable to policy makers (Ritz et al., 2009).

The comparison of different soil organisms suggests that if indicators cannot discriminate between broad classifications such as land use and soil type, their utility as a broad-scale monitoring tool may be relatively poor. Variability within a land-use class will have implications as to whether certain groups will be

useful or not. On the other hand, variability may reflect particular management practices within a land-use class. Overall, nematodes and earthworms provided the greatest discriminatory ability of the different groups of soil organisms examined, particularly across the whole range of land uses. While the nematodes possess many of the relevant attributes required as an indicator group, it is clear that this also has to be balanced with the relatively time-consuming nature of routine nematode identification and a declining expertise for their identification. Current progress in the area of molecular identification of nematodes could solve this issue.

Microbial assemblages, as measured in this study, appeared to be too variable to be a reliable indicator. Although differences in fungal assemblages were distinguished between some land-use classes and soil types, in general it was mainly a distinction between mineral and organic soils and some land-use types. This variability in microbial biodiversity at the spatial scale of the survey suggests that it may be more useful to examine land management effects at a local scale.

Earthworms had very low abundances (and hence diversity) in highly organic soil; they were absent from bog sites. Hence, their value as indicators may be more relevant in mineral or agricultural soils. In contrast, the other macrofauna group (ants) was generally not recorded in arable and many pasture sites, but had relatively greater species richness in land-use classes with higher organic soils, e.g. rough grazing and bog. This suggests that the biodiversity of

Table 2.7. Spearman correlation coefficients between abundance and richness of earthworms and selected soil properties. HS, hand-sort extraction. Significance levels denoted as **P < 0.01, *0.01 > P > 0.05.

Soil property	Abundance	Taxa richness	
	HS	HS	Total ¹
Bulk density	0.56**	0.51**	0.53**
pH	0.50**	0.44*	0.46**
Organic matter	-0.48**	-0.47**	-0.51**
Nitrogen	-0.42*	-0.40*	-0.47**
Carbon to nitrogen ratio	-0.64**	-0.58**	-0.56**

¹Includes taxa recorded using expellant extraction where possible at a site.

different soil fauna groups may be more appropriate in either agricultural soils (e.g. nematodes and earthworms) or extensively managed soils (e.g. mites and ants).

The temporal variability of different organisms must also be considered as a potential indicator of soil biodiversity or land management effects. Between the two sampling years, 2006 and 2007, the AMF community associated with the *Trifolium repens* bioassay and the ERM community associated with the *Vaccinium macrocarpon* bioassay were significantly different (AMF: [Fig. 2.8a](#); ERM: [Fig. 2.8b](#)).

Unlike the arbuscular mycorrhizae, the abundance and taxonomic richness of nematodes was remarkably consistent across 2 years of sampling, especially given the previously reported variability in this group ([Fig. 2.9](#)). Similar to nematode data, earthworm biomass and earthworm species richness from the two sampling years at repeat sites were generally significantly correlated, with some outlier sites.

The biodiversity of these different groups of soil organisms documented by the survey has provided an important set of baseline values under the main land-use classes and soil types of Ireland. However, it is

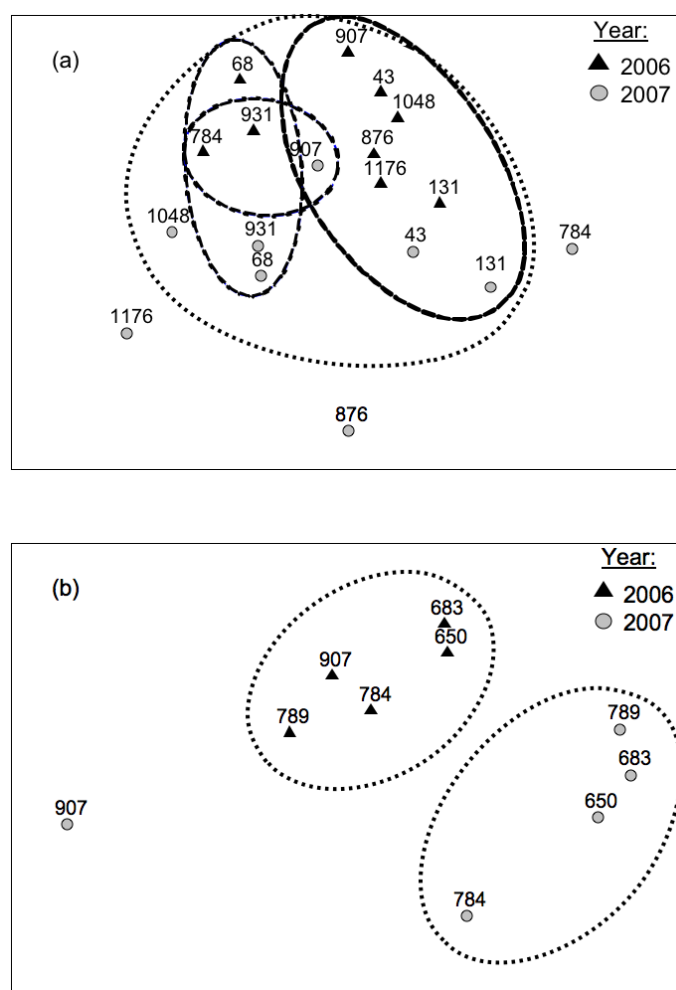


Figure 2.8. Non-metric multidimensional scaling (nMDS) plots of the fungal communities associated with (a) *Trifolium repens* bioassay and (b) *Vaccinium macrocarpon* bioassay from different sampling years. Each point on the plot represents a site's fungal community. Cluster analysis similarity ellipses are shown on each plot (dotted line, 20%; dashed line, 40%). Permutational multivariate analysis of variance (PERMANOVA) was used to test for significant groupings (a) pseudo-F = 2.984, P = 0.009 and (b) pseudo-F = 3.197, P = 0.007.

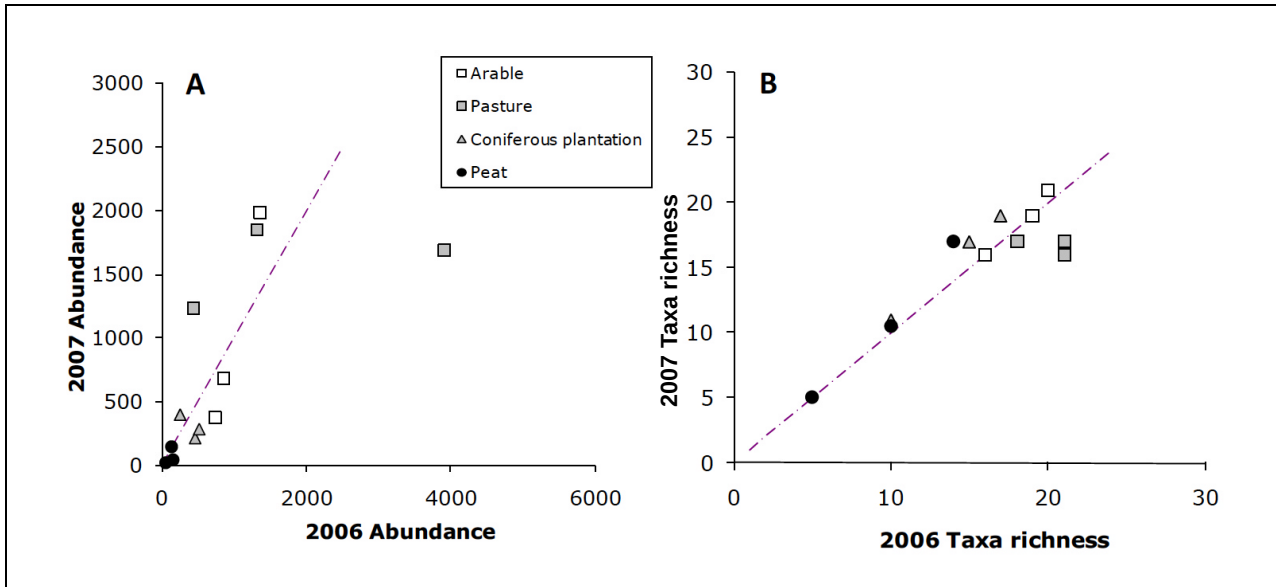


Figure 2.9. Correlation in (A) nematode abundance and (B) taxa richness between successive sampling years at the same sites. Dashed line represents no change between successive years.

also clear that there is a need for a set of reference conditions for soil biodiversity under different land uses as a target of good ecological conditions or sustainably managed land. These reference conditions can then be used to judge whether or not land management has resulted in a deviation from desired status.

2.4 Conclusions and Recommendations

The survey produced a wealth of data on the occurrence, abundance and diversity of these organisms. The discovery of previously unrecorded species, including 13 predatory nematodes, an earthworm endemic to southern France and (possibly) a mite species new to science, highlights the lack of inventory data on soil organisms in Ireland. The data generated can serve as baseline data for future monitoring. Data from one subgroup surveyed in this project, predatory nematodes, have been analysed fully and published (Keith et al., 2009). Repeat sampling of about 20% of sites 1 year after initial sampling showed examples of inter-annual variability for various organism groups under Irish conditions. The detailed analysis of data for other organism groups is likely to reveal further detailed insights into the relationships of these organisms with soil properties, land use and other organisms.

The key findings of this baseline survey can be summarised as follows:

- The CréBeo survey has provided the first systematic baseline data for biological diversity in Irish soils across a range of soil organisms (i.e. microbes, micro- and macrofauna).
- Soil biodiversity was characterised for different groups of soil organisms in relation to the main land-use and soil-type classes in Ireland, thus providing a reference across habitats for future research.
- Patterns of soil biodiversity across land-use classes varied between the different groups of soil organisms examined. For example, the biodiversity of some faunal groups was highest in agricultural soils (nematodes and earthworms), while that of others was highest in extensively managed soils (micro-arthropods and ants).
- The forest sites exhibited large variability in soil biodiversity. This probably reflects the fact that the 'Forest' land-use class included deciduous woodland, mixed woodland and coniferous plantations (the latter often on former peatland).

- A broad division in the composition of different groups of soil organisms was evident between agriculturally managed (arable and pasture) and more extensively managed (rough grazing and bog) soils.
 - The agriculture-extensive land-use gradient also corresponded to a broad division between relatively 'organic' and 'mineral' soils. Consequently, land use and soil type were confounded to a certain extent, e.g. arable sites tended to be on more productive, mineral soils, while more extensive land-use classes (rough grazing and bog) were found on organic, acidic soils.
 - Generally, soil type had limited consistent effects on soil biodiversity. The soil-type classification used may not be wholly relevant to the soil biodiversity measurements since soil was generally sampled to 20 cm. Some soil types are classified based on properties below this depth of sampling.
 - There was often considerable variation within land-use and soil-type classes. Variability within classes was often as large as that between classes for microbial communities. Furthermore, outlier sites were often evident based on diversity and composition of the different groups of soil organisms, and at some sites this may have been due to recent land-use change, e.g. ley pastures.
 - Across all sites, the biodiversity of soil organisms was related to soil properties in many cases. However, these relationships were typically confounded by the separation of land-use classes.
- The distinction that needs to be made between permanent and ley pastures; and
 - Other potentially important land management subdivisions within current land-use classes and those not examined in this survey (e.g. bioenergy crops, urban greenspace).
- A soil-type classification for monitoring soil biodiversity needs to be relevant to the sampling method. The baseline data could be used to determine a more appropriate soil classification.
 - More information on land-use history and land management practices (e.g. stocking densities, fertiliser inputs) is needed for monitoring sites to help explain potential variation within classes or to qualify outliers.
 - The number of sites sampled should be increased so that all land-use × soil-type combinations, and potentially any further land management subdivisions, have adequate replication.
 - Sampling the same sites over time is not necessary in a future soil monitoring scheme if it is only to provide a representative 'picture' of soil biodiversity. However, there are a number of advantages in surveying the same sites over time including:
 - The retained practical and logistical knowledge that can be used to benefit future surveys;
 - The opportunity to build a relationship with land owners where relevant; and
 - It provides an indication of temporal variability within sites against which environmental changes can be assessed.
 - Benchmark or target sites for each land-use × soil-type combination should be identified and sampled so that any monitoring site can be assessed against a soil biological typology. Coupling existing data and expert opinion will be needed to identify the characteristics of these sites.
 - A future monitoring scheme may consider a tiered structure consisting of core indicators measured at all sites and specific indicators measured at appropriate sites.

In conclusion, the following recommendations are offered:

- The land-use classification used to characterise Irish soils for monitoring soil biodiversity needs to be revised. This revision should consider:
 - The separation of land-use class 'Forest' into 'Coniferous plantation' and 'Broadleaf and mixed woodland';

- Measures of soil processes (e.g. soil respiration, nitrogen mineralisation) are needed at monitoring sites in order to make better links between soil biodiversity and functions.
- A working group should be created to oversee the development of soil biological monitoring in Ireland and to ensure that such a scheme is fit for purpose, broadly compatible with other national surveys and meets any requirements under EU soils policy.

3 Conservation: Protecting Specific Habitats

3.1 Background and Aims

Ants (Hymenoptera: Formicidae) are considered keystone species and physical ecosystem engineers in soils where they dominate the fauna, for example in semi-natural sandstone and limestone landscapes in western Ireland (see [Fig. 5.1](#)). Previous surveys on the distribution of ant species in Ireland were performed more than half a century ago (NBDC, 2010). Since then there have been many changes to land use in Ireland and in the ant taxonomy of relevant European genera (Agosti et al., 2000). Against this background, it was necessary to provide a detailed survey of different habitats in order to update the inventory list and to provide data on this important group of invertebrates to decision makers, similar to other European countries, in the light of the need to achieve the 2010 Biodiversity Action Targets (Gardi et al., 2009).

The overall focus of this research was the conservation of ants in Ireland. Its objective was to provide suggestions on which habitats should be given priority with respect to ant conservation. The research also aimed to develop a tool for rapid identification, or short-listing, of those sites in Ireland that could be of conservation value and, consequently, worth investigating. Such data might, in the future, form the basis of a Red List of ant species for Ireland, addressing the five aspects of insect conservation identified by Leather et al. (2008).

3.2 Methods

The following habitat types were included in the survey:

1. Arable fields;
2. Calcareous grasslands;
3. Urban zones;
4. Limestone pavements;
5. Roadsides;

6. Coastal sand dunes;
7. Limestone scrublands;
8. Wetlands: fens bogs;
9. Broadleaf woodlands; and
10. Coniferous woodlands.

The number of habitats visited based upon limestone rock (e.g. 2, 4 and 7 above) was deliberately over-represented compared with their national proportions. These are rare habitats at national level – and even rarer at European level – and deserve thorough investigation. Such habitats have already been found to provide refugia for several rare species of plants and partly enjoy conservation status.

Eighty sampling sites were investigated, 20 in County Limerick, 35 in Clare, 24 in Galway and one site in Mayo. Representative sites of each habitat were chosen and sampled for ants in the period 2006–2009, using a crumb bait line method and hand-sampling in the wider area.

3.3 Summary Results

3.3.1 Characterising ant-species-rich sites

The numbers of ant species found at different habitat types are shown in [Fig. 3.1](#). Among the sites studied, arable fields were found not to support any ant species. This habitat was followed by broadleaf woodland for which an average of less than one species of ant (0.2 species per site; [Fig. 3.1](#)) was found. All other investigated habitat types were found to include at least one species of ant: urban, coniferous woodland, roadside, wetland, calcareous grassland, coastal sand dunes, scrubland on limestone, and limestone pavements. The highest mean value of ant species richness was found for limestone pavements (6.9 species per site; [Fig. 3.1](#)).

A total of 217 records were made, with a total of 14 ant species being recorded across the 80 sites studied. *Myrmica scabrinodis* (40 sites) and *Myrmica ruginodis*

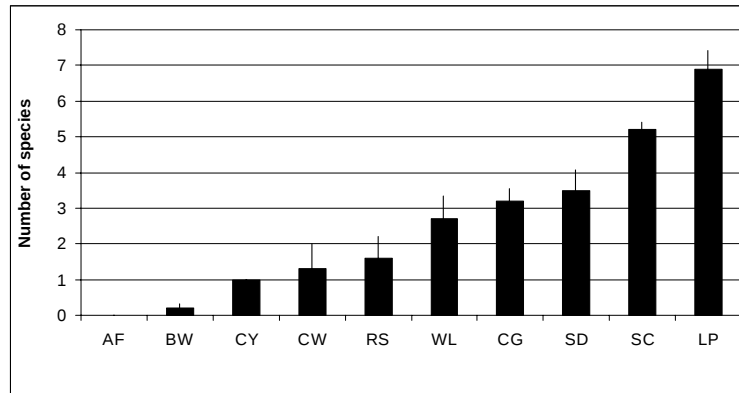


Figure 3.1. Mean number of ant species recorded (± 1 standard error) from each habitat type (AF, arable field; BW, broadleaf woodland; CY, urban; CW, coniferous woodland; RS, roadside; WL, wetland; CG, calcareous grassland; SD, coastal sand dunes; SC, scrubland on limestone; LP, limestone pavements) in order of increasing species richness.

(39 sites) were found on approximately half of the sites (Fig. 3.2). The third most frequent species was the common formicid species, *Lasius flavus*, which was found on 30 sites. Only single records were made for *Formica fusca*, *Lasius fuliginosus* (a rare temporal social parasite) and *Stenamma debile*.

3.3.2 Indicators for conservation status

In general, myrmecologists consider open, southern-facing exposed sites with good drainage to be the best

locations for ant assemblages. This study found that, in Ireland, this can be in particular applied to mainly limestone rock (scrubland on limestone, calcareous grassland, limestone pavement) and sandy habitats (coastal sand dunes). High ant species richness can be expected to include records of rare species. Limestone pavements were found to support the highest species numbers. All 10 sites of this habitat type were found to contain at least four species, including two sites with nine species, which is

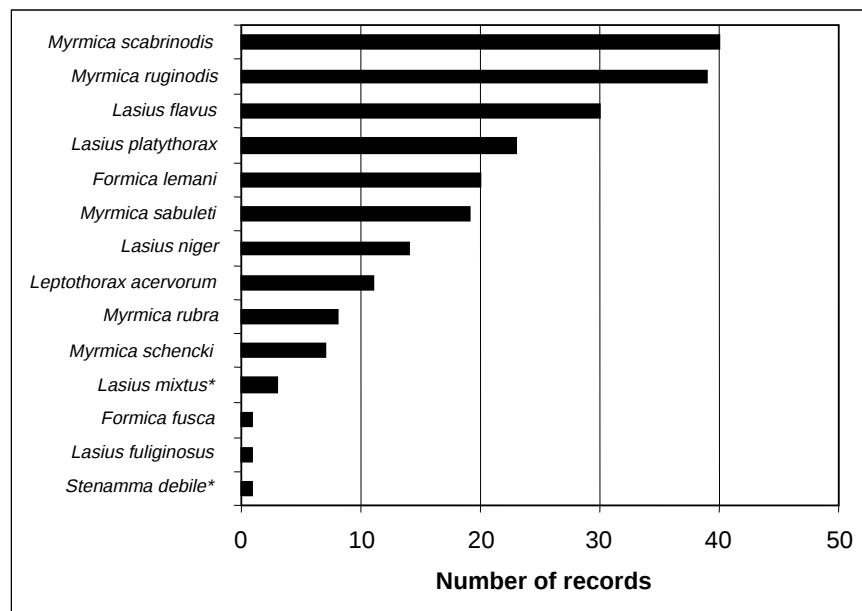


Figure 3.2. Number of records across the 80 sites for each ant species found (the asterisks indicate species recorded as female dealates).

representative of approximately half the number of all Irish native ants. The relatively rare species, *Lasius mixtus*, was recorded at two of the sites. This species is a temporary social parasite on *Lasius flavus*, its main host species. Two single records of other rare species were made: *Formica fusca* was found in open woodland on limestone and *Stenamma debile* was also found nearby. These findings are significant and it is recommended that future studies assess the interconnection of various habitats containing niches for ants.

Furthermore, the potential of sand dunes as a habitat type must be realised, investigated further and protected where possible. *Lasius fuliginosus*, found during this survey only in a sand dune habitat, is not only rare to Ireland, but its life cycle is complicated. *Lasius fuliginosus* is known to support many species of myrmecophiles, i.e. species such as beetles which inhabit ant nests, though the number occurring in Ireland is not known. It is interesting to note, also, that Irish populations of *Formica lemani*, especially in the limestone region of the Burren, are hosts to the larvae of the hoverfly *Microdon mutabilis* (Diptera: Syrphidae) a rare myrmecophilous species.

3.4 Conclusions and Recommendations

This ant survey is the first such survey in more than 50 years in Ireland. Since the study sites are traceable, and a collection of voucher specimens is provided, the survey is valuable for future research and resurveying/monitoring in years to come. Therefore, it not only provides information on current ant biodiversity in Irish habitats, but also provides a baseline for future studies of temporal changes in species distribution, if regular monitoring of habitats is undertaken (Agosti et al., 2000).

The set of sampling sites can be used for future monitoring in the three counties included in the present study. However, it cannot be considered representative for the whole of Ireland. Apart from the obvious geographical restriction of the sites, the lack of at least two native species on the sites suggests that a nationwide extension of the survey should include those species if it is to be used for national monitoring.

The habitats included, and the methodologies adopted, can act as a guideline for setting up surveys in other Irish counties. However, not all categories of prime habitats for conservation are available in the other counties to the same extent (e.g. limestone pavement or coastal sand dunes).

As an alternative to the conservation of ant-rich habitats or particular sites with certain rare ant species, the conservation of fauna in a wider sense must be considered (Leather et al., 2008). Common species of ants acting as hosts might provide stepping stones and suitable expansion paths for other locally common species. This not only applies to ants but also to myrmecophiles, which are supported or entirely depend on ant microhabitats. Also, ants acting as a food source of threatened species such as the chough (*Pyrrhocorax pyrrhocorax*) should find attention in conservation planning for such species. Combining the needs of different target biota will help to identify hot spots of ant-related diversity and key populations of ants.

Based on these conclusions, the following recommendations are made:

- To set up a nationwide recording scheme to provide data, currently lacking on many Irish ant species.
- To set up a nationwide monitoring scheme including the major habitat types used in this study.
- To assure and extend the guaranteed protection of limestone pavements as prime habitats for species richness of ants, and many other species.
- To compile knowledge on localities where ant species are known to support populations of rare species such as the chough or myrmecophiles, e.g. sites with *Formica lemani* and *Microdon mutabilis* (Diptera: Syrphidae) for an integrated approach to conservation.
- To rapidly develop species action plans for the conservation of species which are rare and vulnerable (especially *Formica lugubris*, *Lasius fuliginosus*) and their habitats.

4 Response to Pressures: Biosolids and Soil Biodiversity

4.1 Background and Aims

A number of anthropogenic pressures on soil quality have been identified at international (Francaviglia, 2004), European (Andr n et al., 2004; Louwagie et al., 2009) and national (Brogan, 2008) levels. At all of those levels, loss of soil biodiversity, in itself, and also of soil functions linked with biodiversity are seen as major impacts that require responses in policies, regulations and management strategies, which in turn need to be based on scientific research.

The application of exogenous organic matter (i.e. derived from external sources) to land is one of the most critical anthropogenic pressures on soils in the EU (Robert et al., 2004; Louwagie et al., 2009). In Ireland, land-spreading of sewage sludge is increasing because alternative disposal options have recently been eliminated (sea dumping), are soon to be precluded (landfill), or are not available (incineration). Production of municipal sludge in Ireland is predicted to increase fourfold from 1993 to 2020, while the mode of disposal changed from 90% to landfill in 2000, to >90% spreading onto agricultural land in 2005 (Bartlett and Killilea, 2001). Treated sludge which meets certain standards is termed 'biosolids'. Biosolids are usually applied in agriculture for fertilisation purposes in accordance with Directive 86/278/EC, which establishes the requirements for sludge application to soil based on concentrations of heavy metals. Irish legislation (DoELG, 1998) also imposed that sewage sludge must be treated to ensure the reduction of fermentative activities and the elimination of pathogenic micro-organisms before its use in agriculture. Further, the Nitrates Directive (91/676/EEC), as transposed into national legislation (DoELG, 2006), also applies to organic amendments including biosolids.

While good information is available on the characteristics of biosolids generated in Ireland (Bartlett and Killilea, 2001), none is currently available on their impact on soil systems in general and on soil biological parameters in particular (Brogan et al., 2002;

Brogan, 2008). The objective of this research was to investigate, under field conditions, the response of selected soil organisms to pressures caused by the application of exogenous organic materials (treated sewage sludge or biosolids) to soil. Two replicated field-plot experiments were conducted in order to establish the short-term response (<3 years) of AMF, microbial communities, nematodes, and earthworms.

4.2 Methods

Two factorial, replicated field plot experiments were set up in early 2007 in a pasture and an arable field on two commercial farms in Co. Wicklow. There were three treatments (untreated control, and two types of treated municipal sewage sludge), with five replicates, and field-scale plot sizes (15 m × 20 m) were used in both experiments to facilitate biosolids application with standard commercial spreaders. The biosolids used were Biofert (Class A pasteurised, thermally dried granules), which is approximately 95% dry matter, and Biocake (Class A pasteurised), which is approximately 26% dry matter. Materials were land-spread at the maximum permissible rate (according to National Sewage Sludge Regulations SI 148 of 1998; DoELG, 2006); Biofert was applied at 5 t fresh weight/ha/year and Biocake at 15–20 t fresh weight/ha/year. Samples of the Biofert and Biocake were taken prior to application on the experimental plots and a suite of chemical properties were analysed ([Table 4.1](#)). Sampling methods for the different soil organisms were similar to those used in the baseline survey; full details are given in the Final Technical Report.

4.3 Summary Results

4.3.1 Soil properties

There were generally no significant effects of biosolids treatment on any of the selected soil properties including nitrate and phosphorus concentrations.

4.3.2 Mycorrhizal fungi

Biosolids application had no effect on AMF in terms of root colonisation, mean number of types, or their

Table 4.1. Characteristics of Biocake and Biofert applied to the arable and pasture experimental sites in 2007 and 2008.

Biosolids property	Biocake		Biofert	
	2007	2008	2007	2008
Carbon (%)	32.51	ND	42.80	ND
Nitrogen (%)	3.79	ND	4.26	ND
Total Kjeldahl nitrogen (%)	3.87	4.60	4.07	5.03
Total phosphorus (%)	2.21	1.80	1.04	1.66
Cadmium (µg/g) ¹	1	<0.5	<0.5	0.5
Copper (µg/g) ¹	448	457	221	203
Lead (µg/g) ¹	78	6	38	3
Nickel (µg/g) ¹	25	15	9	7
Zinc (µg/g) ¹	517	621	301	193
Boron (µg/g)	ND	6	ND	5
Aluminium (µg/g)	17494	7049	9963	2807
Antimony (µg/g)	3	4	3	2
Arsenic (µg/g)	6	4	2	2
Barium (µg/g)	193	191	114	87
Beryllium (µg/g)	<0.5	<0.5	<0.5	<0.5
Cobalt (µg/g)	6	3.6	2	2
Iron (mg/g)	10	6	2.1	3
Manganese (µg/g)	718	285	139	191
Selenium (µg/g)	3	3	2	2
Silver (µg/g)	<0.5	10	3	4
Tin (µg/g)	25	22	10	<0.5
Mercury (µg/g)	ND	<0.5	ND	

¹These metals were also measured in the experimental treatments.
ND, not determined.

communities on the grass *Lolium perenne* in the pasture site. Also, in the arable site there was no biosolids effect on the bioassay clover (*Trifolium repens*) root colonisation, mean number of types or AMF community. There was a temporal effect on AMF at both sites over the 2 years of study.

4.3.3 Soil bacteria and fungi

General microbial activity was measured as the activity of soil dehydrogenase enzymes. The enzyme activity

changed over time, but it was not affected significantly by sludge treatments in either site or depth during the experimental period. Soil microbial richness and assemblages (as 16S rRNA ribotypes) were not affected by biosolids treatments, but they were significantly different in time.

4.3.4 Nematodes

A total of 32 genera and 41 genera were recorded in the arable and pasture experimental sites,

respectively. In the arable site there were 11 bacterial feeding, 3 fungivorous, 4 plant-associated (or root-hair feeding), 7 obligate plant parasitic, 3 omnivorous and 4 predatory genera. In the pasture site there were 12 bacterial-feeding, 4 fungivorous, 4 plant-associated (or root-hair feeding), 10 obligate plant parasitic, 4 omnivorous and 7 predatory genera.

At the arable site there was a significant effect of year on total nematode abundance, but there was no effect of treatment or an interaction between year and treatment; at the pasture site there was no effect of year, treatment or their interaction on nematode abundance (Fig. 4.1). There was no significant effect of treatment on any measure of nematode diversity or nematode community composition in either the arable or pasture system (Table 4.2).

4.3.5 Earthworms

In the arable system, earthworm populations under Biofert, Biocake and control treatments were very similar in the first year of the experiment, but there was some divergence in Year 2, about 20 months after the first biosolids application (Fig. 4.2). There was a significant effect of treatment on earthworm biomass but not on total abundance (Table 4.2), with earthworm biomass being significantly higher under the Biocake treatment than the Biofert or control treatments (Fig. 4.2). Earthworm communities exhibited less variation

in the pasture system, where biosolids remained on the soil surface after application. Treatment effects were not significant and statistical power was generally low in this experiment, but nevertheless earthworm abundance and biomass tended to be lower in the control in the second year of the experiment. Analysis of earthworm species suggested that biosolids treatments did not cause systematic shifts in species dominance or in the overall species composition (similarity matrices) of earthworm communities in either the arable or pasture experiment (Table 4.2).

4.3.6 Heavy metal concentrations

The absence of observable detrimental effects, in the short term, of two biosolids materials in these field experiments as well as in laboratory tests (Artuso et al., 2011) on soil biota likely reflects the fact that the materials used had much lower concentrations of all heavy metals than maximum legal limits (DoELG, 1998). Cadmium, lead, mercury, nickel and zinc were all very considerably lower than legal limits, typically at least by a factor of 10. All measured soil concentrations of relevant heavy metals were below the legal values. Maximum application rates for biosolids are determined based on nitrogen and phosphorus contents of the amendments, type of crop, and soil nutrient indices (DoELG, 2006). In Spring barley, the biosolids used here could have been applied at rates of between 1.1 and 3.7 t/ha on nitrogen Index 4 to

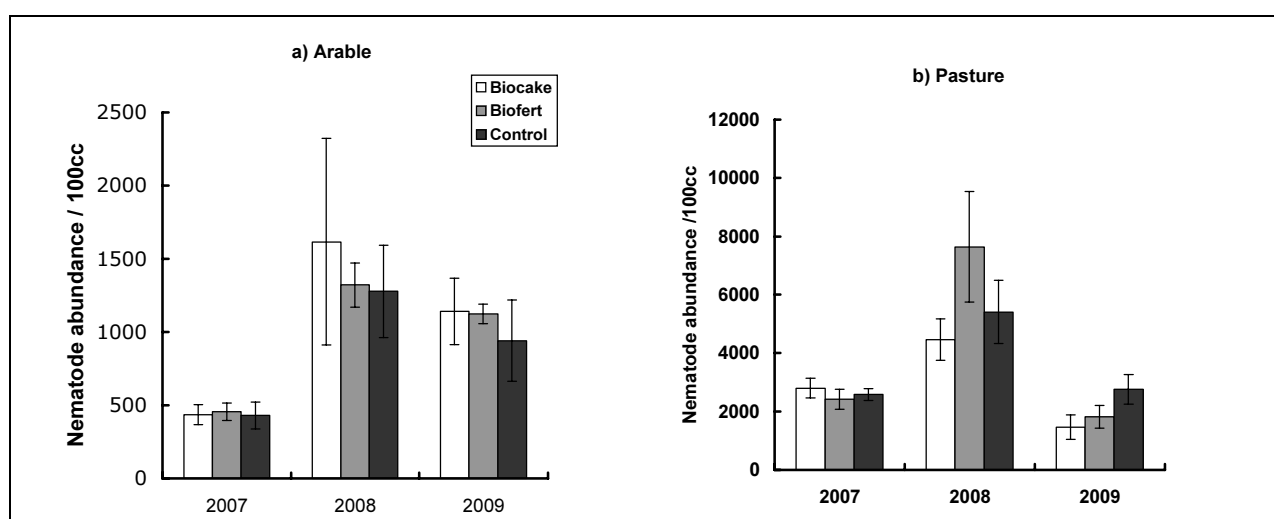


Figure 4.1. Biosolids treatment and total nematode abundance across sampling years in (a) arable and (b) pasture systems. Data from 2007 are pretreatment; values represent means $\pm$ standard error.

Table 4.2. Summary of effects of experimental biosolids application on abundance, diversity and composition of different groups of soil organisms.

	Measure	Differences between treatments?	Temporal changes?
Abundance/Activity			
Soil microbes	Dehydrogenase activity	No	Yes
Mycorrhizae	% Root colonisation	No	Yes
Nematodes	Total abundance	No	Yes
Earthworms	Abundance	No	Yes
Earthworms	Biomass	Yes	Yes
Diversity			
Soil microbes	Number of ribotypes	No	Yes
Mycorrhizae	Number of T-RFs	No	Yes
Nematodes	Number of genera	No	No
Nematodes	Trophic diversity	No	Yes
Earthworms	Number of species	No	No
Composition			
Soil microbes	Similarity in ribotypes	No	Yes
Mycorrhizae	Similarity in T-RFs	No	Yes
Nematodes	Similarity in genera	No	Yes
Earthworms	Similarity in species	No	Yes

T-RF, terminal restriction fragment.

Index 1 soils, and of between 0.0 and 3.9 t/ha on phosphorus Index 4 to Index 1 soils, respectively. For grassland (assuming standard stocking rate), phosphorus would be the deciding nutrient, limiting applications to between 0.0 and 3.4 t/ha on phosphorus Index 4 to Index 1 soils. Overall, these maximum legal limits illustrate that the biosolids application rates investigated in the present study were realistic and representative of commercial land-spreading practice.

4.4 Conclusions and Recommendations

Two types of treated sewage sludge materials, produced at one plant, were applied annually, at the maximum permissible rates, to one arable and one grassland experiment on soils that had not received

sludges before. Several soil organism groups (mycorrhizal fungi, bacteria and fungi, nematodes, earthworms) were sampled prior to the first application and at various dates thereafter, up to 2 years after the initial sampling. All organisms exhibited seasonal and/or annual variability, and in most cases this variation was greater than any potential treatment effect (see [Table 4.2](#) for summary). Mycorrhizal fungi and micro-organisms were not measurably affected by biosolids treatments as compared with an untreated control. Biosolids had a significant effect on the abundance of some nematode groups at some dates, and the total earthworm biomass was higher in the arable system in one biosolids treatment, suggesting that treated sewage sludges can act as a nutrient source for earthworms. Overall, data from two field

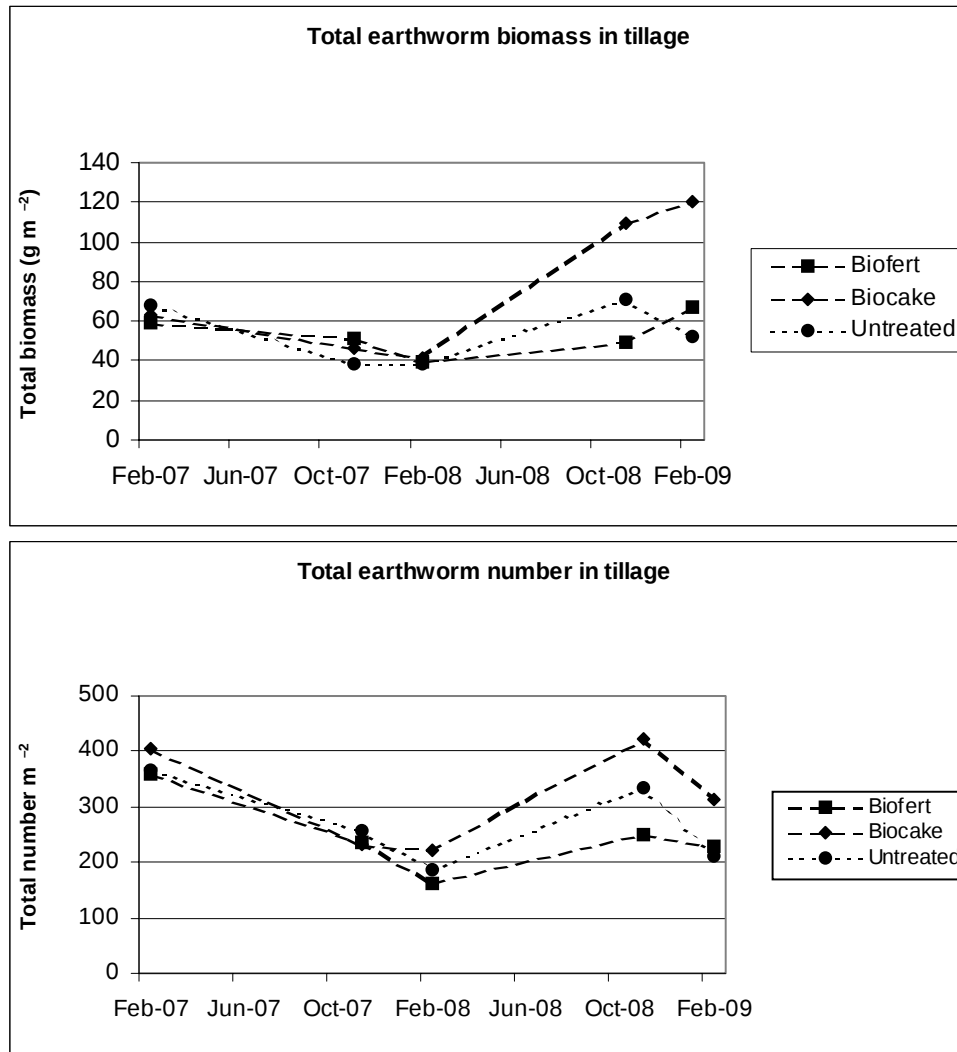


Figure 4.2. Total earthworm biomass (g/m²) and abundance (no./m²) in the three biosolids treatments in the arable system. For overall comparisons between treatment means, the Tukey–Kramer Honest Significant Difference is 22.0 for biomass ($P < 0.05$) and 92.9 for number ($P > 0.05$).

experiments suggest that annual applications of biosolids at low rates to virgin soils did not have systematic effects on the diversity or composition of soil organisms biosolid treatments and did not substantially alter the diversity or composition of soil organism groups studied in the short term (Table 4.2).

While this research suggests that applications of treated sewage at low application rates (~5 t/ha) did not impact negatively on soil biodiversity in the short term (2 years), somewhat higher dry matter rates of similar sludges as those used in these experiments could be applied on certain soils and crops in Ireland, in accordance with the Nitrates Regulations.

Applications of biosolids at substantially higher rates have been documented in the literature to alter soil biodiversity. Furthermore, these research results cannot be used to predict the possible long-term effects of continuous land-spreading of biosolids.

In conclusion, the key scientific findings were as follows:

- Annual applications of two biosolids at realistic levels (according to national regulations) had few measurable effects on soil biodiversity in the 2-year duration of these field experiments.
- Temporal variability in composition was generally

greater than any potential treatment effects for all groups of soil organisms.

The following recommendations are being made:

- These field experiments should be continued to examine longer-term effects of biosolids

application on soil biodiversity.

- Future research should also consider (i) the effect of biosolids applications on soil functions, and (ii) sub-lethal effects that could have longer-term implications for soil populations.

5 Functions: Functional Roles of Keystone Soil Organisms

5.1 Background and Aims

Soil biodiversity and soil functioning are areas of intensive scientific research, analysis and debate (Wolters, 1997; Fitter et al., 2004; Turbé et al., 2010). The present research was concerned with biological processes occurring in Irish soils that have potential applications in soil management in Ireland. Separate work packages were completed, investigating the following research questions:

- The effects of ants on soil and their interactions with micro-organisms ([Section 5.2](#)); and
- The status of anecic (deep-dwelling, surface-feeding) earthworms as keystone species ([Section 5.3](#)).

The objective of this research was to investigate the functions of potential keystone species in soil ecosystem processes, their relationships with other soil organisms and thus their status as keystone species.

5.2 Ants: Effects on Soil and Interactions with Micro-Organisms

5.2.1 Background, aims, methods

Ants have long been recognised as important players in terrestrial ecosystems for their burrowing and nest-building activity which can significantly alter soil characteristics (Bardgett, 2005). Compared with the surrounding soil, ant nests and mounds can be nutrient hot spots containing different concentrations of carbon and nutrients (Laakso and Setälä, 1997). These characteristics can have an effect on the soil food web and (micro-)biological diversity in nests and their close proximity. Information on ant-microbe relations in temperate regions is greatly lacking, especially in grassland ecosystems.

This research had four specific objectives:

1. To examine ant-mediated environment modification by measuring vegetation diversity

and soil parameters in nests of different ant species.

2. To assess microbial diversity in ant nests of different ant species and compare this to that found in reference soils (i.e. soils not worked by ants).
3. To assess functional gene diversity associated with the nitrogen cycle in ant nests and soils without nests of different ant species.
4. To assess microbial diversity in the ant gut system (abdomen) of different ant species.

Ants with different ecological behaviour were chosen (*Lasius flavus*, *Myrmica sabuleti* and *Formica lemani*). *Lasius flavus* is known to farm root aphids in its nests, whereas *Myrmica sabuleti* and *Formica lemani* are known to hunt and scavenge for resources. All ants were sampled at one site in the Burren, Co. Clare ([Fig. 5.1](#)). Six well-developed nests from each ant species were randomly chosen for analysis in the nest and at reference locations (controls), including vegetation composition, soil moisture, carbon and nitrogen content, and stable isotope composition (^{13}C and ^{15}N).

Soil dehydrogenase enzyme activity as an index of microbial activity was determined, microbial abundance was estimated using the most probable number method and DNA was extracted from soil and from the abdomen of 50 individual worker ants from each nest. Bacterial and fungal assemblages were determined by molecular fingerprinting. Further, microbes that can fix atmospheric nitrogen or oxidise ammonium were determined by detecting their functional genes (*nifH* gene and *amoA* gene).

5.2.2 Summary results

Plant species richness was lower and vegetation composition was different on *Lasius flavus* nests. The abundant presence of *Thymus praecox* on *Lasius flavus* nests was notable, followed by *Festuca rubra* and *Lotus corniculatus*. *Lasius flavus* nests were



Figure 5.1. Pictures of *Lasius flavus* nests from a) the limestone site at the Burren, b) the sandstone site in Co. Kerry, c) the peat site on Clare Island, and d) the shale site on Clare Island.

considerably drier than all other samples (Table 5.1). Total soil carbon content was significantly different, with the open reference containing more carbon than all others. Total soil nitrogen content was significantly different, with *Lasius flavus* nests containing the least and open reference soils the most nitrogen; soil carbon to nitrogen ratios and pH were also different (Table 5.1). Ant nest and reference soil ^{13}C isotopic compositions were significantly different, with the open reference and *Lasius flavus* nests being more depleted than the rock soil samples. Further, *Lasius flavus* nest soil was most enriched in ^{15}N followed by rock

reference soil, whereas the open reference was depleted.

Taken together, these findings indicate that all three ant species alter several abiotic soil variables, representing ecosystem engineering effects. These effects were more evident in nests of *Lasius flavus* than in those of *Myrmica sabuleti* and *Formica lemani*. The observed differences in vegetation on and around ant nests may have resulted from the alteration of soil properties.

Soil microbial activity as measured by dehydrogenase enzyme activity was significantly different between

Table 5.1. Soil environmental data of the Burren site. Soils are from three different ant species and two reference soils (Mean $\pm$ standard error, $n = 6$). Superscript letters indicate significant differences between ants and references at $P = 0.05$.

	Moisture (w/w)	Carbon (%)	Nitrogen (%)	Carbon to nitrogen ratio	pH
<i>Lasius flavus</i>	0.24 ± 0.00^c	12.23 ± 0.82^b	1.06 ± 0.05^b	11.48 ± 0.25^{ab}	5.97 ± 0.19^b
<i>Myrmica sabuleti</i>	0.45 ± 0.03^b	13.23 ± 0.60^b	1.15 ± 0.04^{ab}	11.51 ± 0.27^{ab}	6.65 ± 0.06^a
<i>Formica lemani</i>	0.44 ± 0.01^b	13.10 ± 0.54^b	1.28 ± 0.10^{ab}	10.46 ± 0.56^{bc}	6.77 ± 0.03^a
Open reference	0.52 ± 0.02^a	17.50 ± 1.21^a	1.38 ± 0.10^a	12.72 ± 0.21^a	6.20 ± 0.12^b
Rock reference	0.43 ± 0.02^b	11.13 ± 0.64^b	1.16 ± 0.10^{ab}	9.84 ± 0.68^c	6.78 ± 0.03^a

samples, where soils from *Lasius flavus* nests showed the least activity, and those from *Myrmica sabuleti* nests the greatest. Microbial activity in *Myrmica sabuleti* and *Formica lemani* nests was higher than in the rock reference soils.

Bacterial richness (mean ribotype number) was not different among nest and reference soils. However, ant nest and reference soils from *Lasius flavus*, *Myrmica sabuleti* and *Formica lemani* from the Burren site had significantly different bacterial assemblages, where *Lasius flavus* nests differed from those found in the open reference soils (Fig. 5.2). Bacterial assemblages in soils from *Lasius flavus* nests on different parent material were highly significantly different among sites and each was different from its reference soil. This difference in soil microbial assemblages can possibly be attributed to either ecosystem engineering by ants (by altering pH and moisture content) or to the direct influence that ants may have in controlling micro-organisms, especially in galleries.

Bacterial genes were successfully amplified from all ant abdomens. The *Lasius flavus* specimens had

similar assemblages in their abdomen regardless of the parent material their nests were built on. *Lasius flavus*, *Myrmica sabuleti* and *Formica lemani* were found to harbour very different bacterial assemblages in their abdomens. However, it is unclear if feeding strategies determine microbial assemblages, or vice versa. Overall, soil fungal gene assemblages showed patterns between ant species, nest locations and sites that were comparable to those of bacterial genes.

The presence of *nifH* genes in ant gut systems was verified. In total, 165 different microbial *nifH* genes were amplified from *Lasius flavus*, *Myrmica sabuleti* and *Formica lemani* abdomens from nests from the Burren site, and each ant species harboured highly different microbial *nifH* assemblages in their abdomen.

5.2.3 Conclusions

The three ant species in this study harboured very different bacterial and diazotrophic assemblages in their abdomen. Some members of these assemblages were found to be ant specific, suggesting that ants can be a source of unique microbes that do not occur in soil, possibly playing roles in various processes

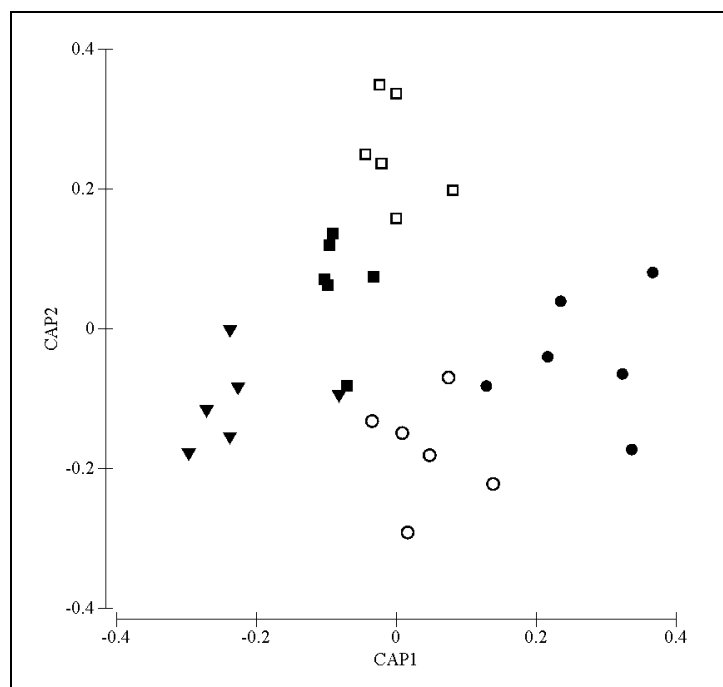


Figure 5.2. Canonical analysis of principal coordinates (CAP) of ant nest and reference soil 16S rRNA gene community profiles (CAP1 $\delta^2 = 0.887$, $P = 0.004$; CAP2 $\delta^2 = 0.819$). Filled circle, *Lasius flavus*; open circle, open reference; triangle, *Myrmica sabuleti*; filled square, *Formica lemani*; open square, rock reference.

including the fixation of atmospheric nitrogen. These are exciting, novel findings. However, it is unclear how ants achieve these diverse and specific microbes. Different diets or vertical, maternal transmission of symbionts may explain the differences. *Lasius flavus* harboured similar microbial assemblages regardless of the nest environment, suggesting that ants specifically obtain certain microbial assemblages that are uniform. Examining and comparing ants of the same species from different countries (not only the island of Ireland) may confirm the hypothesis that ants harbour diverse, but ant-specific and geographically stable, microbes in their abdomens. Also, from a conservation perspective, the ecology of specialised ant abdomen-specific microbes warrants more research, especially since many ant-microbe associations have been found to be obligatory in other studies.

In conclusion, the key scientific findings were as follows:

- Ants alter soil conditions and thus can be seen as ecosystem engineers in Irish temperate grasslands.
- Different ant species with different ecological behaviour generally harbour different microbial assemblages in their nests, also compared to reference soils.
- Different ant species with different ecological behaviour generally harbour different microbial assemblages in their abdomen.
- Individual ant species have similar microbial assemblages in their abdomen regardless of the environmental conditions of their nests.
- Temperate ants have the potential for a symbiotic relationship with nitrogen-fixing micro-organisms.

5.3 Anecic Earthworms as Keystone Species

5.3.1 Background, aims, methods

Earthworms are abundant, diverse and highly productive animals recognised as keystone species and ecosystem engineers in biogeochemical cycling, soil carbon storage, soil hydrology and crop productivity (Bardgett, 2005). However, the functional

role of different species belonging to different ecological groups in dung and residue decomposition is unclear and has not been quantified under realistic field conditions (Bengtsson, 1998). Here, a novel removal experiment was conducted in the field. The two anecic species present at the study site (*Aporrectodea longa* and *Lumbricus terrestris*) were removed from removal treatment plots at the start of the experiment and repeatedly thereafter during active seasons (spring, autumn). Selected disappearance of certain earthworm species under Irish conditions is conceivable, for example caused by the exclusively earthworm-eating, invasive New Zealand flatworm (*Arthurdendyus triangulatus*), which is widespread in northern Britain and the Island of Ireland (Bolger et al., 2002).

The objective of this research was to test experimentally the status of anecic earthworms as keystone species, with minimum disturbance to the soil-plant system and remaining earthworm community. Stable isotope tracer techniques were used to quantify the effect of anecic earthworm species on the incorporation and decomposition of green-cover crop residues (^{13}C , ^{15}N dual-labelled mustard, *Sinapis alba*), linking key functional processes to biodiversity.

The experiment was conducted in a field with a large and species-rich (12 species) earthworm community. There were three treatments, with five replicate plots each:

1. An isotopic background control with undisturbed earthworm populations to which no labelled residues were added (NM, non-mustard);
2. A control with undisturbed earthworm populations to which labelled residues were added (CON, control); and
3. A treatment in which anecic earthworms were removed and labelled residues were added (REM, earthworm removal).

Large-bodied, anecic earthworms were removed by injecting a mustard oil irritant into their burrows and the location of burrows in each plot was recorded and mapped. The fate of ^{13}C and ^{15}N was measured in soil, vegetation and earthworms by mass spectrometry.

5.3.2 Summary results

From the start of the removal until introduction of the mustard residues, between two and seven (mean 4.2) adult anecic earthworms per plot were removed from the removal plots, with a mean biomass of 10.6 g; most were adult or sub-adult *Lumbricus terrestris*.

At final harvest, earthworm live biomass in the non-mustard control (NM 51 g/m²) was significantly lower than in treatments with mustard residue (91 g/m² in CON, 113 g/m² in REM). Endogeic earthworm species (*Aporrectodea rosea*, *Aporrectodea caliginosa* and *Allolobophora chlorotica*) did have slightly elevated tissue $\delta^{15}\text{N}$ values (<10‰) in the two treatments with added mustard residue, but without a consistent effect of anecic removal (Fig. 5.3, CON and REM). By contrast, the litter-feeding species (*Satchellius mammalis*, *Lumbricus rubellus*, *Lumbricus festivus*, *Aporrectodea longa* and *Lumbricus terrestris*) had very ^{15}N -enriched values in the mustard treatments,

reflecting substantial assimilation of ^{15}N from the surface residues. Again, there was no consistent effect of anecic removal on the ^{15}N content of other species, but *Lumbricus terrestris* itself was significantly less enriched in the removal treatment (Fig. 5.3, REM). Since the mustard residue was dual labelled (^{15}N and ^{13}C), the carbon isotope composition of earthworms reflected the nitrogen isotope composition.

At the time of sampling, the mass of mustard residue remaining on control plots and removal plots was not significantly different. Grasses accounted for 95% of the harvested total plant biomass and the grass yield was significantly higher in the two treatments in which labelled mustard residue (CON and REM) was applied than in the control treatment without mustard (NM). The nitrogen isotope composition of above-ground plant biomass reflected the uptake of mustard-derived nitrogen (Fig. 5.4). Plants from plots without labelled mustard residue had natural abundance $\delta^{15}\text{N}$ values of

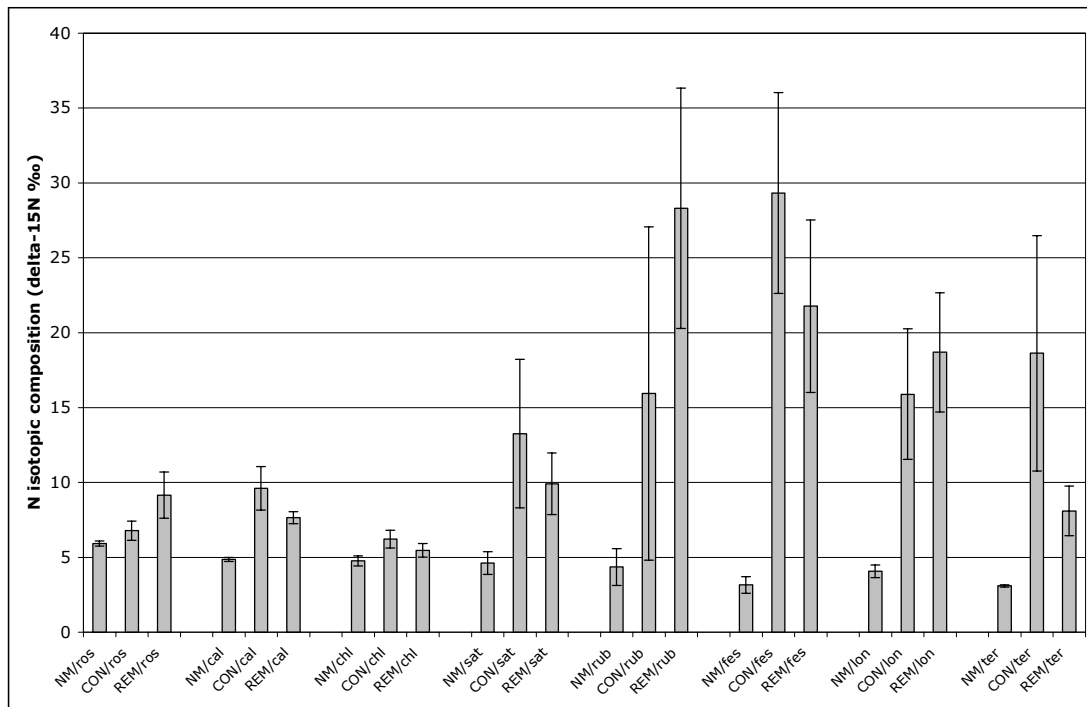


Figure 5.3. Nitrogen isotopic composition of earthworm whole-body tissues ($\delta^{15}\text{N}$, ‰). Treatment codes: NM, non-mustard; CON, control; REM, earthworm removal. Earthworm species codes (from left to right) – Endogeics: ros, *Aporrectodea rosea*; cal, *Aporrectodea caliginosa*; chl, *Allolobophora chlorotica*. Epigeics: sat, *Satchellius mammalis*; rub, *Lumbricus rubellus*; fes, *Lumbricus festivus*. Anecics: lon, *Aporrectodea longa*; ter, *Lumbricus terrestris*. Mean $\pm$ standard error ($n = 2-5$). The mean enrichment of mustard residue was 163‰ $\delta^{15}\text{N}$.

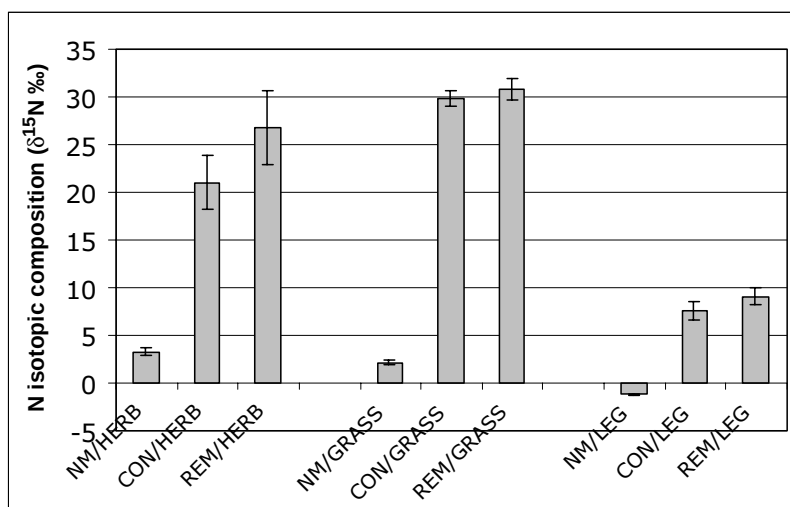


Figure 5.4. Nitrogen isotopic composition of above-ground plant biomass ($\delta^{15}\text{N}$, ‰). Treatment codes: NM, non-mustard; CON, control; REM, earthworm removal. Plant group codes (from left to right) – HERB, herbs; GRASS, grasses; LEG, legumes. Mean $\pm$ standard error ($n = 5$). The mean enrichment of mustard residue was 163‰ $\delta^{15}\text{N}$.

<5‰ in herbs and grass and <0‰ in legumes which probably relied on fixed atmospheric nitrogen in this system rather than soil nitrogen. In the two treatments with mustard residues, CON and REM, herbs and grasses had taken up substantial amounts of mustard-derived nitrogen. Legumes from CON and REM were also enriched in ^{15}N but much less so than herbs and grass. There were statistically significant treatment and plant type effects, and the plant type by treatment interaction was also significant due to the different response by legumes. Plant $\delta^{15}\text{N}$ levels in the two mustard treatments (CON and REM) were not different from each other, but they were significantly higher than in the non-mustard treatment in which no labelled mustard had been applied. However, anecic earthworm removal did not have a statistically significant effect.

Nitrogen and carbon isotopic compositions of the eight earthworm species studied here clearly reflected typical endogeic (soil feeding) and anecic/epigeic (litter feeding) feeding behaviours. Carbon and nitrogen assimilation from mustard residues was tightly coupled and worm tissue data clearly show that earthworms have a function in the incorporation, decomposition and mineralisation of surface plant residues. Removal of anecic worms did not result in consistent effects on other earthworm species, as assessed by ^{15}N and ^{13}C

tracer assimilation from surface-applied plant residues. Some ecologically similar species responded differently, for instance *Lumbricus rubellus* was much more enriched in removal plots but *Lumbricus festivus* was less enriched. This could reflect reduced food competition from *Lumbricus terrestris*, but it could also reflect differences in migration behaviour.

5.3.3 Conclusions

Selective removal of anecic earthworms was successful, but mustard residues acted as strong attractants to earthworms in this unfertilised grassland system and removal plots were recolonised by anecic conspecifics. The addition of mustard residues strongly stimulated above-ground plant biomass production and residue-derived nitrogen was taken up by grasses, herbs and, to a lesser extent, legumes. Removal of anecic earthworms did not affect plant biomass or nitrogen uptake, neither did it have systematic effects on the assimilation of residue nitrogen and carbon by other earthworm species. While the measured assimilation of ^{13}C and ^{15}N by various earthworm species is strong evidence for the roles these earthworms play in the decomposition and mineralisation of plant residues, this experiment did not provide evidence for the keystone status of anecic earthworm species. Additional research at the level of individual *Lumbricus terrestris* burrows suggests that

residue-derived carbon is incorporated rapidly into the 'drilosphere' (soil layers surrounding earthworm burrows) and that microbial communities of the drilosphere are different from those in bulk soil (M. Stromberger, Colorado State University, unpublished data).

In conclusion, the key scientific findings were as follows:

- The measured assimilation of ^{13}C and ^{15}N by various earthworm species is strong evidence for the roles that these earthworms play in the decomposition and mineralisation of plant residues.
- The experiment with the design used here did not generate evidence for the keystone status of anecic earthworm species.

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Acronyms

AMF	Arbuscular mycorrhizal fungi
CAP	Canonical analysis of principal coordinates
CON	Control
DNA	Deoxyribonucleic acid
ECM	Ectomycorrhizae
ERM	Ericoid mycorrhizae
EU	European Union
GIS	Geographic information system
GPS	Global positioning system
IGS	Intergenic spacer
ITS	Internal transcribed spacer
NM	Non-mustard
nMDS	Non-metric multidimensional scaling
NSD	National Soil Database
PERMANOVA	Permutational multivariate analysis of variance
REM	Earthworm removal
T-RF	Terminal restriction fragment

Appendix 1 Project Outputs (as of November 2010)

Journal Publications

- Keith, A. M and Schmidt, O., in press. First record of the earthworm *Proselodrilus amplisetosus* (Oligochaeta: Lumbricidae) outside continental Europe. *Irish Naturalists' Journal*
- Keith, A.M., Griffin, C.T. and Schmidt, O., 2009. Predatory soil nematodes (Nematoda: Mononchida) in major land-use types across Ireland. *Journal of Natural History* **43**: 2571–2577.
- Schmidt, O. and Keith, A., 2010. Soils – the last frontier. *Biodiversity Ireland: Bulletin of the National Biodiversity Data Centre* **6** (Autumn), p. 11.

Doctoral Theses

- Boots, B., 2010. *Microbial Ecology in Soils – The Baseline Data, Pressures by Biosolids, and Microbial Associations with Ants in Temperate Grassland Ecosystems*. PhD Thesis, University College Dublin, Dublin, Ireland.
- Hazard, C., 2010. *The Impact of Land Use and Management on the Diversity of Mycorrhizal Fungi*. PhD Thesis, University College Dublin, Dublin, Ireland.

Conferences Organised

- Soil Biological Monitoring in Ireland. CréBeo Research Seminar Day*, Urban Institute, University College Dublin, Dublin, Ireland. 2 September 2008.
- Soil Biodiversity Research in Ireland and Britain. CréBeo End-of-Project Workshop, Satellite Workshop to the BSSS-SSSI Joint Conference*, Teagasc, Johnstown Castle, Wexford, Ireland. 8 September 2009.

Conference Presentations and Posters (excluding those at project's own conferences)

- Boots, B., Niechoj, R., Keith, A.M., Breen, J., Clipson, N. and Schmidt, O., 2007. Linking ant species and microbial community structures in habitats of conservation value in Ireland. *3rd Annual Postgraduate Ecology Forum*, Trinity College, Dublin, Ireland. 10–12 March 2007. [Poster]
- Boots, B., Niechoj, R., Keith, A.M., Breen, J., Clipson, N. and Schmidt, O., 2009. CréBeo: Microbial community fingerprints in Irish soils. *ENVIRON09: 19th Colloquium of Environmental Science Association of Ireland*, Waterford, Ireland. 18–20 February 2009. [Poster]
- Hazard, C., Mitchell, D., Doohan, F. and Bedning, G., 2009. The diversity of mycorrhizal fungi in different land-uses and soil types across Ireland. *ENVIRON09: 19th Colloquium of Environmental Science Association of Ireland*, Waterford, Ireland. 18–20 February 2009. [Oral presentation]
- Keith, A.M., 2009. Land-use and biodiversity in Irish soils. *Ecology Seminar Series*, Trinity College Dublin, Dublin, Ireland. 30 April 2009. [Invited talk]
- Keith, A.M., 2009. Diversity and indicator value of micro- and macro-organisms in Irish Soils. *NUI Maynooth, Department of Biology Postdoctoral Seminar Series*, 20 January 2009. [Invited talk]
- Keith, A., Griffin, C. and Schmidt, O., 2007. CréBeo: the distribution, diversity and indicator value of nematodes in Irish soils. *1st International Symposium on Nematodes as Environmental Bioindicators*, Heriot-Watt University, Edinburgh, Scotland. 11–13 June 2007. [Poster]
- Keith, A.M., Schmidt, O., Boots, B., Clipson, N., Hazard, C., Mitchell, D., Niechoj, R., Breen, J., Griffin, C., Fay, D. and Bolger, T., 2008. Soil biodiversity: Shining light on the hidden half. *EPA Environmental Research Conference: Today's Environmental Research, Tomorrow's Environmental Protection*. Royal Hospital Kilmainham, Dublin, Ireland. 6–7 February 2008. [Invited talk]
- Keith, A.M., Boots, B., Hazard, C., Niechoj, R., Clipson, N., Mitchell, D., Breen, J., Griffin, C.T., Curry, J., Bolger, T. and Schmidt, O., 2008. CréBeo: the diversity and indicator value of soil micro- and macro-organisms in Irish soils. *11th European Ecological Conference of the European Ecological Federation*, Leipzig, Germany. 15–19 September 2008. [Poster]
- Keith, A.M., Boots, B., Hazard, C., Niechoj, R. and Schmidt, O., 2009. What lies beneath? Insights from a systematic survey of biodiversity in Irish soils. *ENVIRON09: 19th Colloquium of Environmental Science Association of Ireland*, Waterford, Ireland. 18–20 February 2009. [Oral presentation]
- Niechoj, R., Schmidt, O. and Breen, J., 2007. Ants as keystone species in Irish grasslands: species mosaic, conservation status and trophic relationship. *Environ2007: 14th Irish Environmental Researchers' Colloquium*. Institute of Technology, Carlow, Ireland. 26–28 January 2007. [Poster]
- Schmidt, O., 2007. Current earthworm research in Ireland. *UK and Irish Earthworm Researchers' Meeting sponsored by the British Soil Science Society*, The Natural History Museum, London, UK.

28 September 2007. [Keynote lecture]

Schmidt, O, Bolger, T., Breen, J., Clipson, N., Curry, J., Doohan, F., Griffin, C., Fay, D., Mitchell, D. and Mullin, P., 2006. A national project on soil biodiversity. *EPA Soils Workshop 2006: A showcase of recent progress in soils research and identification of future requirements and challenges for the EPA Soils Research Strategy 2007–2013*. Tullamore, Ireland. 17 May 2006. [Invited talk]

Datasets

CréBeo Project, 2007. Earthworm and microarthropod records from Ireland as a Pilot Area. *ENVASSO: ENVironmental ASsessment of Soil for mOnitoring, WP5: Prototype Evaluation*. Report online <http://www.envasso.com/publications.htm>

Keith, A.M. and Schmidt, O., 2009. CréBeo Earthworm Records 2006/7. *Biodiversity Maps*, National Biodiversity Data Centre, Waterford. Online at <http://maps.biodiversityireland.ie>

An Gníomhaireacht um Chaomhnú Comhshaoil

Is í an Gníomhaireacht um Chaomhnú Comhshaoil (EPA) comhlachta reachtúil a chosnaíonn an comhshaol do mhuintir na tíre go léir. Rialaímid agus déanaimid maoirsiú ar ghníomhaíochtaí a d'fhéadfadh truailliú a chruthú murach sin. Cinntímid go bhfuil eolas cruinn ann ar threochtaí comhshaoil ionas go nglactar aon chéim is gá. Is iad na príomh-nithe a bhfuilimid gníomhach leo ná comhshaol na hÉireann a chosaint agus cinntiú go bhfuil forbairt inbhuanaithe.

Is comhlacht poiblí neamhspleách í an Gníomhaireacht um Chaomhnú Comhshaoil (EPA) a bunaíodh i mí Iúil 1993 faoin Acht fán nGníomhaireacht um Chaomhnú Comhshaoil 1992. Ó thaobh an Rialtais, is í an Roinn Comhshaoil agus Rialtais Áitiúil a dhéanann urraíocht uirthi.

ÁR bhFREAGRACHTAÍ

CEADÚNÚ

Bíonn ceadúnais á n-eisiúint againn i gcomhair na nithe seo a leanas chun a chinntiú nach mbíonn astuithe uathu ag cur sláinte an phobail ná an comhshaol i mbaol:

- áiseanna dramhaíola (m.sh., líonadh talún, loisceoirí, stáisiúin aistrithe dramhaíola);
- gníomhaíochtaí tionsclaíocha ar scála mór (m.sh., déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta);
- diantalmhaíocht;
- úsáid faoi shrian agus scaoileadh smachtaithe Orgánach Géinathraithe (GMO);
- mór-áiseanna stórais peitreal.
- Scardadh dramhuisce

FEIDHMIÚ COMHSHAOIL NÁISIÚNTA

- Stiúradh os cionn 2,000 iniúchadh agus cigireacht de áiseanna a fuair ceadúnas ón nGníomhaireacht gach bliain.
- Maoirsiú freagrachtaí cosanta comhshaoil údarás áitiúla thar sé earnáil - aer, fuaim, dramhaíl, dramhuisce agus caighdeán uisce.
- Obair le húdaráis áitiúla agus leis na Gardaí chun stop a chur le gníomhaíocht mhídhleathach dramhaíola trí chomhordú a dhéanamh ar líonra forfheidhmithe náisiúnta, díriú isteach ar chiontóirí, stiúradh fiosrúcháin agus maoirsiú leigheas na bhfadhbanna.
- An dlí a chur orthu siúd a bhriseann dlí comhshaoil agus a dhéanann dochar don chomhshaol mar thoradh ar a ngníomhaíochtaí.

MONATÓIREACHT, ANAILÍS AGUS TUAIRISCIÚ AR AN GCOMHSHAOIL

- Monatóireacht ar chaighdeán aer agus caighdeán aibhneacha, locha, uisce taoide agus uisce talaimh; leibhéil agus sruth aibhneacha a thomhas.
- Tuairisciú neamhspleách chun cabhrú le rialtais náisiúnta agus áitiúla cinntiú a dhéanamh.

RIALÚ ASTUITHE GÁIS CEAPTHA TEASA NA HÉIREANN

- Cainníochtú astuithe gáis ceaptha teasa na hÉireann i gcomhthéacs ár dtiomantas Kyoto.
- Cur i bhfeidhm na Treorach um Thrádáil Astuithe, a bhfuil baint aige le hos cionn 100 cuideachta atá ina mór-ghineadóirí dé-ocsaíd charbóin in Éirinn.

TAIGHDE AGUS FORBAIRT COMHSHAOIL

- Taighde ar shaincheisteanna comhshaoil a chomhordú (cosúil le caighdeán aer agus uisce, athrú aeráide, bithéagsúlacht, teicneolaíochtaí comhshaoil).

MEASÚNÚ STRAITÉISEACH COMHSHAOIL

- Ag déanamh measúnú ar thionchar phleananna agus chláracha ar chomhshaol na hÉireann (cosúil le pleananna bainistíochta dramhaíola agus forbartha).

PLEANÁIL, OIDEACHAS AGUS TREOIR CHOMHSHAOIL

- Treoir a thabhairt don phobal agus do thionscal ar cheisteanna comhshaoil éagsúla (m.sh., iarratais ar cheadúnais, seachaint dramhaíola agus rialacháin chomhshaoil).
- Eolas níos fearr ar an gcomhshaol a scaipeadh (trí cláracha teilifíse comhshaoil agus pacáistí acmhainne do bhunscoileanna agus do mheánscoileanna).

BAINISTÍOCHT DRAMHAÍOLA FHORGHNÍOMHACH

- Cur chun cinn seachaint agus laghdú dramhaíola trí chomhordú An Chláir Náisiúnta um Chosc Dramhaíola, lena n-áirítear cur i bhfeidhm na dTionscnamh Freagrachta Táirgeoirí.
- Cur i bhfeidhm Rialachán ar nós na treoracha maidir le Trealamh Leictreach agus Leictreonach Caite agus le Srianadh Substaintí Guaiseacha agus substaintí a dhéanann ídiú ar an gcrios ózóin.
- Plean Náisiúnta Bainistíochta um Dramhaíl Ghuaiseach a fhorbairt chun dramhaíl ghuaiseach a sheachaint agus a bhainistiú.

STRUCHTÚR NA GNÍOMHAIREACHTA

Bunaíodh an Gníomhaireacht i 1993 chun comhshaol na hÉireann a chosaint. Tá an eagraíocht á bhainistiú ag Bord lánaimseartha, ar a bhfuil Príomhstíúrthóir agus ceithre Stíúrthóir.

Tá obair na Gníomhaireachta ar siúl trí ceithre Oifig:

- An Oifig Aeráide, Ceadúnaithe agus Úsáide Acmhainní
- An Oifig um Fhorfheidhmiúchán Comhshaoil
- An Oifig um Measúnacht Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáide

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag ball air agus tagann siad le chéile cúpla uair in aghaidh na bliana le plé a dhéanamh ar cheisteanna ar ábhar imní iad agus le comhairle a thabhairt don Bhord.

Science, Technology, Research and Innovation for the Environment (STRIVE) 2007-2013

The Science, Technology, Research and Innovation for the Environment (STRIVE) programme covers the period 2007 to 2013.

The programme comprises three key measures: Sustainable Development, Cleaner Production and Environmental Technologies, and A Healthy Environment; together with two supporting measures: EPA Environmental Research Centre (ERC) and Capacity & Capability Building. The seven principal thematic areas for the programme are Climate Change; Waste, Resource Management and Chemicals; Water Quality and the Aquatic Environment; Air Quality, Atmospheric Deposition and Noise; Impacts on Biodiversity; Soils and Land-use; and Socio-economic Considerations. In addition, other emerging issues will be addressed as the need arises.

The funding for the programme (approximately €100 million) comes from the Environmental Research Sub-Programme of the National Development Plan (NDP), the Inter-Departmental Committee for the Strategy for Science, Technology and Innovation (IDC-SSTI); and EPA core funding and co-funding by economic sectors.

The EPA has a statutory role to co-ordinate environmental research in Ireland and is organising and administering the STRIVE programme on behalf of the Department of the Environment, Heritage and Local Government.