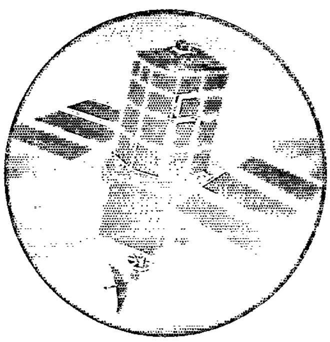
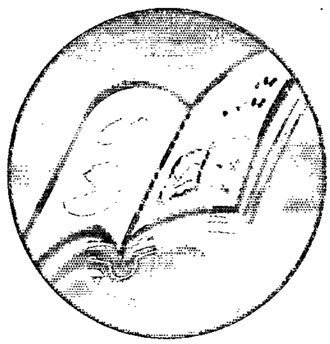
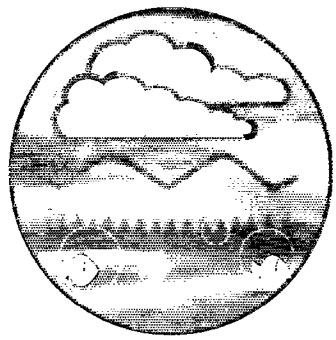
A Demonstration of the Feasibility of SOILPACS

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A Demonstration of the Feasibility of SOILPACS

R&D Technical Report P213

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Statement of use
This study demonstrates the potential for the development and use of an assessment method for determining the biological quality of the soil environment - the terrestrial equivalent of RIVPACS. The information will be of interest to staff involved in the monitoring and assessment of soil quality. Extensive sampling and identification work would be required to take the ideas forward and recommendations for further work are presented.

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EXECUTIVE SUMMARY

One way of quantifying pollution impact is to predict which species should be present at a site based on ecological surveys of uncontaminated areas, and then to survey the polluted sites to see which species are absent. The degree of absence could then be used as an indicator (or predictor) of pollution impact. This approach has been developed extensively in freshwaters. The most comprehensive approach has been RIVPACS from which the title of this report is derived. This report demonstrates the potential for the development and use of a terrestrial counterpart to the familiar means of determining the biological quality of freshwaters (RIVPACS). It investigates the availability and overall suitability of existing data and information, and gives an example of a specific case study. It also outlines the theoretical and practical aspects of a soil biological site classification system. Recommendations concerning future research and development requirements for SOILPACS are suggested. The programme of work undertaken in this study compared the situation for a soil system with the current RIVPACS scheme, analysed existing soil biological field data for invertebrates, identified the needs for new data and technique requirements and provided a SOILPACS case study.

If such a system were already in place today, it would be possible for Environmental Agency officers in the field to relate the effects of possible deleterious releases from, for example prescribed processes (IPCC) in the UK, to deleterious effects upon soil faunal communities; and ultimately to effects upon decomposition and other soil processes that may pose a threat to soil health and sustainability. However, much more detailed investigation is required before we are in a position to be able to make such predictions with the reliability afforded by the current RIVPACS system.

This report recognises the need for good quality data. As would be expected, any assessment can only be as good as the data upon which it is based. It is apparent that existing data on soil fauna are inadequate, the archives of readily available data (such as held by the ITE, Biological Records Centre) being insufficient in detail to be useful except in a regional context e.g. exact collection location and specific local habitats). Furthermore, distribution data for some of the invertebrate groups that show promise as indicators of pollution are very limited or unavailable. For example, soil-dwelling species such as the Collembola and oribatid mites, have no recording scheme in the UK. In addition, there has been very little interest in the development of a standard sampling strategy for these and other groups.

Not only is the distribution of particularly useful species or groups not known in sufficient detail, but simple practical keys for their identification do not exist. Thus, even if there were a recording or collecting scheme, very few people in the UK would be able to identify their catch. Both these points, differ markedly from the starting basis of RIVPACS, where excellent keys were already in widespread use for the identification of stream-dwelling invertebrates. Furthermore, there was extensive information on the distribution of the fauna in the peer-reviewed scientific literature. Despite this, existing biological data were considered inadequate as the starting point for RIVPACS and a new sampling strategy was developed. In the first four years, 268 sites across Great Britain were sampled in an attempt to establish whether prediction of the fauna from environmental features was a feasible option.

The findings of the consortium [comprised of ecotoxicologists' Jason Weeks and Claus Svendsen of the Pollution and Ecotoxicology Section of the Institute of Terrestrial Ecology (ITE), David Roy and Brian Eversham of the Biological Recording Scheme (Environmental Information Centre), ITE. Helaina Black, a soil zoologist at Merlewood Research Station (ITE) and Steve Hopkin an ecotoxicologist and taxonomist at Reading University. Finally, John Wright of the River laboratory, Institute of Freshwater Ecology who remains involved in the continuing development of RIVPACS] also suggest that great

care is needed in the development of a sampling strategy. The distribution of soil organisms is affected by many environmental factors and to encompass all the major habitats with their own characteristic assemblage of soil organisms will be a very substantial undertaking. Even in a structurally-simple habitat type, such as lowland grassland, whose relevant management history may be only years/decades, rather than centuries of management practice which shape the biota of woodlands, detailed information will be required on within-site and among-site variation in faunal composition.
We have a worked example for a locality impacted by contaminants that shows clear differences in the numbers of soil invertebrate groups and the numbers of individuals (particularly, earthworms, springtails, woodlice, spiders and mites) surrounding a metal smelter in Avonmouth, i.e. a change in invertebrate species composition with distance/proximity from/to a point-source of pollution. However, a mini-prediction system that would compare the observed fauna with any predicted fauna has not been undertaken for this site; such an undertaking would require a reference data set which is unavailable from existing sources.

In summary a SOILPACS scheme may be feasible in the UK, but much more development is a prerequisite to a workable system, as suggested below.

RECOMMENDATIONS FOR FUTURE WORK

Essentially there is no shortcut to developing a comprehensive system that may (with time) evolve into the terrestrial equivalent to the freshwater assessment system of RIVPACS. However, we propose the following stages are necessary to advance the concept:

- Undertake a full (England and Wales) quantitative soil invertebrate faunistic survey of many different sites within as many different types of habitat that are believed to be clean "reference" locations (the initial choice of sites may include locations which are found to be unacceptable as reference sites during sample processing or in the initial analyses). An alternative strategy would be to undertake a full survey which included both reference and impacted sites, and distinguish between these at the analysis phase. At all sites there will be a need to consider seasonal and annual variations in faunal compositions. It is recommended that several sampling strategies be adopted at least initially for each site, e.g. pit-fall trapping, "random" searching and quantitative soil cores.

- A further requirement is the collection of a wide range of physical, geological, and biotic and chemical factors for each site at the time of faunal collection. These data are needed to provide the link to the site classification groups based on the soil fauna in order to develop a predictive system. It may well be possible to eliminate many parameters later, but the important issue is to gather as complete a complement of data as possible.

- At all times a full commitment to the quality of the data is essential to the success of the project. Good house-keeping from field sampling to animal sorting and identification will be required, and standard operating procedures and strict QA and QC guidelines put in place, including the archiving of samples (*cf.* RIVPACS)

- The development of suitable identification keys is a crucial limiting factor, because many of the groups suggested as potentially useful "indicators" of pollution are currently without a key to their identification. Thus, only specialists would be able to identify species within some groups likely to be the most useful in indicating stress(for example, the Collembola (Springtails), Molluscs (slugs and snails), mites and earthworms). A major emphasis should be given to facilitating the production of suitable practical keys, possibly in line with the development of an expert-system, or a taxonomic database (such being a major national activity and requiring exclusive funding).

- It is recognised that the composition of the flora at a particular location will affect the composition of the soil fauna. Therefore we recommend that botanical observations be made simultaneous with the faunal determinations for each site, and at each seasonal visit.

- The time and expertise required for field collection, laboratory sorting and laboratory identification requires further investigation. In addition, the field protocols are fundamental to the data collected. For example, how does temporal variation in returning to pitfall traps influence the nature of the final catch? Many of these questions need to be addressed through the use of relevant literature and/or through a pilot sampling programme.

- A centre will be required where samples are sorted, an information database maintained, and activities co-ordinated. There will be the requirement for the maintenance of a suitably archived central specimen bank, and it is recommended that such a facility is housed within a major institute (*cf.* RIVPACS)

- A recently submitted proposal to the Environment Agency entitled "Monitoring and assessing soil quality - biological indicators"addresses a potential way forward with some of these aims listed in more detail and develops a sampling strategy in association with the Countryside Survey 2000.

KEYWORDS

Soils, invertebrate, soil invertebartes, prediction, taxonomy, soil health, classification scheme, monitoring, pollution, RIVPACS, SOILPACS.

1. THE NEED FOR A SOIL INVERTEBRATE PREDICTION AND CLASSIFICTION SCHEME (SOILPACS)

Jason M. Weeks, Institute of Terrestrial Ecology, Monks Wood

1.1 Introduction

Most research in environmental toxicology focuses on the understanding of effects at lower levels of biological organization (such as molecules, cells and individuals), and usually such work is accomplished in the laboratory. However, contaminants exert their effects at all levels of biological organization, from molecules to ecosystems. Although effects at the lower levels may influence populations, communities and ecosystems, surprisingly little research has been conducted to demonstrate a causal relationship between effects at different levels of organization. Molecular endpoints and other biomarkers inclusive of other sublethal measures may be effective as endpoints to assess contaminant exposure, or may provide good early warning signs of potential contaminant impacts; however, the ecological consequences of exposure to contaminants are probably best examined at higher levels of organization. This report intends to assess the potential of using the biodiversity of soil organisms as an insight into the health and functioning of soils. As a measure it has the advantages of being seen as integrative and responsive to a wide range of factors in the soil. Such systems are widely used in environmental monitoring, especially in aquatic systems (*cf.* RIVPACS). However, there are major conceptual and practical issues that need to be further researched before we can usefully use soil invertebrate biodiversity as a purposeful bioindicator of soil health. Some of the more pertinent of these issues and gaps are addressed in the following chapters.

1.2 Why soil invertebrates?

Due to their essential functions in ecosystems, soil invertebrates are useful targets to assess the ecological effects of chemicals. Soil invertebrate tests can measure acute toxicity at the species level and/or the population and community levels. The preliminary endpoints of these tests are survival, growth (measured as biomass), reproductive success and behavioral changes. This report considers the merits and feasibility of assessing the effects of pollutants at higher levels of biological organization (populations and community changes in soil invertebrates), and in particular considers the enhanced value (if any) of doing so in terms of evaluating the significance of any effects of pollutants on ecosystems. Major invertebrate groups are present over a range of diverse habitats, are relatively easy to sample and can be simple to identify when good keys are available. In addition, the low mobility of groups such as earthworms means that they are representative of the habitat being sampled. This is not always the case for groups such as vertebrates. Disadvantages of using terrestrial invertebrates include problems in species level identification, (since the taxonomy of some groups is not clear), and the limitations of the sampling techniques.

The true nature of ecosystems is complex, consisting of many communities and assemblages of thousands of species of plant and animal each in dynamic equilibrium and each interacting with the complex physico-chemical components of their ecosystems. The grouped biota of an ecosystem play major structuring roles in the maintenance of ecological processes, and modify its physical and chemical environment, and in turn the ecosystem influences the composition and overall diversity of the communities that contribute the ecosystem. Thus, it may be considered important in terms of ecological risk assessment that attention is paid and effort made to appraise the effects of chemical stressors on the community structure and dynamics of an ecosystem. This has been the ultimate goal of much of the current research undertaken in the field of ecotoxicology.

However, the belief by many scientists that if one were to reduce the properties of an ecosystem to its individual components the total of the separated parts would equate to the sum of the original properties is misleading and is hindering the development of appropriate technologies. Were such a concept robust then the isolated use of bioindicator and biomonitoring techniques would be sufficient. However, such a hypothesis may be argued against for many reasons. It is known that the detrimental effects of many chemicals occur at concentrations well below those that cause lethality-particularly effects on reduced feeding, growth and fitness and reductions in reproductive performance. Furthermore, a comprehensive knowledge of the toxicity of a single chemical on a particular population (e.g. from short-term laboratory toxicity testing) will be insufficient to predict the characteristic toxicity that may be manifest at the level of the whole ecosystem. For these and numerous other reasons, the approach of ecological risk assessment must be replaced with a paradigm that focuses on the toxicity of pollutants throughout entire ecosystems. This can only be undertaken with the development and validation of new techniques and methodologies that more accurately assess the impacts of chemicals at the ecosystem level, such methodologies requiring a strong ecological basis and approach.

1.3 Structural and functional characteristics required to evaluate the condition of ecosystems

In order to evaluate the effects of chemical (and other) stresses on an ecosystem it is necessary to differentiate between and examine the structural and functional properties of that ecosystem. Structural properties (e.g., productivity, species composition and demographic descriptions) and functional parameters (e.g., nutrient cycling and trophic structure) are interdependent, yet still have distinct characteristics. Structural parameters describe the parts that make up an ecosystem i.e., what is there. Functional parameters describe the actions or inner-workings of a system i.e., how the components work. Generally, structural properties of a more descriptive nature are much easier to assess or measure because fewer parameters can be measured over a shorter time period. Structural properties correlate with functional properties, that are expressed as rates and must then be measured in a more complicated manner. For example, measuring a functional property such as decomposition of plant matter on a forest floor requires taking complex, multiple measurements over time, conversely describing the composition of the microbial biomass is all the more complicated and time consuming.

Additionally, it is possible that functional redundancies can buffer ecosystems from the effects of chemical perturbations within specific populations of soil invertebrate. Thus, if groups of organisms are killed their function(s) may be replaced by other groups of organism. The overall effect may thus be that the functioning of that particular ecosystem remains unchanged, whilst the structure of the ecosystem changes considerably. Populations within ecosystems are further able to resist stress-induced changes through compensatory (often deleterious) alterations in, for example, growth and reproduction, which may in turn alter the structural characteristics of the ecosystem. Ultimately, if the magnitude or duration of such a stressor persists for any prolonged period the limitations of the compensatory mechanisms will be exceeded, and consequently the condition of the ecosystem may decline. Environmental management tends to favour sustaining ecosystem function at the expense of preserving ecosystem structure, the danger here of course is that in a chemically-stressed ecosystem many of the functions may be performed by a severely diminished community, and may ultimately be more susceptible to yet further future stress (either anthropogenic or not).

Many functional properties of ecosystems can be monitored to evaluate ecosystem condition, for example, primary production, biotic factors and trophic interactions, rates of decomposition and mineralization and so on. Structural properties may also be useful indicators of ecosystem conditions. These may include changes in species composition and abundance, reduced biodiversity, less complex food webs and many more. It was recently suggested in the Scientific Group on Methodologies for the safety Evaluation of Chemicals (Scope 53,1995) that many of these parameters may be monitored to evaluate changes in ecosystems or to assess trends that may be of cause for concern. However, the assessment of environmental impacts of chemicals on ecosystems at the ecosystem level raises theoretical and methodological problems of substantial magnitude. The ultimate protection of an ecosystem from an ecological point of view should be the preservation of and prevention from extinction of each individual species. Due to the difficulties of operating at the ecosystem level, and given the time scale, it is difficult to measure extinction. At the ecosystem level, gradual (and potentially unnoticed) extinction of interconnecting species will result in potential malfunctioning of the system.

1.4 Levels of organization to evaluate the effects of chemicals

The methods available to evaluate the effects of chemicals range from the molecular to the ecosystem level. Evaluating effects becomes more difficult as one moves toward the more complex organizational level. One may start at either end, namely the molecular or the ecosystem. If one starts at the lower levels the difficulty begins with the need to extrapolate laboratory data or limited field trials to effects at the ecosystem level. Conversely, starting at a higher tier within this scale, say at the individual or physiological level, effects are summised by examining contaminated ecosystems. Ideally, both approaches should be adopted to determine how chemicals are affecting the ecosystem at all levels. Each approach, simple or complex has advantages and disadvantages. The first approach has the clear advantage of the ability to establish a laboratory dose/response scenario. However, this approach then suffers from the increasing degree of complexity in extrapolating results and observations at the lower levels to higher organizational levels, whereas the second requires a well-defined contaminated ecosystem to be studied. As stated earlier, ecosystems are not the simple sum of their components, but encompass several ecosystem functions that are the products of interactions of the species. Measuring ecosystem changes directly, does have the advantage of allowing us to determine the effects of chemicals on these systems, and hence extrapolation is not required. However, the lack of appropriate technologies and the costs in time and money may well be prohibitive to measure the effects of even one chemical on all aspects of the structure and function of a single ecosystem. Thus, for ecosystems one must be selective in the choice of suitable indicators of structures and functions. Such a choice is problematic.

The effects of chemicals on ecosystem functions can only be assessed by studying these functions, and cannot be directly measured or estimated by merely examining individual species. As with measuring effects on species, measuring effects requires indicators for endpoints. These indicators should be sufficiently sensitive to provide early warnings, distributed over a wide range of stresses, independent of sample size and be cost-effective. Ecosystem indicators must be ecologically significant phenomena. Indicators for ecosystems might include indices of species diversity, relative species abundance, indices of species richness and landscape parameters. Ramade (1995) provides a brief review of methods to estimate damage to terrestrial ecosystems. He concluded that current knowledge of ecosystems was insufficient to identify key species that may affect either structure or function, and to improve the knowledge of species that may serve as bioindicators as a tool to monitor the effects of chemicals on communities. In an ideal world laboratory studies should be predictive of ecosystem effects. Such extrapolation should be possible as one learns to use micro and mesocosm studies to duplicate the structure and function of ecosystems.

1.5 Diagnosis and establishment of a link to causation

This introduction has attempted to review briefly some of the problems requiring solution to enable scientists to define the effects of soil contamination on soil invertebrates and to establish linkages between effects measured at different levels of biological complexity and observed adverse effect on the ecosystem. The final step is to demonstrate that the contaminants (if any) have caused the damage. In most cases the extent and nature of the toxic effects do not unequivocally demonstrate which agent was responsible for the injury. Correlations between a substance and a form of damage may be obvious, but causation is most difficult to prove, and often can be established only indirectly.

Methods need to be developed that will more easily allow the translation of observed or measured effects into value or benefits for the overall assessment process at higher biological levels of organization. Some questions pertinent to this undertaking that must be addressed are given below.

Techniques for the sampling and measuring of soil invertebrate biodiversity require further development.

We require standardised approaches to the analysis and interpretation of soil invertebrate abundance indices.

We require more information about the linkages between soil invertebrate communities and above ground plant communities and plant production.

We require more information concerning the responses of soil invertebrate communities to perturbations (e.g. soil contamination).

We need more information concerning the relationship between soil biomass, biodiversity and soil biotic activity.

We need to obtain a better understanding of the complex interactions between soil invertebrates and how this affects soil biodiversity and soil functional processes.

We need to understand how invertebrate diversity at one spatio-temporal scale may affect diversity at other levels of organisation.

We require more information about the minimum requirements for soil invertebrate biodiversity and ecosystem functioning and how to maintain biodiversity.

We need to be able to predict what degree of human-induced disturbance on the soil is needed to reduce soil invertebrate biodiversity to the point where functional processes proceed at reduced efficiency.

8. RIVPACS has a single classification system for Great Britain and a separate system for Northern Ireland** (due to differences in faunal compositions). **For SOILPACS, it may be more efficient to develop a series of systems, one for each of the major sampling strata and possibly one for each sampling methodology.

The RIVPACS classification system for Great Britain includes 614 sites within 35 classification groups, and therefore holds information on a very wide range of macroinvertebrate assemblages. In the Australian National River Health Program (NRHP), the current thinking is to develop separate systems for each State/Territory and also for each habitat sampled. (Riffles and edge habitats are being sampled separately in NRHP).

9. The circumstances in which RIVPACS and SOILPACS are needed may differ.

RIVPACS is appropriate for use in National surveys where a quick and simple protocol is required at many sites, but it also has inbuilt flexibility for more detailed predictions where this is required at individual sites. SOILPACS may have greatest application at selected sites where pollution is a major concern. In these circumstances, the time and cost of acquiring the detailed biological and environmental data at a series of locations around the area of concern will be justified.

10. The role of the end-users in RIVPACS and SOILPACS may differ with respect to initial input, but should then be minimised.

In developing RIVPACS, the end-users made a substantial contribution to the field collection of biological and environmental data, and later to the testing of successive versions of the system. Although it may be necessary for the Consortium to undertake the collection and processing of data for SOILPACS development, it is important that those who will apply the system are actively involved at the earliest opportunity.

2.3 DEVELOPMENT OF RIVPACS

2.3.1 Availability of appropriate biological data

In 1977, at the outset of the research project which eventually led to RIVPACS, the sponsoring organisations suggested the use of existing data, with identifications upgraded where necessary. This idea was considered, but rejected after an examination of the available data, because of the incompatibility of data-sets collected with different objectives in mind. It was clear that a carefully designed sampling strategy with standard methods for the collection and processing of biological data would be the essential prerequisite for a site classification based on the macroinvertebrate fauna.

2.3.2. Site selection

In an initial 4 year project (1977-81), a total of 268 reference sites on 41 different river systems throughout Great Britain were sampled. Care was taken to include high quality sites on rivers encompassing a wide range of geographical locations and geological formations and also to include longitudinal changes in faunal composition. A series of later contracts enabled the IFE to enlarge the range of river types, increase the geographical range of the system and respond to local demand for new reference sites where the prediction capability appeared inadequate. The latest version of the system, RIVPACS III, has 614 reference sites in Great Britain and a further 70 sites in Northern Ireland.

2.3.3 Site Quality

It was essential that the reference sites were of the highest biological quality, because they set the standard from which all predictions are derived. All sites were chosen after detailed discussion with local Water Industry biologists. Nevertheless, some of these sites had to be rejected when the samples were processed, because it became apparent that they were inadequate as reference sites. Experience in setting criteria for high quality has emerged over time, and in each version of RIVPACS, progressively higher standards for site acceptance have been set.

2.3.4 Sampling method

At each reference site, it was essential to have a standard protocol. This related to where samples were taken, how they were taken and when they were taken. These decisions determined the data available for site classification.

For RIVPACS, it was concluded that a reasonably comprehensive species list was required from each site in order to act as a 'fingerprint' for site classification, and that all habitats present should be sampled roughly in proportion to their occurrence. This decision meant that quantitative sampling on the wide range of different habitats encountered at different sites was impractical, and instead, a pond-net was used to sample all the habitats at a given site over a period of three minutes. This procedure was repeated in each of three seasons (spring, summer and autumn). The total of 9 minutes of field sampling at each site generated a list of between 31 and 134 'species' per site.

2.3.5 Field Sampling

In view of the scale of the field sampling operation, it was necessary for the IFE to draw up detailed guidelines for sampling and obtain help in the collection of the samples from the 'Water Industry' regional biologists in England, Wales, Scotland and, more recently, in Northern Ireland. Nevertheless, samples from a wide range of river systems throughout Great Britain were collected by IFE staff at various stages of the project.

2.3.6 Laboratory Processing and Identification

Without exception, all samples collected during the project were sent to the IFE River Laboratory for sorting, followed by identification of the macroinvertebrate fauna. Specimens were identified to the highest practical level. For most major groups with adequate keys this was species level, but in some cases, generic or even family level had to be accepted.

Prior to any analyses, it was necessary to standardize the precision of the taxon lists for each site. This involved making informed decisions on the taxonomic level to which the majority of the specimens of a taxon could be allocated most precisely, and then implementing these rules for each site. For example, where a species was normally identified to species in one season, further records of the same species when only identifiable at generic or family level were removed from the dataset to avoid duplication of taxa. Where a taxon could not be identified reliably to species, it was assigned to a 'species group' or higher taxon as appropriate. The standardized list of taxa for the full version of RIVPACS III, including Great Britain and Northern Ireland comprised 642 taxa.

2.3.7 Site Classification

In RIVPACS, the sites were classified using their faunal composition. From the outset of the project, TWINSPAN (Two-way indicator species analysis - a species classification programme) has been the method of choice. However, many other options were examined prior to the development of RIVPACS III. The results indicated that a number of widely differing approaches have the potential to offer workable classifications from which prediction systems can be developed. Nevertheless, when the number of sites increased from around 400 to over 600 and encompassed a wider range of locations, TWINSPAN classifications were still effective as the basis for developing a prediction system but some other classifications failed to retain this capability.

Alternative classification procedures were used with success in the RIVPACS approach on the Great Lakes, and further procedures are being examined in Australia where the RIVPACS approach is being used in the National River Health Program.

RIVPACS II and also RIVPACS III have a mean of around 18 sites per classification group within Great Britain, although the number of sites per group varies considerably (RIVPACS II has 438 sites in 25 groups and RIVPACS III has 614 sites in GB distributed between 35 groups).

2.3.8 Environmental data for prediction

In the initial stages of the RIVPACS project, a large number of both physical and chemical attributes were acquired for each site. Some physical features were obtained during field work and others were taken from maps. Chemical data were requested from the appropriate Water Authority/River Purification Board etc. Some of the environmental variables were time invariant (eg. altitude, distance from source), whereas others varied with the seasons (eg. river width, depth, substratum composition and water chemistry). For the latter, annual mean values were used in the initial development of RIVPACS and when using RIVPACS to predict the fauna of a new site.

Around 30 variables were used for prediction in the earliest prototype of what was later to become RIVPACS. Many of these variables were highly correlated and some were redundant. Subsets were therefore examined and eventually, by the time RIVPACS II was in place, decisions had been reached on those variables with high predictive capability which were also easy to acquire. The variables selected should not be affected by environmental stress and should be capable of being acquired with minimal error.

2.3.9 Some basic features of RIVPACS

RIVPACS offers the facility to predict the fauna of a given site from a standard set of environmental variables. (There are, in addition, four variations on the standard list for use in cases where some variables are unavailable.)

The fauna can be predicted at one or more of the following taxonomic levels:

BMWP family level (presence/absence) with BMWP family indices
Family level (Log categories of abundance) with abundance index
Family level (presence/absence)
Species level (presence/absence)
Customisation (presence/absence)

In addition, the fauna can be predicted at one or more of the following seasons:

Spring
Summer
Autumn
Spring and Summer Combined
Spring and Autumn Combined
Summer and Autumn Combined
Spring, Summer and Autumn Combined

Family level predictions (log categories of abundance) can only be made for single seasons.

Predictions for single sites or a small number of sites can be undertaken by inputting the data directly. Predictions for large numbers of sites are best carried out by inputting the appropriate environmental data into a computerfile and undertaking a batch-mode operation. Biological data for the same sites can also be held on file and used for automated comparison of the observed and expected (predicted) fauna.

New sites can be classified if their macroinvertebrate fauna is sampled using the standard protocol and they are identified to BMWP family or 'species' level.

2.4 ADDITIONAL CONSIDERATIONS

2.4.1 The End-Users

The current end-users of RIVPACS are the Environment Agency (previously the National Rivers Authority), the Scottish Environmental Protection Agency (previously the River Purification Boards) and the Department of the Environment (Northern Ireland). These organisations, or their predecessors have been involved in all previous stages of the development of the system, including the testing of RIVPACS I (an early BBC-B microcomputer version) and the use of the operational versions of RIVPACS II and III for the 1990 and 1995 National surveys, respectively.

The standard field and laboratory procedures required for RIVPACS have become the standard procedures used by these organisations for all RIVPACS-related work and they undertake internal quality control of their sorting and identification procedures. External audit of these procedures is undertaken by the IFE.

The IFE continues with the further development of the system to meet the requirements of the end-users.

2.4.2 Further Aspects of RIVPACS III

It is important to recognise that RIVPACS is a static, rather than a dynamic model. That is, it predicts a reference or 'target' community to be expected in the absence of environmental stress for comparison with the observed fauna. It has not been designed to provide information on the extent to which a community will change when exposed to a stated level of stress.
The variables used for prediction should not necessarily be viewed as the factors responsible for the observed differences in community structure between and along river systems. In many cases, the variables used for prediction will be correlated with factors genuinely influencing community type.

The method used to generate the faunal predictions draws on information from many reference sites. The fauna predicted at a new site should therefore be regarded as the assemblage to be expected at an average site with those environmental features. It should also be viewed as the long-term average fauna to be expected in the absence of stress. Even when a site has not been polluted or subjected to habitat degradation, 'natural' stresses such as a drought or flood may have a temporary impact on the observed fauna and result in a lowering of the Observed/Expected ratio.

2.4.3 Extensions of the RIVPACS Approach

The RIVPACS approach has also been used successfully on nearshore sites throughout the Great Lakes of North America (Reynoldson et al. 1995). The reference sites were identified and stratified among 17 ecoregions and a classification was developed using the structure of benthic invertebrate communities. This work was prompted by the need to develop sediment quality criteria. Benthic invertebrates were selected as the most appropriate biological indicators because they are most directly associated with contaminants in sediments through their feeding and behavioural activities.

A new development by Reynoldson et al (1995) involved the functional responses (survival, growth and reproduction) of four species of benthic invertebrates exposed, in the laboratory, to sediment collected from the same sites. This approach was included to identify the sediment rather than the water column or other physical disturbance as the cause of the observed effect at any given site.

2.5 INTRODUCTION TO SOILPACS

Although individual rivers differ in character due to their geological and climatic setting, they all share the fundamental characteristic of being unidirectional systems in which many of their environmental attributes show progressive changes downstream (e.g altitude, discharge, width, depth, substratum etc). The overriding importance of this gradient with all its associated environmental attributes and consequences for the biota suggests that rivers pose fewer problems for the development of a prediction system than terrestrial ecosystems.

Classification of reference sites in the Great Lakes using the benthic fauna and subsequent development of a prediction system, demonstrates that this approach is still viable where there are progressive changes in the environmental attributes and faunal composition in the nearshore sediments on the bottom of each lake.

Nevertheless, the concept of developing SOILPACS for predicting the terrestrial fauna to be expected in the absence of environmental stress is more challenging than the freshwater equivalent because of the very wide range of terrestrial ecosystems and their associated fauna. In addition, spatial heterogeneity of the fauna over short distances and seasonal changes in faunal composition will pose further challenges.

Existing data have been examined by the Consortium (Chapter 3) and provide valuable guidance. However, based on the RIVPACS experience, a new sampling programme will be necessary in order to develop SOILPACS. This is because reference site data must be acquired using standard protocols in order to build a valid classification and prediction system. In addition, the same sampling procedures must be used at test sites in order to have reliable data for site appraisal. The magnitude of the sampling operation required to develop a comprehensive version of SOILPACS will be very substantial.

An early challenge will be the formulation of an appropriate series of strata/land types to act as a framework for the sampling programme.This framework will be devised by members of the Consortium who are familiar with the complexities of the environmental features and faunal assemblages of terrestrial ecosystems.

For the prediction system to succeed, it is critical to be able to demonstrate a strong correlation between the environmental features of sites and their faunal assemblages. In the case of SOILPACS, it will be crucial to establish that the various strata (and divisions within these strata) chosen for the sampling programme support distinct assemblages of invertebrates in the absence of environmental stress.

An early proposal in the tender document was the use of the 17 Land Cover types as the basic framework. Further subdivisions of each land cover type, based on additional attributes such as geographical region, soil type etc. would also be needed. This idea has now been superceded and a recommended strategy is offered in a later section of this report, after consideration of existing data.

2.6 A COMPARISON BETWEEN RIVPACS AND SOILPACS

In this section, the emphasis will be on the differences between the current version of RIVPACS and our vision of the form that SOILPACS will take in the future. Clearly, the fauna and environmental variables used to develop RIVPACS are different from those required for SOILPACS, and there is little point in listing these and similar differences.

In addition, it would be premature to suggest that the detailed methodologies used sucessfully in developing RIVPACS will be the optimal procedures for SOILPACS. There is evidence, from the Great Lakes study and recent work in Australia, where the RIVPACS approach is being used in the National River Health Program, that variations to the methods used in RIVPACS itself can also be effective. The considerable expertise in multivariate statistics available within ITE will ensure that the most appropriate techniques are used when data-sets are available for the initial analyses.

The list of differences (areas of non-compatibility) between RIVPACS and SOILPACS which are given below have not been prioritised simply because they are all of significance. Some relate to basic differences between flowing water and terrestrial ecosystems, others to the circumstances in which the two systems would be used and still others to practical considerations in developing the sampling strategy. All these aspects have to be identified and acted on in order to be able to define the form and scale of the future SOILPACS project.

For simplicity, the sequence in which the differences are presented reflects the approximate sequence in which they will be considered in making decisions on the next stages of the project.

1. The strong unidirectional gradient which characterises all flowing systems means that RIVPACS is a much simpler system than that anticipated for SOILPACS.

SOILPACS must take account of the surface of the land with its many different ecosystems and environmental gradients. On a local scale, it must also take account of spatial heterogeneity of the fauna and temporal (seasonal) changes in composition.

2. RIVPACS has been designed to include the geological and regional variation in stream type, together with the downstream changes which typify flowing water systems. Development of a sampling strategy for SOILPACS to encompass all the major habitats with their own characteristic assemblages of soil organisms will be a more substantial undertaking.

It will be necessary to decide on an appropriate series of strata/land types for the sampling strategy, based on a knowledge of the environmental features which influence faunal assemblages in terrestrial ecosystems.

3. The latest version of RIVPACS attempts to include all major river types in the United Kingdom. SOILPACS will be confined to England and Wales initially, and will also initially exclude agricultural sites.

Agricultural soils are not in a natural state, but have been extensively modified through human use of the land. Therefore detrimental changes or improvements in the soil may arise from either the continuation of existing practices or from their modification or cessation. Most changes to soil conditions can be reversed in the long-term, although it may not be economical to do so. Current adverse changes to the agricultural use of soils include effects from the application of fertilisers and pesticides, compaction, loss of organic matter and soil erosion. These changes not only affect the physical and chemical characteristics of the soil, but also the soil fauna and vegetation. Changes (if any) to soil invertebrate communities in these instances are difficult to interpret and beyond the scope of this study. Such applications are "deliberate", and any change almost expected (anticipated). The application of insecticide and pesticides to kill "pest" species (the definition of pest in this circumstance being any insect that is not welcomed within the crop) will have significant affects on other associated soil invertebrate populations. However, the scene is

artificial, and would require extensive independent survey and study, with the involvement of MAFF.
4. All major groups of macroinvertebrates were included when developing RIVPACS, although not all taxa could be identified to species. In SOILPACS, attention will be focused on taxa relevant to pollution.

Because the RIVPACS reference data-set is so comprehensive, the information is also relevant to nature conservation. For example, the 642 taxa in the data-set provide useful information on the geographical occurrence and frequency of occurrence of individual species, and data on site species richness and composition is also available.

5. The sampling strategy and consequently the data available for analysis will differ substantially between RIVPACS and SOILPACS.

At each reference site in RIVPACS, all available habitats were sampled by pond-net in proportion to their occurrence for a total of three minutes in each of spring, summer and autumn in order to generate a reasonably comprehensive **qualitative** species list. Logarithmic categories of abundance were also determined for each three-minute sample (family level only). The complex patchwork of habitats present at most sites meant that the use of quantitative sampling devices was impractical.

In SOILPACS, more than one sampling procedure may be appropriate at each site (e.g pitfall traps and soil cores) and replicate samples will be needed to obtain a reasonably comprehensive listing of the local fauna. If pitfall trapping is undertaken, separate visits will be necessary for the setting and collection of traps, thereby adding to the costs. There will be greater opportunity for the collection of **quantitative** data, but these benefits must be weighed against the additional time costs. The seasonal variability of the soil fauna and the need to be able to predict the fauna expected in a given season will determine the temporal sampling programme at each site.

6. In SOILPACS, an intensive study is required at a subset of sites to determine the optimum number of replicates and the most appropriate seasonal sampling regime.

Some pilot studies on sample replication were undertaken at the outset of RIVPACS, and decisions on season of sampling were based on existing knowledge of life cycles.

For SOILPACS, it will be necessary to select a range of sites at which a high level of sample replication is undertaken on a monthly basis. This will provide a sound scientific basis for decisions on the number of replicates and the seasons to be included in the main sampling programme. Repeat sampling at some sites in consecutive years will provide further valuable information on the variation to be expected in the fauna in response to normal among-year variations in the climate, unrelated to pollutional stress.

The same sites also provide an opportunity to check that the environmental data for each site is relevant to the task ahead (i.e.measurements are repeatable and seasonal variation is understood and can be taken into account).

7. In developing RIVPACS, keys were already available for most groups of freshwater macroinvertebrates. In contrast, there is an urgent need to develop practical keys for some components of the soil fauna in order to service the future requirements of SOILPACS.
See Section 4.51 and Table 4.2.3 in particular for discussion about soil fauna identification.

8. RIVPACS has a single classification system for Great Britain and a separate system for Northern Ireland** (due to differences in faunal compositions)**. For SOILPACS, it may be more efficient to develop a series of systems, one for each of the major sampling strata and possibly one for each sampling methodology.

The RIVPACS classification system for Great Britain includes 614 sites within 35 classification groups, and therefore holds information on a very wide range of macroinvertebrate assemblages. In the Australian National River Health Program (NRHP), the current thinking is to develop separate systems for each State/Territory and also for each habitat sampled. (Riffles and edge habitats are being sampled separately in NRHP).

9. The circumstances in which RIVPACS and SOILPACS are needed may differ.

RIVPACS is appropriate for use in National surveys where a quick and simple protocol is required at many sites, but it also has inbuilt flexibility for more detailed predictions where this is required at individual sites. SOILPACS may have greatest application at selected sites where pollution is a major concern. In these circumstances, the time and cost of acquiring the detailed biological and environmental data at a series of locations around the area of concern will be justified.

10. The role of the end-users in RIVPACS and SOILPACS may differ with respect to initial input, but should then be minimised.

In developing RIVPACS, the end-users made a substantial contribution to the field collection of biological and environmental data, and later to the testing of successive versions of the system. Although it may be necessary for the Consortium to undertake the collection and processing of data for SOILPACS development, it is important that those who will apply the system are actively involved at the earliest opportunity.

3.0 OVERVIEW OF THE BRITISH SOIL FAUNA

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3.1 Introduction

This section provides a context for the use of soil fauna in pollution studies. It defines 'soil fauna' and explores the factors which confuse the definition, especially the features of the ecology of species and of higher taxonomic groups. Here and elsewhere, the range of groups chosen for analysis is as broad as practicable. The following higher taxa are included to some extent:

Platyhelminthes
Annelida
Crustacea
Chilopoda
Diplopoda
Thysanura
Diplura
Protura
Collembola
Orthoptera, Dermaptera, Dictyoptera
Psocoptera
Heteroptera
Homoptera: Auchenorhyncha
Homoptera: Sternorhyncha
Thysanoptera
Raphidioptera, Mecoptera, Neuroptera
Lepidoptera
Trichoptera
Diptera
Hymenoptera
Coleoptera
Arachnida: Opliones
Arachnida: Pseudoscorpiones
Arachnidae: Araneae
Arachnida: Acarina
Mollusca: Gastropoda

These groups represent a wide range of taxonomic levels, from Phylum to Suborder, and contain widely differing numbers of species, from a handful to more than 6000. Hence, they are broken down more finely, and in the most speciose taxa, such as the Diptera and Coleoptera, individual families are considered which are of greatest importance in the soil, and others of little or no relevance are explicitly excluded.

Problems in interpreting the term 'soil fauna' remain. Should all the different horizons of the soil be considered? What about leaf-litter and plant roots? Some species are exclusive to soil, while other use the soil but also occupy the lower layers of vegetation, or live in dead and decaying plant material, for instance. Many invertebrates occupy the soil in their immature stages, but forage much more widely as adults, eg flies (Diptera) with soil-dwelling larvae and flower-visiting adults. Many groups contain both soil-dwelling and non-soil species, in varying proportions, and only a minority of groups are entirely soil fauna.

The discussion then moves to the diversity of each group (usually taken to be the number of species present). These analyses begin with national assessments: the numbers of species occurring in Britain (and the proportion of these which are native rather than introduced, if such a distinction is practicable). Patterns in national-scale diversity are then explored briefly. The strength and direction of any latitude and other gradients in diversity is quantified, and the more striking patterns of diversity are discussed, and where possible related to environmental factors (eg higher diversity of molluscs is found on chalk and limestone). Various comparisons are made between national and regional diversity, both in terms of species-turnover (ß-diversity) and in the variation of regional species-pool with location and pool radius.

An attempt is made to partition species-richness between the major habitats, using information on habitat use drawn from BRC's Biotope Occupancy Database (a summary of the literature). Having associated species with their habitats, the study explores the possibilities for predicting the numbers of species of each group which occur in 'typical', 'rich', and 'poor' examples of each habitat. It is commonplace that acid soils are lacking in molluscs and earthworms, but the difference in species-richness and species 'quality' between woodland, grassland and heathland, for instance, is less readily quantified. By combining databases of habitat occupancy with regional species-pools, we hope to derive standard 'expected values' for the fauna of any habitat in any region: the values below which pollution impacts might be expected to depress diversity. Suggestions are made for the most suitable habitats to target in later phases of SOILPACS, and the factors influencing such targeting are discussed.

The second major part of the report is an assessment of the quality of available data on each group of soil fauna, both in terms of species distribution and of ecology. This is done using national biogeographic databases where these exist, and using specialist knowledge of published work, and of current data-gathering and research in other cases.

The ease with which organisms can be sampled and identified is then discussed. For the British soil fauna, this is very uneven. Many economically important groups have been subject to lengthy methodological study, such that confidence limits can be applied to standard extraction methods, and their biases are well understood. For some other groups, the currently used methods have seldom or never been put to rigorous testing. The cost-effectiveness and representativeness of some intensive sampling protocol is questioned. The extent, quality, comprehensiveness and ease of use of the current taxonomic literature is evaluated. Some attempt is made to determine whether taxonomic problems are due to lack of basic research on delimitation of species (eg nematodes?), confusion and lack of adequate collation of available taxonomic works and reference material (Collembola?), difficulty in using keys even though the taxonomy is clear (earthworms), or the intricate nature of preparation of specimens for identification (nematodes?). Some groups suffer from more than one of these problems.

3.1.2 DEFINITIONS

The table (1.) following explores the levels of dependency on the soil for the major taxonomic groups which may be considered part of the British soil fauna. A finer taxonomic resolution (Family level in many Orders?) and a wider taxonomic range, may be possible in the future.

3.1.2.1 Groups with only a proportion of species in the soil

At the taxonomic levels shown in Table 1, some groups, such as Platyhelminthes, are represented in the soil by only a small proportion of the total species, because most are primarily aquatic: hence the occurrence of the groups across biomes is presented as column **A**:

0 Most species freshwater or marine
1 Many species terrestrial but some freshwater/marine
2 Most species terrestrial
3 All species terrestrial

Within the terrestrial component, some groups have most species living in non-soil situations; this is presented in column B:

0 Few of terrestrial species soil-dwelling
1 Many of terrestrial species soil-dwelling
2 Most terrestrial species soil-dwelling
3 All terrestrial species soil-dwelling

3.1.2.2 Species dependent for only part of their life-cycle

Many organisms which are regularly found in the soil spend part of their life elsewhere. In some cases, such as insects with cryptic soil-dwelling larvae (many scarabaeid beetles, flies, cicadas, etc.), these stages may take many months or years compared with an adult, aerial or vegetation-bound stage which survives only days or weeks. The table presents information on this aspect as follows (column **C**):

1 Soil species utilise soil only briefly or inactively (e.g. Orthoptera which deposit eggs in the soil, but whose nymphs ascend the vegetation immediately on hatching
2 Soil species utilize soil for much of their life-cycle (e.g. larval stages, which in many Diptera occupy 80% or more of the year)
3 Species which seldom or never leave the soil

3.1.2.3 Degrees of dependency on soil

The inclusion of leaf-litter as an integral component of the soil encompasses a rich and readily sampled fauna, which should probably be included in the study. However, many litter-dwellers can also be found in plant detritus in other situations, and are therefore less intimately associated with the soil than taxa which occur directly in the mineral layer. Three divisions have been named, and are shown in column **D**:

1 Epedaphon: inhabitants of the soil surface, such as ground-beetles and some spiders

2 Hemiedaphon: inhabitants of the litter layer, such as many woodlice and millipedes

3 Euedaphon: inhabitants of the mineral soil, such as most earthworms, Symphyla etc.

Table 1: definitions of soil fauna

(In many groups, there are species with a range of lifestyles; the coding aims to reflect the most frequent lifestyle)

Taxonomic group	A	B	C	D
Platyhelminthes	A0	B2	C3	D2
Annelida	A0	B2	C3	D3
Crustacea	A0	B2	C2	D2
Chilopoda	A2	B2	C2	D2
Diplopoda	A2	B2	C2	D2
Thysanura	A3	B1	C3	D2
Diplura	A3	B2	C3	D3
Protura	A3	B3	C3	D3
Collembola	A2	B2	C3	D2
Orthoptera	A3	B1	C1	D2
Dermaptera	A3	B1	C1	D2
Dictyoptera	A3	B2	C2	D2
Psocoptera	A3	B0	C2	D2
Heteroptera	A2	B1	C2	D2
Homoptera: Auchenorhyncha	A2	B0	C3	D3
Homoptera: Sternorhyncha	A2	B1	C3	D3
Thysanoptera	A3	B0	C2	D1
Raphidioptera	A3	B1	C2	D2
Mecoptera	A3	B1	C2	D2
Neuroptera	A3	B1	C2	D2
Lepidoptera	A3	BO	C2	D2
Trichoptera	A3	BO	C2	D2
Diptera	A2	B2	C2	D3
Hymenoptera	A3	BO	C2	D2
Coleoptera	A2	B1	C2	D2
Arachnida: Opiliones	A3	B2	C3	D2
Arachnida: Pseudoscorpiones	A2	B2	C2	D3
Arachnida: Araneae	A2	BO	C2	D2
Arachnida: Acarina	A2	B2	C3	D3
Mollusca: Gastropoda	A1	B2	C3	D2

3.1.3 NUMBERS OF SPECIES

In this and the next section, tabulations and other explorations of available data have been performed for the woodlice (Isopoda) and ground-beetles (Coleoptera: Carabidae).

The woodlice are a small group, of around 40 species, which is among the best known, with excellent modern keys (Hopkin, 1991), a national distribution atlas which also analyses habitat requirements in detail (Harding & Sutton 1985), and active and coordinated research through the British Isopod Study Group.

The ground-beetles are a much larger group (*c.* 350 species), and although fairly popular among amateur entomologists, the quality of national data is mediocre. Available data are sparse in the north and west. Taxonomically difficult groups, such as some *Amara*, *Harpalus* and *Bembidion* species, may be particularly under-recorded. The best available key (Lindroth 1974) is adequate, but contains significant errors, and is currently out-of-print. An Atlas will appear later this year (Luff in press), but with rather patchy coverage. Although very popular subjects for ecologists, with a large number of research papers published each year, there is no convenient digest of biological data on the British fauna.

3.1.3.1 Diversity in Britain

Table 2 below shows the numbers of species, subspecies, forms and aggregates (species-complexes which are often not identified precisely by recorders) in Britain. It also attempts to distinguish native from introduced species and casuals (counts of established native species are given in brackets), though the available data are uncertain.

Taxonomic rank	*Woodlice*	*Ground-beetles*
Aggregates	2 (2)	2 (2)
Species	33 (29)	350 (337)
Forms	2 (2)	0

3.1.3.2 Regional diversity, species-turnover (ß-diversity)

Three example sites have been chosen for regional species-pool analyses: Avonmouth (a rich southern area, with coast, estuary, Somerset Levels, and upland habitats within the larger radii), Coventry (a midland location with some estuarine habitat but no coast or uplands) and Teesside (a northern site, with lower overall diversity but some very rich coastal and upland habitats).

For each site, the total species-pools of woodlice and of ground-beetles have been calculated for regions of size 50km, 90km and 130km^2: see tables 3 to 5.

A provisional analysis of the species-pools characteristic of each major habitat has also been attempted (see Table 1. for methods of classification).

Techniques have been developed to calculate species-turnover (ß-diversity) between any square and its neighbours, at 10km, 20km or larger scales. The resultant values of ß-diversity can be mapped, to show areas with high local variation in species-complement (Lee, Eversham & Griffiths 1995), and mean values can provide an insight into the overall heterogeneity of the fauna (low ß-diversity implies that the same species occur over much of the country).

It is also possible to explore the direction and degree of gradients in species-richness (latitude, east-west) and the relation to other environmental gradients (temperature, rainfall) and variables (soils, geology), although for the pilot study only a few preliminary examples will be provided.

3.1.3.3 Habitat occupancy and within-habitat diversity

Information on the habitat affinities of the woodlice and ground-beetles was extracted from the Biotope Occupancy Database (BOD - Eversham 1993). This is a coded summary of habitat descriptions given in the standard literature on each taxonomic group, corrected and supplemented by reference to specialists in each taxonomic group. The coding in BOD is based on the Palaearctic Habitat Classification (Devillers & Devillers-Terschuren 1993). BOD lists each of the main habitats which a species is recorded as occupying, but does not in general assess the strength of the preference of a species for each. It may be possible to assign species to four categories of preference, by specialists in the groups:

0 Occurs within habitat (but also in many others);
1 Poor indicator (usually present, but also occurring in other habitats);
2 Moderate indicator (present in habitat more often than elsewhere);
3 Good indicator (seldom found in other habitats)

Many soil fauna groups do not yet figure in BOD. There is scope to extend coverage further, and to evaluate it by reference to independent datasets on the spatial distribution of habitats (using the premise that species with the strongest preferences will have a national distribution which coincides closely with the distribution of the habitat). For this project, if it is possible to define them for sufficient groups, category 2 and 3 species could be taken to be sufficiently dependent on the habitats to be useful in mapping, quantifying and assessing trends in them. (Note that all except grade 3 indicators will occur in more than one habitat, so that summing the species in several habitats will exceed the actual number of species present due to double-counting.)

The following table shows the number of species of woodlice, ground-beetles, myriapods, molluscs and two fly families which BOD regards as being associated with the named habitats. This classification was also used in partitioning the regional species-pools by habitat in section 3.1.3.2.

Fig 1 Regional diversity: study regions

Study region - Avonmouth | Study region - Coventry | Study region - Tees-side

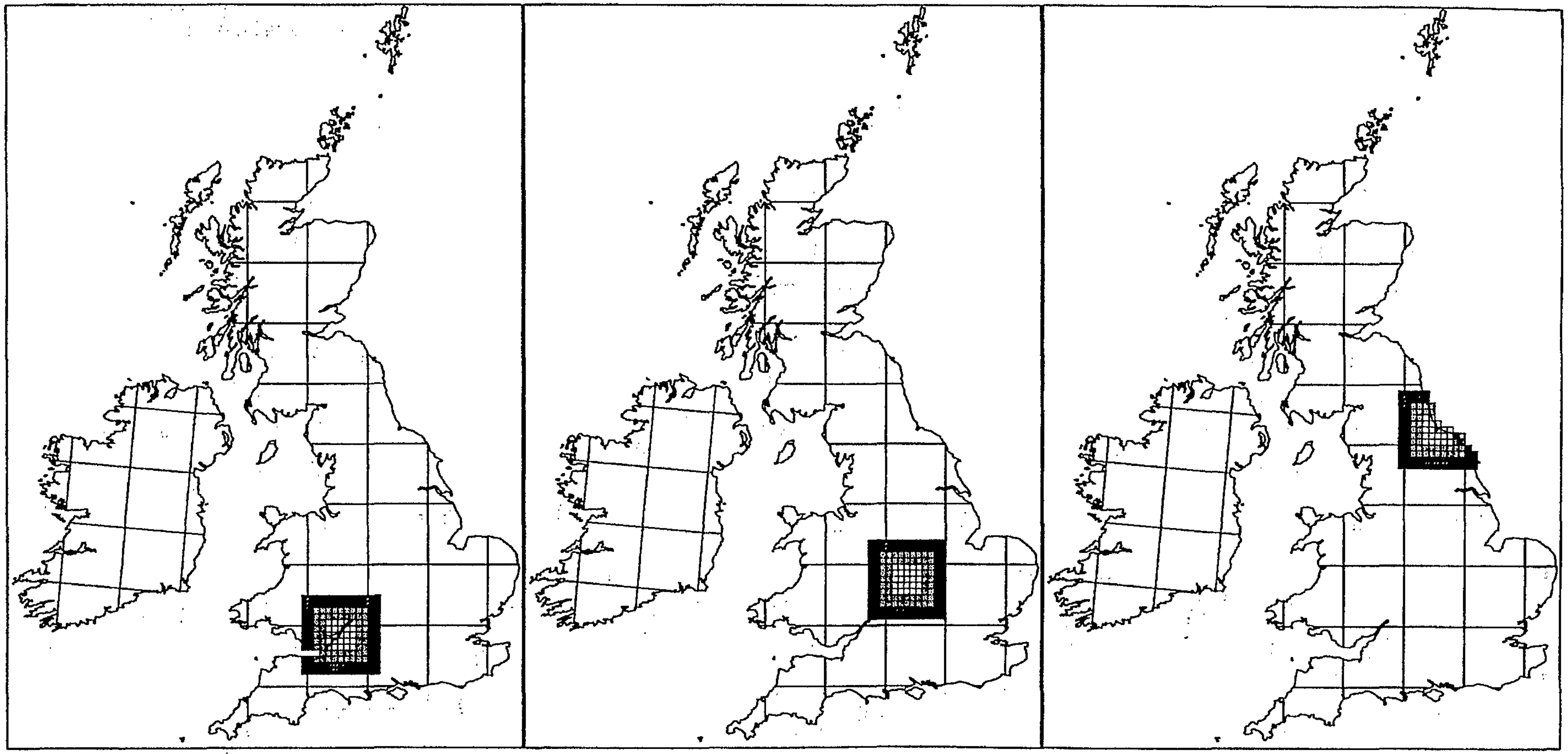


Table 3 Regional diversity (km²)

Habitat	Woodlice								
Region ⇒	Tees side			Coventry			Avonmouth		
Region size ⇒	130	90	50	130	90	50	130	90	50
Salt marsh	0	0	0	0	0	0	1	1	1
Sand dunes/beaches	0	0	0	0	0	0	1	1	1
Shingle beaches	0	0	0	0	0	0	1	1	0
Non-marine waters	0	0	0	0	0	0	1	1	0
Lowland heath	0	0	0	0	0	0	1	0	0
Upland/moorland heath	0	0	0	0	0	0	1	0	0
Calcareous grassland	3	3	2	5	5	3	6	6	4
Sandy grassland	1	1	1	3	3	2	3	3	3
Montaine/subalpine grassland	1	1	1	2	2	2	3	3	3
Mesotrophic grassland	1	1	1	3	3	2	3	3	3
Broadleaved woodland	0	0	0	1	1	0	2	1	1
Wet woodland	0	0	0	1	1	0	1	1	1
Raised/blanket bog and wet heath	0	0	0	0	0	0	1	0	1
Fens/mires/water-fringe vegetation	0	0	0	1	1	0	1	1	0
Inland rocks/screes	3	3	2	1	1	1	7	4	3
Arable	1	1	0	1	1	1	1	1	1
Bocage	1	1	0	1	1	1	1	1	1
Improved grassland	4	4	3	7	6	4	10	7	6
Unclassified	3	3	0	6	5	3	8	6	4

Table 4 Regional diversity

Habitat	Carabids								
Region ⇒	Tees side			Coventry			Avonmouth		
Region size ⇒	130	90	50	130	90	50	130	90	50
Salt marsh	9	8	6	12	10	4	22	21	13
Sand dunes/beaches	46	37	26	39	31	18	59	50	33
Shingle beaches	6	5	3	4	1	0	11	9	2
Non-marine waters	25	21	16	26	19	8	28	24	14
Lowland heath	37	31	30	33	27	12	35	33	21
Upland/moorland heath	8	7	6	4	4	0	6	4	0
Calcareous grassland	34	29	26	43	33	20	47	45	35
Sandy grassland	50	45	40	52	48	28	54	52	40
Montaine/subalpine grassland	9	8	6	4	3	1	6	5	1
Mesotrophic grassland	34	32	29	35	34	24	34	33	29
Broadleaved woodland	39	34	32	38	36	29	41	40	32
Wet woodland	8	7	6	7	7	5	7	6	5
Raised/blanket bog and wet heath	14	14	11	18	17	11	18	18	17
Fens/mires/water-fringe vegetation	36	32	27	35	34	19	33	30	27
Inland rocks/screes	45	38	27	55	51	30	61	55	45
Arable	9	8	5	14	8	2	16	13	6
Bocage	28	25	21	31	30	24	30	29	24
Improved grassland	15	13	11	14	14	13	15	15	13
Industrial	27	19	11	32	21	6	39	34	21
Unclassified	59	49	37	54	44	23	78	70	48

Table 5 Habitat occupancy and within-habitat diversity (numbers of species)

Habitat	Crustacea (Woodlice)	Coleoptera (Carabids)	Diptera (Dixidae)	Diptera (Sepsidae)	Myriapoda (Millipedes & Centipedes)	Mollusca (Terrestrial)
Salt marsh	2	28	0	0	0	0
Sand dunes/beaches	1	81	0	0	0	20
Shingle beaches	2	16	0	0	0	0
Non-marine waters	3	38	3	4	0	36
Lowland heath	1	52	0	0	2	3
Upland/moorland heath	1	10	0	0	2	2
Calcareous grassland	7	58	0	1	0	30
Sandy grassland	4	66	0	1	0	16
Montaine/subalpine grassland	3	14	0	0	0	8
Mesotrophic grassland	4	41	0	2	0	20
Broadleaved woodland	2	45	0	0	4	25
Coniferous woodland	0	8	0	0	0	4
Wet woodland	1	19	0	0	3	11
Raised/blanket bog and wet heath	1	50	0	0	2	1
Fens/mires/water-fringe vegetation	1	71	3	0	0	25
Inland rocks/screes	8	26	0	1	2	25
Arable	1	34	0	0	1	11
Bocage	1	16	0	0	1	28
Improved grassland	10	0	0	0	0	0
Industrial	0	50	0	0	0	7
Unclassified	8	104	9	3	5	34

3.2 DATA AVAILABILITY

3.2.1 Geographical distribution

This section is intended as an assessment of the extent and quality of available data on species distributions. The 'ideal' would be a comprehensive national database, containing up-to-date, fine-resolution data, accompanying a published atlas with clear explanatory text. For many groups of soil fauna, all that will be available is anecdotal statements in old literature: 'common everywhere', 'frequent on the chalk', 'found in Cornwall, Devon and Caithness' etc.

3.2.1.1 National databases

BRC maintains national databases for several important groups of soil fauna, and simple statistics are presented for most. The woodlice and ground-beetles were chosen for a more detailed exploration of methods of describing and quantifying the available data in BRC: woodlice are a well-recorded group of around 40 species, ground-beetles a less well-recorded group of 350 species. This analysis could be extended to include all groups for which BRC holds data.

The following descriptive statistics have been used, and are presented in the following tables and graphics.

Total numbers of records per species
The proportion of common and rare species varies from group to group. A simple definition of >common and >rare is based on the number of 10km squares in which each species is recorded (British Red Data Books tend to include species found in 15 or fewer squares; nationally scarce or notable species have been defined as occurring in 100 or fewer squares (maximum = 2860). In figures 2f to 2j, each point represents one species. The horizontal axis shows the number of squares in which each is recorded. A strong clustering at the left, as seen for myriapods and woodlice, suggests there are many rare species; a more even spread, as for molluscs and harvestmen (Opiliones) suggests a higher proportion of common species.

Shape of records-per-species curves
Given that most BRC data come from volunteer amateur specialists, there may be a tendency for >rare species to be sought out, and commoner ones to be ignored. If this occurred, one would expect the plots of squares against records (2f to 2j) to have a concave form, with many more records per square for rare species than for common ones. All the plots approximate to straight lines, so this is not a problem in these taxa.

Spatial resolution (proportions of records at 10km, 1km and 100m resolution)
The origins of much systematic biological recording in Britain lies with the publication Ordnance Survey national grid in the late 1940s. The 10km squares of the national grid were soon perceived to provide an ideal framework for mapping species distributions. Unfortunately, many recorders confused (and continue to confuse) mapping and recording: although fieldwork should generate fine-resolution (say, 100m precision) data, which can subsequently be summarised at coarser scales, a proportion of pre-1980 data provided to BRC was in the form of summary lists of species per 10km square. Since 1980, recorders have been strongly urged to provide fine-resolution, site-relatable data, which is suitable

for much wider research applications. Table 11 indicates the proportion of records which provide each level of spatial resolution (10km, 1km, 100m) and which possess or lack site details, for each group.

Spatial resolution and species frequency
The possible tendency of recorders to provide more information for rare species than common ones is tested in figures 2c to 2e. The species are ranked by their national frequency (in terms of occupied 10km squares, so the rarest species are on the left, the commonest on the right. If rare species have more fine-resolution data, the dark-shaded columns (coarse data) will be higher on the right. This appears not to be a problem with any of the datasets. A contrary trend in the carabids, for rare species to have less finely-localised data, is probably due to these rare species having seldom been found since the recording scheme was launched, and the records being abstracted from literature sources (which do not always provide grid references or precise locality details).

Number of available data points at different resolutions
This analysis is provided only for the woodlice. It gives a measure of the clustering of finer-resolution records within larger grid squares, which helps clarify whether finer data are geographically widely scattered, or whether a small number of local surveys at a fine scale have inflated the figures, while most areas have poorer data. The approximate parity of figures at the three scales suggests an even spread.

Modernity
Many biologists began collating distribution information on species in the 1950s or earlier. For certain taxa, this allows trends in distribution to be examined, but it also raises the danger that analyses may reflect species former rather than present status. To test this, for woodlice only, the proportion of records which were made since 1970 (post-1970 records) is tabulated. For almost all woodlice, this is greater than 70% of all records, suggesting that the database provides a reliable picture of the present distributions.

Analyses of additional data fields for particular groups, e.g. fully coded habitat data based on specialised field surveys for woodlice, millipedes and centipedes, could also be carried out.

3.2.1.2 Published atlases

A summary of published information on geographic distribution is available from Harding (1989) and subsequent updates.

3.2.1.3 Target Strata for the Next Phase of SOILPACS

The following major habitat divisions or strata have been used in studies of the habitat use of species (e.g. Eversham *et al.* 1992; Eversham & Roy in press), and in assessing the composition of industrial and conservation sites (e.g. Eversham, Roy & Telfer 1996). The terms and codes used for the divisions are taken from the Palaearctic Habitat Classification (Devillers & Devillers-Terschuren 1993). (The following list omits a few habitats which are very poorly characterised by their fauna, and cannot therefore be defined by characteristic or 'indicator' species.)

15 Saltmarsh
16 Sand dunes/beaches
17 Shingle beaches

20	Non-marine waters
31.2	Lowland heath
31.3	Upland heath and moorland
34	Calcareous grassland
35	Sandy grassland
36	Montane and subalpine grassland
37	Mesotrophic grassland
41	Broadleaved woodland
44	Wet woodland
51	Raised bog and blanket bog
53	Fens, mires and water-fringe vegetation
60	Inland rocks and scree
ARAB	Arable
BOC	Bocage (reticulate landscape of hedges, small fields and woods etc.)
IMP	Improved grassland

Not all these habitats are equally suited to the development of SOILPACS, for several reasons.

As a terrestrial assessment protocol, aquatic systems are excluded:

20	Non-marine waters

At an early stage, it was decided to exclude agricultural land from the study, so two categories are removed:

ARAB	Arable
BOC	Bocage (reticulate landscape of hedges, small fields and woods etc.)

Most major industrial installations are in the lowlands, so exclusively- or mainly-upland habitats may be omitted, at least in the initial developmental stages (but such may be useful to assess the impacts of long-range transport and deposition of gaseous pollutants and their effects, eg SO_2, VOC's, NO_x, pH):

31.3	Upland heath and moorland
36	Montane and subalpine grassland
51	Raised bog and blanket bog
60	Inland rocks and scree

Two of the coastal habitats are so rare or geographically restricted in Britain as to be of little relevance to most industrial sites. These habitats may therefore be excluded from the next phase of development, although it would be beneficial to extend the system to include them later:

17	Shingle beaches
16	Sand dunes/beaches

This leaves a set of 9 major habitats which it is recommended could form the core of SOILPACS.

Each is sufficiently widely distributed in the lowlands that significant areas occur in the vicinity of certain industrial sites; most are well characterised by their associated fauna and flora; and they provide a wide range of ecological conditions in which to test the robustness of the SOILPACS methods.

15	Saltmarsh
31.2	Lowland heath
34	Calcareous grassland
35	Sandy grassland
37	Mesotrophic grassland
41	Broadleaved woodland
44	Wet woodland
53	Fens, mires and water-fringe vegetation
IMP	Improved grassland

If a narrower range of habitats, confounded by fewer extraneous variables (such as vegetation structure) which are not immediately relevant to SOILPACS, is desired, the grassland divisions have much to recommend them:

34	Calcareous grassland
35	Sandy grassland
37	Mesotrophic grassland
IMP	Improved grassland

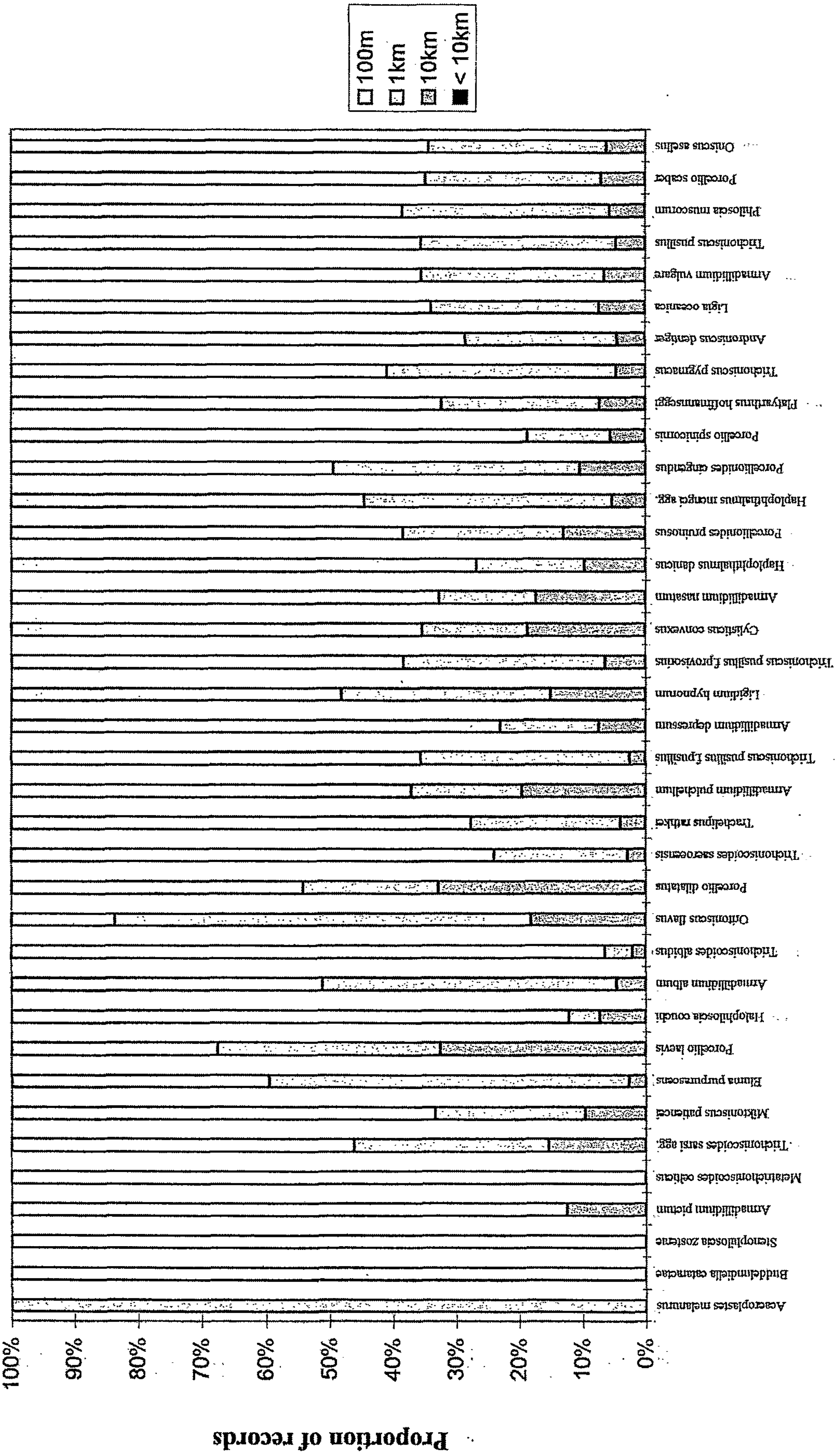


Figure 2a. Woodlice: spatial resolution of records (proportion of records at 10km, 1km and 100m resolution)

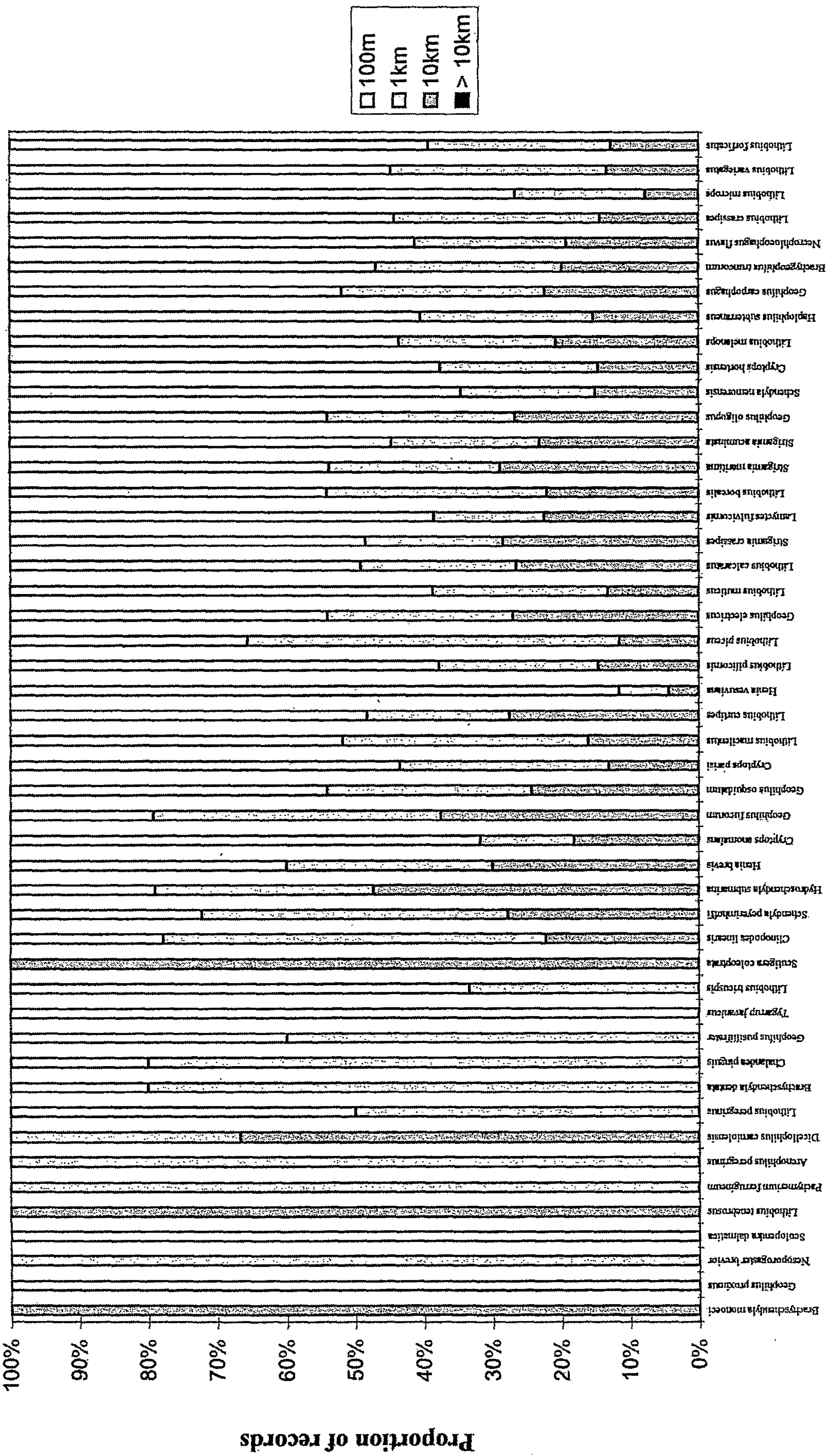


Figure 2b. Centipedes: spatial resolution of records (proportions of records at 10km, 1km and 100m resolution)

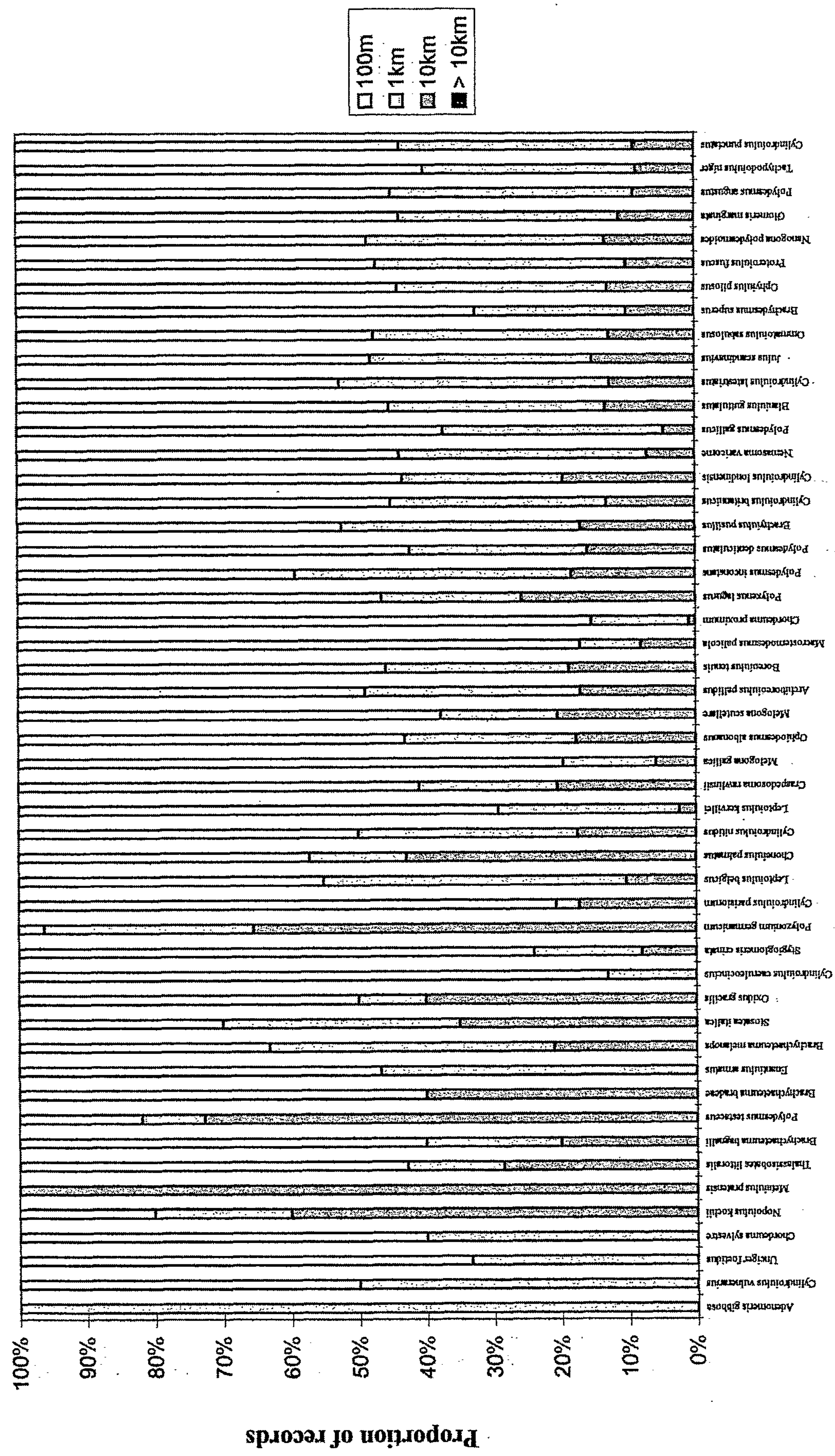


Figure 2c. Millipedes: spatial resolution of records (proportions of records at 10km, 1km and 100m resolution)

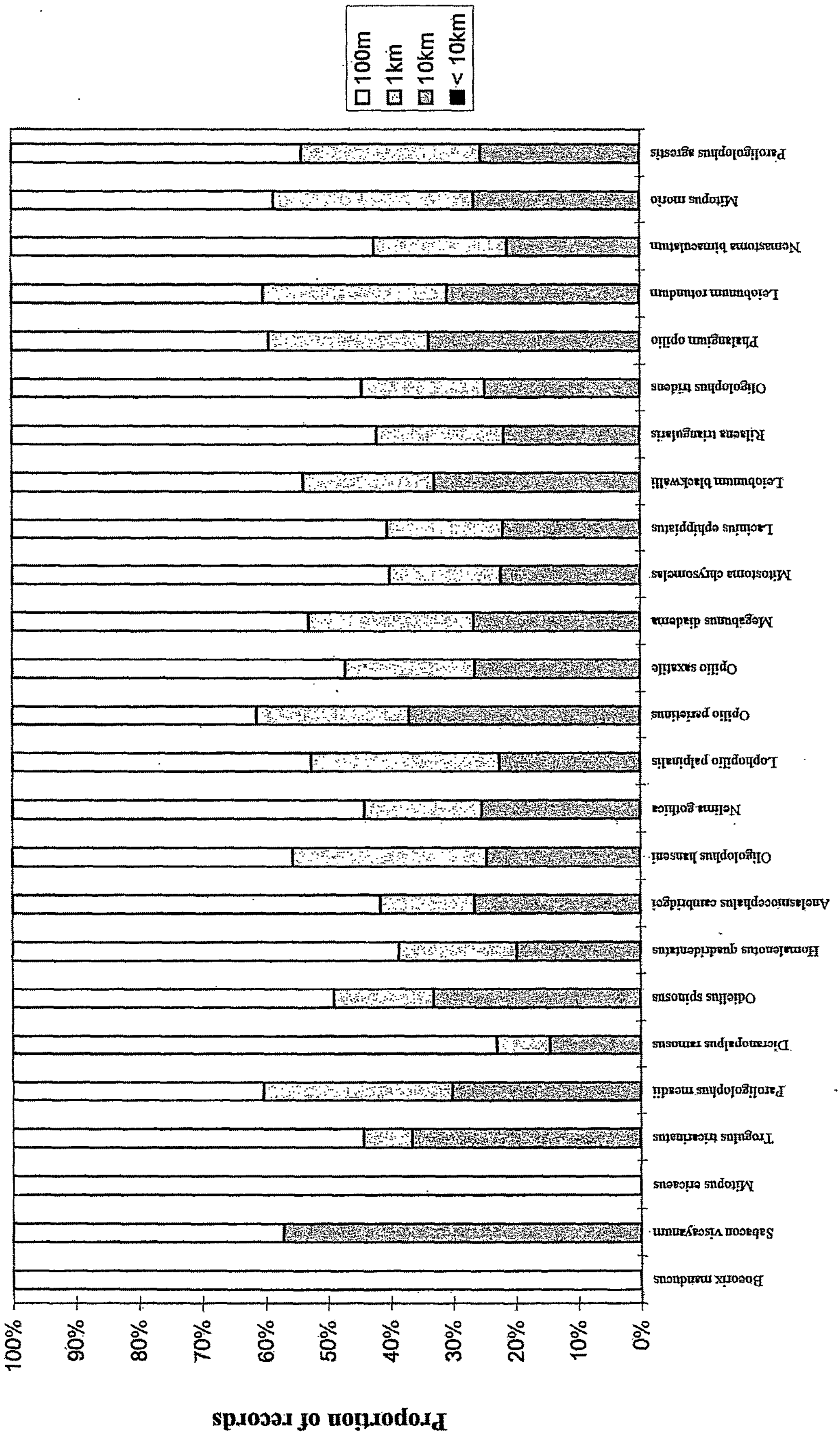


Figure 2d. Opiliones: spatial resolution of records (proportions of records at 10km, 1km and 100m resolution)

Figure 2e. Carabidae: spatial resolution of records (proportions of records at 10km, 1km and 100m resolution)

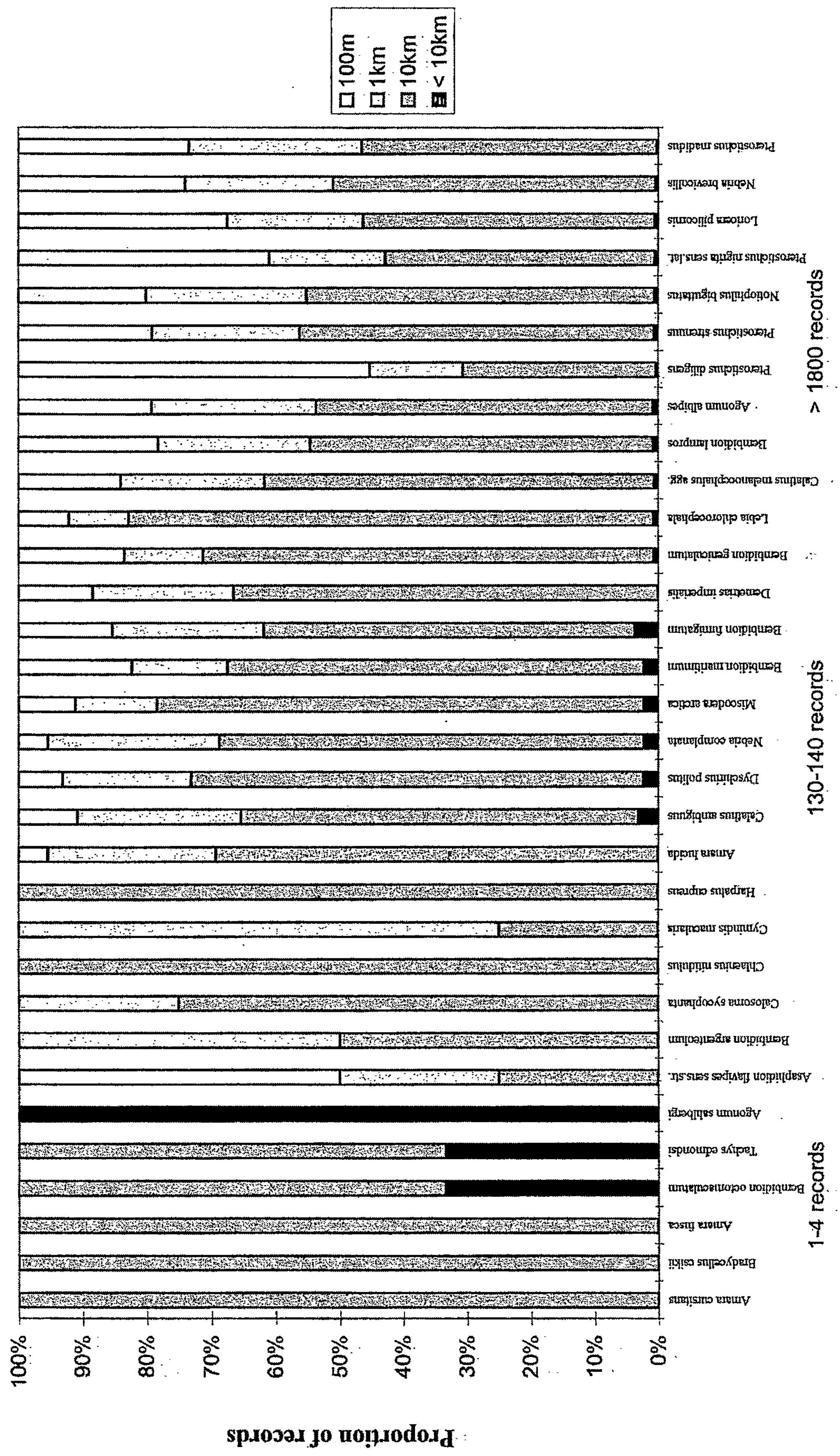


Figure 2f. Myriapoda: scattergram showing per species the number of 10 x 10 km squares in which the given number of records occurred (see section 2.1.1 for explanation)

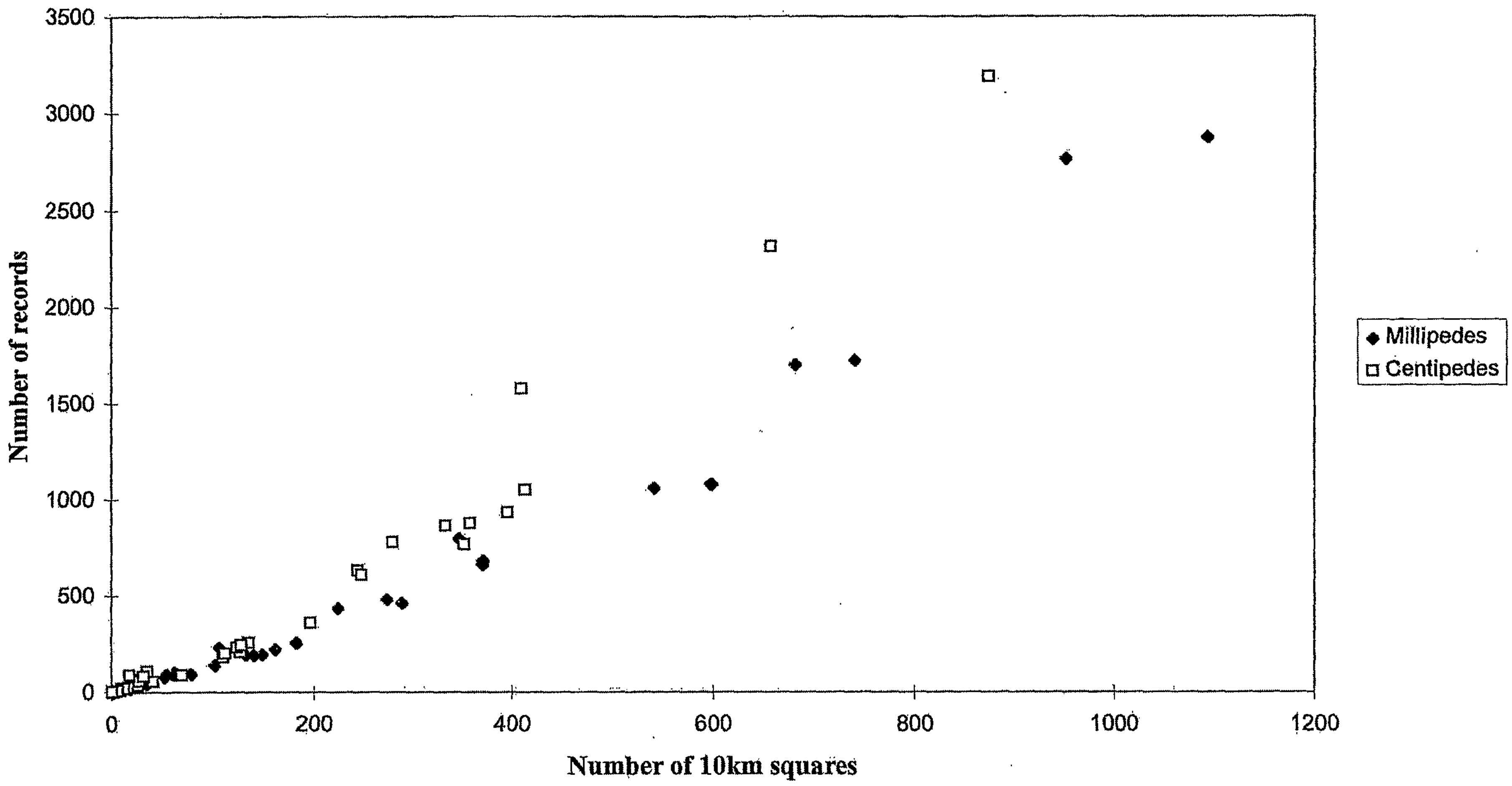


Figure 2g. Woodlice: scattergram showing per species the number of 10 x 10 km squares in which the given number of records occurred (see section 2.1.1 for explanation)

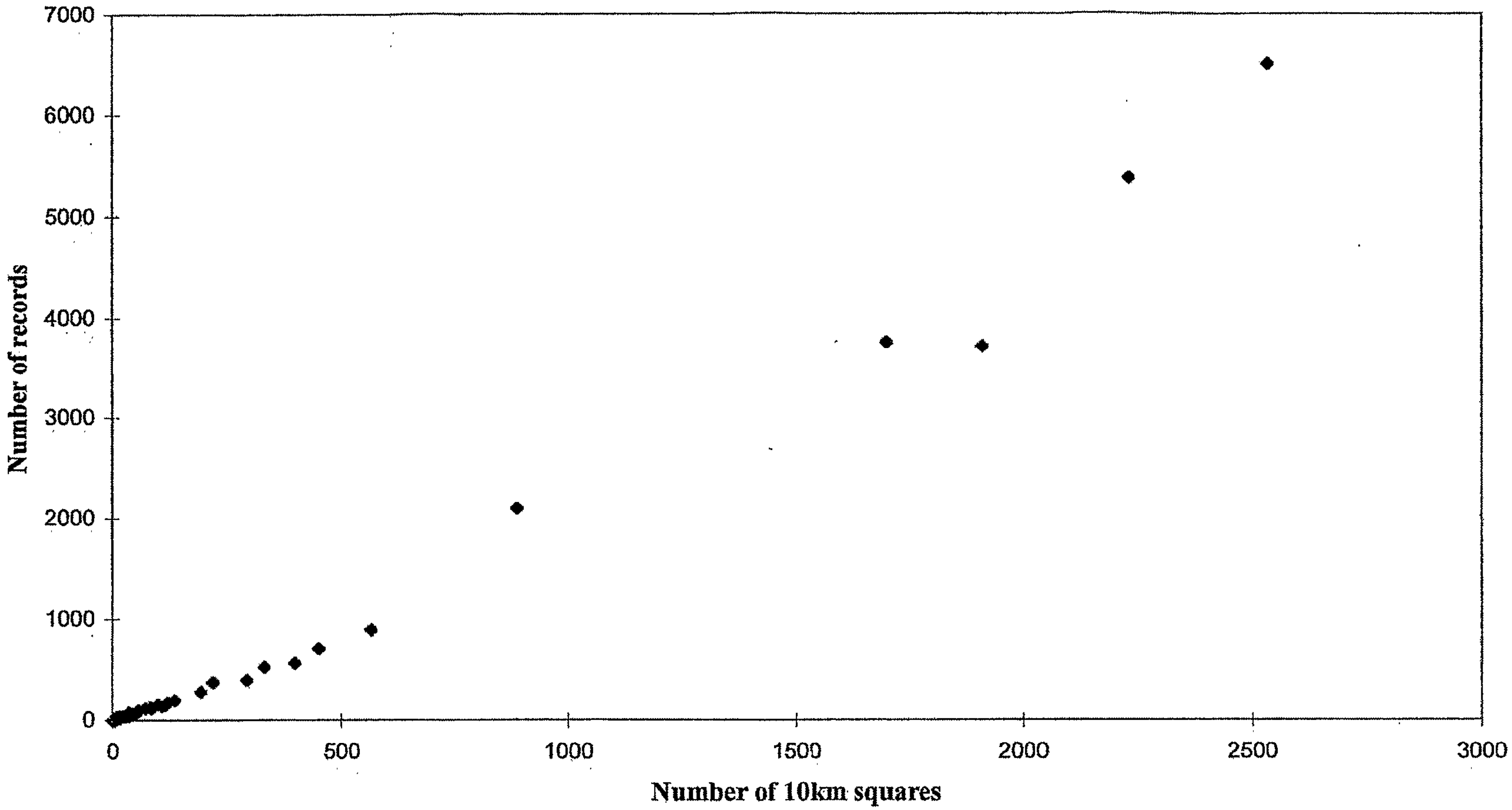


Figure 2h. Opiliones: scattergram showing per species the number of 10 x 10 km squares in which the given number of records occurred (see section 2.1.1 for explanation)

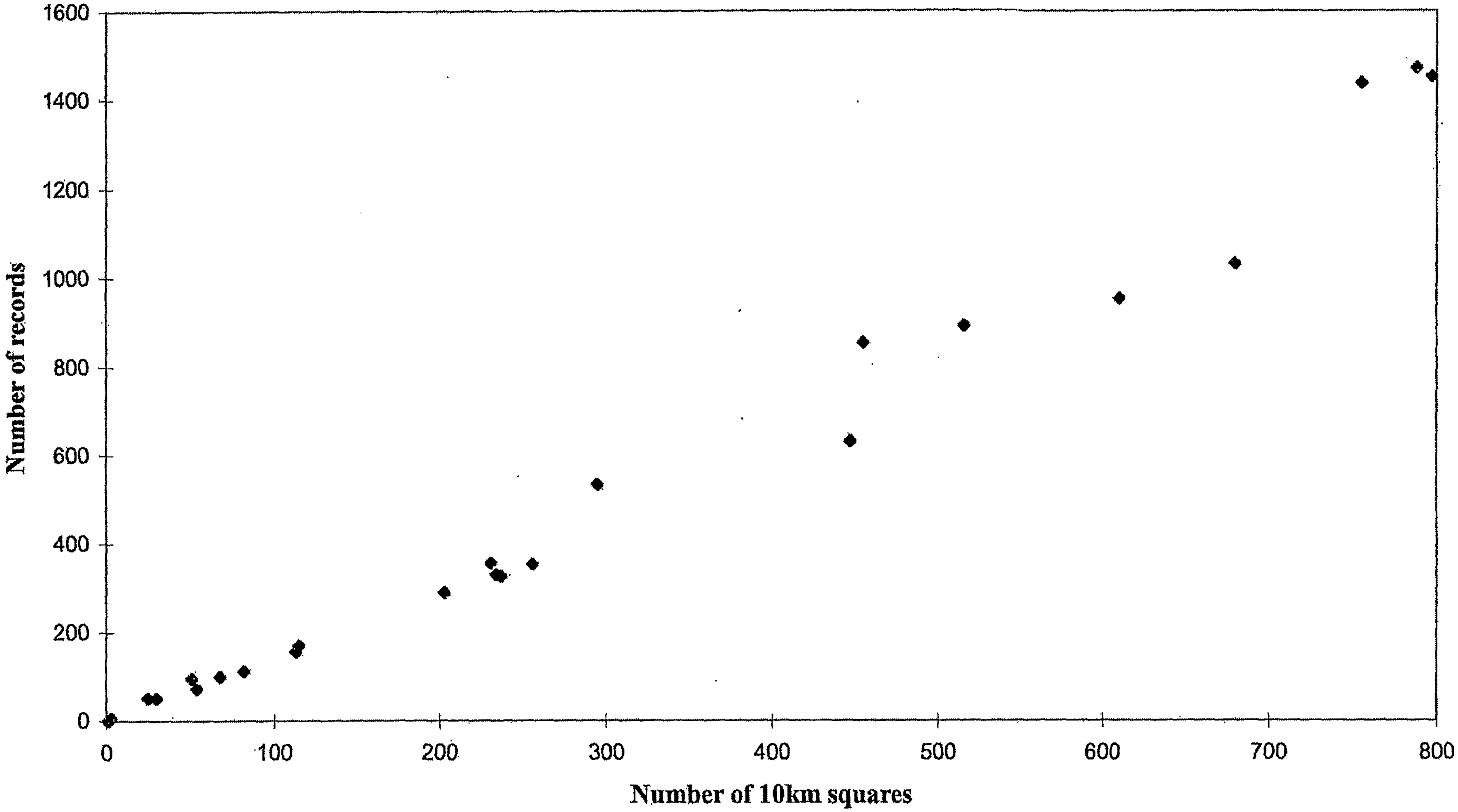


Figure 2i. Mollusca: scattergram showing per species the number of 10 x 10 km squares in which the given number of records occurred (see section 2.1.1 for explanation)

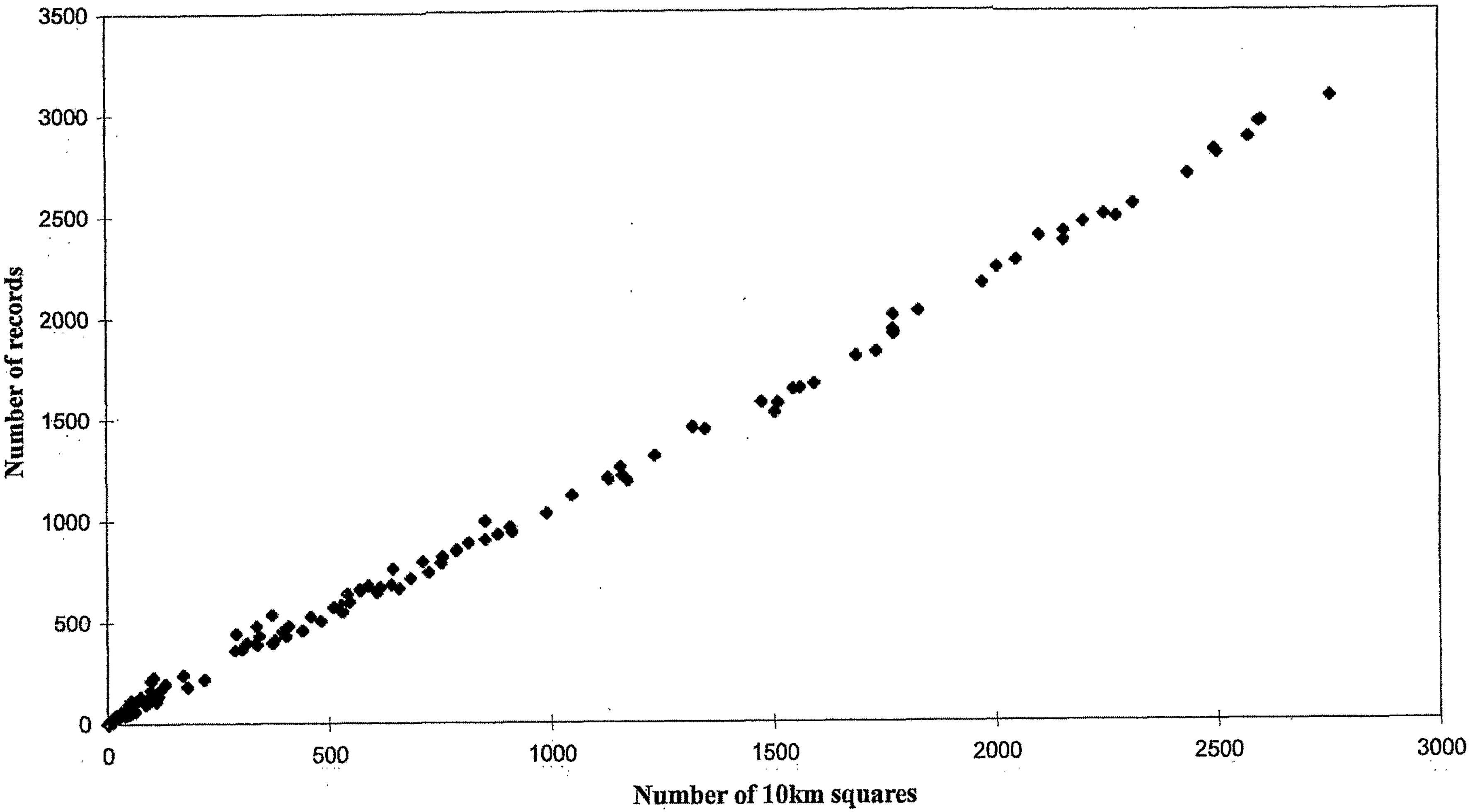


Figure 2j. Carbidae: scattergram showing per species the number of 10 x 10 km squares in which the given number of records occurred (see section 2.1.1 for explanation)

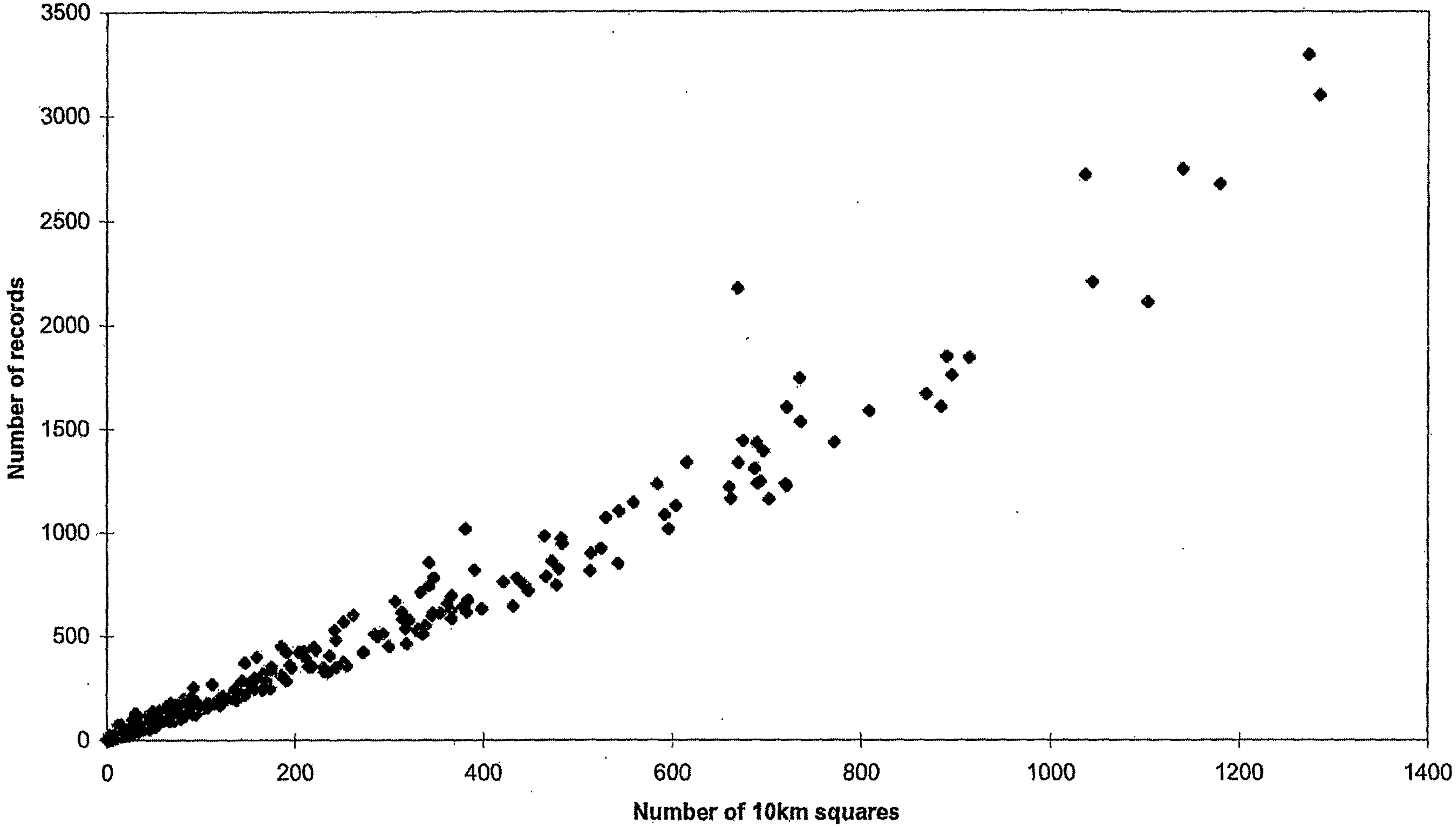


Table 6 Spatial coverage and modernity of Woodlice species at 10km, 1km and 100m resolution (post 70 is the proportion of these records recorded after 1970).

		10km		1km		100m	
SPECIES	NAME	Number	post %70	Number	post %70	Number	post %70
6567 101	*Acaeroplastes melanurus*	1	0.00	1	0.00	0	0.00
6567 901	*Androniscus dentiger*	450	90.89	593	89.71	473	89.01
6567 1001	*Armadillidium album*	23	60.87	32	53.13	20	60.00
6567 1002	*Armadillidium depressum*	72	88.89	99	94.95	86	95.35
6567 1003	*Armadillidium nasatum*	99	79.80	107	94.39	98	93.88
6567 1004	*Armadillidium pictum*	5	60.00	7	71.43	7	71.43
6567 1005	*Armadillidium pulchellum*	56	73.21	61	93.44	54	100.00
6567 1006	*Armadillidium vulgare*	888	96.28	1595	94.67	1234	95.71
6567 2201	*Buddelundiella cataractae*	3	100.00	3	100.00	3	100.00
6567 3801	*Cylisticus convexus*	114	75.44	107	93.46	87	97.70
6567 4701	*Eluma purpurascens*	10	100.00	21	95.24	12	100.00
6567 5201	*Halophiloscia couchi*	16	93.75	24	100.00	28	96.43
6567 5401	*Haplophthalmus danicus*	120	87.50	135	95.56	119	96.64
6567 5402	*Haplophthalmus mengei agg.*	193	90.67	227	94.27	137	96.35
6567 6801	*Ligia oceanica*	566	92.05	727	88.31	547	93.97
6567 6901	*Ligidium hypnorum*	82	86.59	99	86.87	68	94.12
6567 7501	*Metatrichoniscoides celticus*	2	100.00	5	100.00	7	100.00
6567 7702	*Miktoniscus patiencei*	16	100.00	16	100:00	13	100.00
6567 8801	*Oniscus asellus*	2532	97.95	5016	96.33	3855	97.07
6567 8901	*Oritoniscus flavus*	41	80.49	42	92.86	8	100.00
6567 9401	*Philoscia muscorum*	1699	95.94	2974	93.28	2133	93.25
6567 9601	*Platyarthrus hoffmannseggi*	331	91.24	437	92.91	341	95.60
6567 9701	*Porcellio dilatatus*	50	70.00	37	86.49	25	92.00
6567 9702	*Porcellio laevis*	30	66.67	26	88.46	13	92.31
6567 9703	*Porcellio scaber*	2228	97.80	4100	95.90	3198	97.03
6567 9704	*Porcellio spinicornis*	293	93.17	333	97.30	304	98.03
6567 7601	*Porcellionides cingendus*	219	93.15	295	92.54	175	96.00
6567 7602	*Porcellionides pruinosus*	135	82.22	147	94.56	111	96.40
6567 5202	*Stenophiloscia zosterae*	3	100.00	3	100.00	3	100.00
6567 12001	*Trachelipus rathkei*	36	88.89	59	88.14	49	85.71
6567 12101	*Trichoniscoides albidus*	34	94.12	36	97.22	37	100.00
6567 12102	*Trichoniscoides saeroeensis*	40	92.50	47	93.62	46	93.48
6567 12103	*Trichoniscoides sarsi agg.*	8	50.00	7	57.14	5	80.00
6567 12201	*Trichoniscus pusillus*	1910	97.85	3039	96.22	2208	97.06
6567 12201.1	*Trichoniscus pusillus f.provisorius*	107	84.11	115	88.70	76	93.42
6567 12201.2	*Trichoniscus pusillus f.pusillus*	85	92.94	102	92.16	72	100.00
6567 12202	*Trichoniscus pygmaeus*	398	95.73	480	96.46	310	97.10

Table 7 Spatial coverage and modernity of Millipede species at 10km, 1km and 100m resolution (post 70 is the proportion of these records recorded after 1970).

SPECIES		NAME	10km Number	post %70	1km Number	post %70	100m Number	post %70
6100	101	*Archiboreoiulus pallidus*	55	72.73	60	81.67	40	95.00
6100	201	*Blaniulus guttulatus*	290	76.55	344	87.21	229	93.45
6100	301	*Boreoiulus tenuis*	79	79.75	73	97.26	48	97.92
6100	401	*Brachychaeteuma bagnalli*	7	71.43	6	100.00	4	100.00
6100	402	*Brachychaeteuma bradeae*	13	61.54	8	100.00	8	100.00
6100	403	*Brachychaeteuma melanops*	19	73.68	15	93.33	7	100.00
6100	501	*Brachydesmus superus*	348	83.91	602	90.70	502	96.02
6100	601	*Brachyiulus pusillus*	149	79.19	143	89.51	89	92.13
6100	701	*Choneiulus palmatus*	24	58.33	18	100.00	13	100.00
6100	801	*Chordeuma proximum*	63	95.24	93	96.77	83	100.00
6100	802	*Chordeuma sylvestre*	2	50.00	2	50.00	2	0.00
6100	901	*Craspedosoma rawlinsii*	35	71.43	28	89.29	22	95.45
6100	1001	*Cylindroiulus britannicus*	162	84.57	172	93.02	116	98.28
6100	1002	*Cylindroiulus latestriatus*	275	84.00	366	87.70	216	96.30
6100	1003	*Cylindroiulus londinensis*	107	66.36	148	81.08	118	96.61
6100	1004	*Cylindroiulus nitidus*	25	60.00	23	82.61	17	100.00
6100	1005	*Cylindroiulus parisiorum*	19	73.68	18	94.44	18	88.89
6100	1006	*Cylindroiulus punctatus*	1093	90.39	2036	91.94	1410	96.52
6100	1007	*Cylindroiulus caeruleocinctus*	18	100.00	22	100.00	19	100.00
6100	1009	*Cylindroiulus vulnerarius*	2	100.00	2	100.00	1	100.00
6100	1101	*Stosatea italica*	12	66.67	12	66.67	6	100.00
6100	1301	*Stygioglomeris crinata*	20	95.00	22	100.00	18	100.00
6100	1401	*Glomeris marginata*	682	88.12	1167	91.26	835	96.65
6100	1501	*Thalassisobates littoralis*	7	57.14	5	80.00	4	100.00
6100	1502	*Nemasoma varicorne*	183	88.52	210	90.00	137	92.70
6100	1601	*Julus scandinavius*	371	83.56	446	91.03	311	96.14
6100	1701	*Leptoiulus belgicus*	21	66.67	22	72.73	10	90.00
6100	1702	*Leptoiulus kervillei*	15	86.67	29	96.55	22	100.00
6100	1801	*Enantiulus armatus*	5	80.00	9	55.56	6	33.33
6100	1901	*Macrosternodesmus palicola*	62	90.32	81	96.30	75	97.33
6100	2001	*Metaiulus pratensis*	5	0.00				
6100	2101	*Melogona gallica*	37	94.59	41	95.12	36	94.44
6100	2102	*Melogona scutellare*	62	67.74	63	73.02	51	72.55
6100	2201	*Nopoiulus kochii*	3	66.67	2	100.00	1	100.00
6100	2301	*Ommatoiulus sabulosus*	371	88.95	490	92.04	322	97.20
6100	2401	*Ophiodesmus albonanus*	53	71.70	53	88.68	43	95.35
6100	2501	*Ophyiulus pilosus*	542	86.72	774	91.34	539	95.73
6100	2601	*Oxidus gracilis*	13	61.54	7	100.00	5	100.00
6100	2701	*Polydesmus angustus*	741	84.48	1215	88.40	822	96.35
6100	2702	*Polydesmus inconstans*	141	68.09	133	80.45	75	88.00
6100	2703	*Polydesmus denticulatus*	133	75.94	139	87.05	96	95.83
6100	2704	*Polydesmus gallicus*	225	90.67	348	93.10	246	96.34
6100	2705	*Polydesmus testaceus*	8	37.50	3	66.67	2	100.00
6100	2801	*Nanogona polydesmoides*	598	86.12	810	92.10	508	95.87
6100	2901	*Polyxenus lagurus*	103	73.79	87	91.95	65	93.85
6100	3001	*Polyzonium germanicum*	11	54.55	9	44.44	1	100.00
6100	3101	*Proteroiulus fuscus*	599	87.31	820	90.37	528	94.70
6100	3201	*Tachypodoiulus niger*	952	88.66	1895	91.19	1447	96.82
6100	3301	*Adenomeris gibbosa*	1	100.00	1	100.00		
6100	3501	*Unciger foetidus*	1	100.00	1	100.00	2	100.00

Table 8 Spatial coverage and modernity of Centipede species at 10km, 1km and 100m resolution (post 70 is the proportion of these records recorded after 1970).

SPECIES		NAME	10km Number	post %70	1km Number	post %70	100m Number	post %70
6200	101	*Brachygeophilus truncorum*	359	62.95	512	74.22	385	82.34
6200	201	*Brachyschendyla dentata*	4	50.00	4	50.00	1	100.00
6200	202	*Brachyschendyla monoeci*	1	0.00				
6200	301	*Henia brevis*	14	64.29	12	75.00	6	100.00
6200	302	*Henia vesuviana*	23	82.61	46	93.48	53	96.23
6200	401	*Chalandea pinguis*	2	100.00	5	100.00	1	100.00
6200	501	*Clinopodes linearis*	10	20.00	8	37.50	4	75.00
6200	601	*Cryptops anomalans*	13	69.23	13	69.23	12	83.33
6200	602	*Cryptops hortensis*	245	75.51	400	83.25	339	93.22
6200	603	*Cryptops parisi*	29	86.21	34	97.06	23	95.65
6200	701	*Dicellophilus carniolensis*	3	0.00	1	0.00		
6200	801	*Geophilus carpophagus*	334	68.26	503	78.93	362	89.50
6200	802	*Geophilus electricus*	70	74.29	60	81.67	40	95.00
6200	803	*Geophilus fucorum*	19	68.42	15	86.67	5	100.00
6200	804	*Geophilus oligopus*	197	65.48	210	77.62	148	90.54
6200	805	*Geophilus osquidatum*	27	77.78	24	91.67	16	93.75
6200	806	*Geophilus pusillifrater*	3	66.67	3	66.67	2	100.00
6200	807	*Geophilus proximus*	1	100.00	1	100.00	1	100.00
6200	901	*Haplophilus subterraneus*	281	71.89	445	85.39	382	92.93
6200	1001	*Hydroschendyla submarina*	12	33.33	7	71.43	4	100.00
6200	1101	*Lamyctes fulvicornis*	128	67.97	128	89.06	106	94.34
6200	1202	*Lithobius macilentus*	41	82.93	41	87.80	25	96.00
6200	1203	*Lithobius borealis*	125	58.40	133	81.20	96	85.42
6200	1204	*Lithobius calcaratus*	111	61.26	111	80.18	86	87.21
6200	1205	*Lithobius crassipes*	414	76.33	683	85.94	519	92.87
6200	1206	*Lithobius curtipes*	28	53.57	26	65.38	17	82.35
6200	1207	*Lithobius microps*	410	80.24	1070	86.73	1044	95.88
6200	1209	*Lithobius forficatus*	874	76.54	1986	84.44	1680	93.04
6200	1211	*Lithobius melanops*	353	71.95	505	88.32	389	95.89
6200	1212	*Lithobius muticus*	36	52.78	48	41.67	28	67.86
6200	1213	*Lithobius tenebrosus*	2	0.00				
6200	1214	*Lithobius piceus*	18	27.78	53	18.87	28	25.00
6200	1215	*Lithobius pilicornis*	32	71.88	47	89.36	40	95.00
6200	1216	*Lithobius tricuspis*	5	80.00	5	80.00	4	75.00
6200	1217	*Lithobius variegatus*	658	77.96	1344	83.11	1046	87.86
6200	1218	*Lithobius peregrinus*	1	100.00	2	100.00	2	100.00
6200	1301	*Necrophloeophagus flavus*	396	62.37	613	79.77	497	90.95
6200	1401	*Nesoporogaster brevior*	1	0.00	1	0.00		
6200	1501	*Pachymerium ferrugineum*	1	0.00	1	0.00		
6200	1601	*Schendyla nemorensis*	249	73.90	435	84.60	371	95.42
6200	1602	*Schendyla peyerimhoffi*	13	84.62	10	70.00	5	100.00
6200	1701	*Scutigera coleoptrata*	7	0.00				
6200	1801	*Strigamia acuminata*	136	68.38	146	78.08	107	86.92
6200	1802	*Strigamia crassipes*	113	60.18	112	76.79	81	92.59
6200	1803	*Strigamia maritima*	129	66.67	136	87.50	100	95.00
6200	1901	*Scolopendra dalmatica*	1	100.00	1	100.00	1	100.00
6200	9998	*Tygarrup javanicus*	1	100.00	1	100.00	1	100.00
6200	9999	*Arenophilus peregrinus*	1	100.00	1	100.00		

Table 9 Spatial coverage and modernity of Harvestman species at 10km, 1km and 100m resolution (post 70 is the proportion of these records recorded after 1970).

SPECIES	NAME	10km Number	10km post %70	1km Number	1km post %70	100m Number	100m post %70
6707 101	*Anelasmocephalus cambridgei*	82	54.88	70	57.14	62	56.45
6707 201	*Dicranopalpus ramosus*	51	96.08	75	96.00	70	95.71
6707 301	*Homalenotus quadridentatus*	68	52.94	68	50.00	56	57.14
6707 401	*Lacinius ephippiatus*	295	58.98	277	67.51	214	80.37
6707 501	*Leiobunum blackwalli*	447	68.90	387	77.26	275	77.45
6707 502	*Leiobunum rotundum*	680	73.24	652	74.69	392	80.36
6707 601	*Megabunus diadema*	256	67.58	237	71.31	162	75.31
6707 701	*Mitopus morio*	797	73.53	934	73.66	561	86.63
6707 702	*Mitopus ericaeus*	25	100.00	42	100.00	51	100.00
6707 801	*Mitostoma chrysomelas*	231	70.13	237	75.53	202	81.68
6707 901	*Nelima gothica*	115	80.87	105	88.57	81	95.06
6707 1001	*Nemastoma bimaculatum*	755	80.79	1004	88.84	785	91.72
6707 1101	*Paroligolophus agrestis*	788	74.11	957	74.19	622	87.14
6707 1102	*Oligolophus hanseni*	113	54.87	106	56.60	63	61.90
6707 1103	*Paroligolophus meadii*	54	59.26	43	60.47	26	50.00
6707 1104	*Lophopilio palpinalis*	203	64.04	195	60.51	125	66.40
6707 1105	*Odiellus spinosus*	68	61.76	57	64.91	43	72.09
6707 1106	*Oligolophus tridens*	516	68.02	477	73.58	340	80.29
6707 1201	*Opilio parietinus*	237	54.43	181	59.12	112	62.50
6707 1202	*Opilio saxatile*	234	70.09	217	77.42	164	84.15
6707 1301	*Phalangium opilio*	610	66.72	566	72.61	364	78.30
6707 1401	*Rilaena triangularis*	455	76.92	579	82.56	450	87.78
6707 1501	*Trogulus tricarinatus*	30	40.00	29	41.38	27	37.04
6707 1601	*Boeorix manducus*	1	100.00	1	100.00	1	100.00
6707 1701	*Sabacon viscayanum*	3	100.00	2	100.00	2	100.00

Table 10 Spatial coverage and modernity of Carabidae species at 10km, 1km and 100m resolution (post 70 is the proportion of these records recorded after 1970).

SPECIES	NAME	10km Number	10km post %70	1km Number	1km post %70	100m Number	100m post %70
6453 101	*Abax parallelepipedus*	809	85.29	644	94.88	296	98.31
6453 301	*Acupalpus brunnipes*	12	33.33	2	100.00	1	100.00
6453 302	*Acupalpus dorsalis*	86	61.63	40	92.50	15	100.00
6453 303	*Acupalpus dubius*	252	74.60	161	97.52	90	98.89
6453 304	*Acupalpus elegans*	7	14.29	1	0.00		
6453 305	*Acupalpus exiguus*	63	36.51	17	88.24	4	100.00
6453 306	*Acupalpus flavicollis*	26	26.92	5	60.00	1	100.00
6453 307	*Acupalpus meridianus*	165	53.94	61	93.44	22	95.45
6453 401	*Aepus marinus*	59	52.54	18	100.00	14	100.00
6453 402	*Aepus robini*	41	58.54	16	81.25	10	100.00
6453 601	*Agonum assimile*	584	85.45	551	95.10	238	94.54
6453 602	*Agonum dorsale*	690	74.49	405	91.60	189	95.77
6453 603	*Agonum ericeti*	63	77.78	53	100.00	47	100.00
6453 604	*Agonum fuliginosum*	735	85.31	577	96.01	380	98.16
6453 605	*Agonum gracile*	343	74.64	225	96.00	186	98.39
6453 606	*Agonum gracilipes*	7	85.71	4	100.00		
6453 607	*Agonum livens*	44	56.82	19	100.00	5	100.00
6453 608	*Agonum marginatum*	444	72.75	232	93.10	103	95.15
6453 609	*Agonum micans*	121	59.50	52	100.00	17	100.00
6453 610	*Agonum moestum*	314	78.03	201	98.01	134	99.25
6453 611	*Agonum muelleri*	721	71.84	412	94.42	232	97.84
6453 612	*Agonum nigrum*	55	50.91	25	96.00	11	100.00
6453 613	*Agonum obscurum*	315	72.38	161	96.89	66	98.48
6453 614	*Agonum piceum*	140	65.00	67	91.04	49	95.92
6453 615	*Agonum quadripunctatum*	11	9.09	1	0.00		
6453 616	*Agonum albipes*	1102	85.12	855	94.62	404	96.53
6453 618	*Agonum scitulum*	27	62.96	9	100.00	2	100.00
6453 619	*Agonum sexpunctatum*	29	34.48	8	87.50	1	100.00
6453 620	*Agonum thoreyi*	343	81.34	260	96.15	196	98.47
6453 621	*Agonum versutum*	32	53.13	4	75.00	1	100.00
6453 622	*Agonum viduum*	196	62.76	105	97.14	81	100.00
6453 623	*Agonum lugens*	4	75.00	4	75.00		
6453 701	*Amara aenea*	696	77.30	531	95.67	217	97.70
6453 702	*Amara alpina*	5	60.00	4	100.00	1	100.00
6453 703	*Amara anthobia*	49	46.94	10	100.00	4	100.00
6453 704	*Amara apricaria*	336	62.50	155	91.61	60	96.67
6453 705	*Amara aulica*	477	70.86	244	90.98	103	94.17
6453 706	*Amara bifrons*	252	69.44	90	93.33	37	100.00
6453 707	*Amara communis*	319	63.95	157	90.45	55	98.18
6453 708	*Amara consularis*	71	35.21	18	88.89	4	100.00
6453 709	*Amara convexior*	113	71.68	54	87.04	13	76.92
6453 710	*Amara convexiuscula*	149	73.15	72	93.06	22	100.00
6453 711	*Amara cursitans*	1	0.00				
6453 712	*Amara curta*	19	63.16	13	76.92	3	66.67
6453 713	*Amara equestris*	38	50.00	17	94.12	7	100.00
6453 714	*Amara eurynota*	122	56.56	55	94.55	28	96.43
6453 715	*Amara famelica*	13	7.69	2	50.00	1	0.00
6453 716	*Amara familiaris*	660	78.79	441	94.10	185	95.14
6453 717	*Amara fulva*	99	49.49	37	78.38	14	78.57
6453 718	*Amara fusca*	2	0.00				
6453 719	*Amara infima*	10	60.00	8	87.50		

SPECIES		NAME	10km Number	post %70	1km Number	post %70	100m Number	post %70
6453	720	*Amara lucida*	81	50.62	34	88.24	6	100.00
6453	721	*Amara lunicollis*	331	72.21	192	96.88	95	96.84
6453	722	*Amara montivaga*	42	50.00	17	94.12	8	100.00
6453	723	*Amara nitida*	19	31.58	6	50.00	3	100.00
6453	724	*Amara ovata*	300	64.33	128	95.31	48	97.92
6453	725	*Amara plebeja*	687	84.13	537	94.41	262	96.56
6453	726	*Amara praetermissa*	47	53.19	22	95.45	8	100.00
6453	727	*Amara quenseli*	8	62.50	1	100.00	1	100.00
6453	728	*Amara similata*	330	70.91	181	96.69	100	98.00
6453	729	*Amara spreta*	11	72.73	8	100.00		
6453	730	*Amara strenua*	9	22.22	2	100.00	1	100.00
6453	731	*Amara tibialis*	244	74.59	181	97.79	55	100.00
6453	801	*Anisodactylus binotatus*	133	50.38	47	82.98	14	92.86
6453	802	*Anisodactylus nemorivagus*	13	30.77	2	50.00		
6453	803	*Anisodactylus poeciloides*	16	18.75	2	100.00		
6453	901	*Acupalpus consputus*	91	51.65	31	96.77	10	90.00
6453	1001	*Asaphidion flavipes agg.*	366	73.22	181	92.27	92	92.39
6453	1002	*Asaphidion pallipes*	41	41.46	15	86.67	7	100.00
6453	1003	*Asaphidion curtum*	54	92.59	49	95.92	17	94.12
6453	1004	*Asaphidion stierlini*	15	100.00	10	100.00	5	100.00
6453	1005	*Asaphidion flavipes sens.str.*	4	100.00	3	100.00	2	100.00
6453	1201	*Badister anomalus*	7	28.57	2	100.00		
6453	1202	*Badister bipustulatus*	596	71.81	327	92.66	153	94.77
6453	1203	*Badister dilatatus*	44	68.18	25	100.00	7	100.00
6453	1204	*Badister meridionalis*	5	80.00	2	100.00		
6453	1205	*Badister peltatus*	19	36.84	7	85.71	1	100.00
6453	1206	*Badister sodalis*	144	54.86	47	93.62	16	100.00
6453	1207	*Badister unipustulatus*	48	41.67	12	91.67	4	100.00
6453	1301	*Bembidion aeneum*	367	79.29	297	95.96	143	97.20
6453	1302	*Bembidion andreae*	96	71.88	57	96.49	32	96.88
6453	1303	*Bembidion argenteolum*	2	50.00	1	100.00		
6453	1304	*Bembidion articulatum*	214	66.36	117	94.87	40	97.50
6453	1305	*Bembidion assimile*	220	75.91	132	98.48	71	100.00
6453	1306	*Bembidion atrocoeruleum*	218	81.19	163	96.93	101	97.03
6453	1307	*Bembidion stomoides*	51	47.06	13	84.62		
6453	1308	*Bembidion biguttatum*	421	75.06	249	94.78	127	98.43
6453	1309	*Bembidion bipunctatum*	94	63.83	30	90.00	10	90.00
6453	1310	*Bembidion bruxellense*	255	79.22	113	92.92	46	93.48
6453	1311	*Bembidion clarki*	106	54.72	33	96.97	9	100.00
6453	1312	*Bembidion decorum*	185	67.57	112	100.00	68	100.00
6453	1313	*Bembidion dentellum*	322	66.46	202	94.06	81	97.53
6453	1314	*Bembidion doris*	133	63.16	76	93.42	32	100.00
6453	1315	*Bembidion ephippium*	24	54.17	14	92.86		
6453	1316	*Bembidion femoratum*	230	69.57	104	93.27	42	97.62
6453	1317	*Bembidion fluviatile*	27	40.74	5	80.00	2	100.00
6453	1318	*Bembidion fumigatum*	73	73.97	43	90.70	18	88.89
6453	1319	*Bembidion genei*	285	78.25	166	97.59	74	98.65
6453	1320	*Bembidion geniculatum*	90	67.78	37	89.19	21	90.48
6453	1321	*Bembidion gilvipes*	146	52.74	41	90.24	15	100.00
6453	1322	*Bembidion guttula*	736	81.25	581	96.90	323	97.21
6453	1323	*Bembidion harpaloides*	512	75.59	309	93.53	126	96.83
6453	1324	*Bembidion iricolor*	90	73.33	61	93.44	19	94.74
6453	1325	*Bembidion lampros*	891	83.16	692	95.23	348	97.70
6453	1326	*Bembidion laterale*	93	41.94	29	82.76	11	100.00

SPECIES		NAME	10km Number	post %70	1km Number	post %70	100m Number	post %70
6453	1327	*Bembidion litorale*	61	57.38	33	100.00	21	100.00
6453	1328	*Bembidion lunatum*	58	53.45	24	95.83	11	100.00
6453	1329	*Bembidion lunulatum*	482	76.56	330	96.67	155	98.06
6453	1330	*Bembidion maritimum*	81	44.44	34	91.18	20	100.00
6453	1331	*Bembidion minimum*	159	81.76	124	95.16	34	97.06
6453	1332	*Bembidion monticola*	90	51.11	32	96.88	14	92.86
6453	1333	*Bembidion nigricorne*	53	54.72	32	87.50	8	87.50
6453	1334	*Bembidion nigropiceum*	22	22.73	7	71.43	3	100.00
6453	1335	*Bembidion nitidulum*	355	80.00	214	96.26	101	98.02
6453	1336	*Bembidion normannum*	89	67.42	55	94.55	10	100.00
6453	1337	*Bembidion obliquum*	56	60.71	22	90.91	6	100.00
6453	1338	*Bembidion obtusum*	378	70.11	190	95.79	94	100.00
6453	1339	*Bembidion octomaculatum*	2	50.00				
6453	1340	*Bembidion pallidipenne*	88	45.45	32	75.00	12	100.00
6453	1341	*Bembidion prasinum*	94	69.15	49	100.00	27	100.00
6453	1342	*Bembidion properans*	244	68.85	114	99.12	47	100.00
6453	1343	*Bembidion punctulatum*	156	69.23	103	98.06	64	100.00
6453	1344	*Bembidion quadrimaculatum*	479	73.07	304	93.75	133	94.74
6453	1345	*Bembidion quadripustulatum*	45	24.44	9	77.78	4	100.00
6453	1346	*Bembidion quinquestriatum*	81	61.73	40	97.50	22	100.00
6453	1347	*Bembidion saxatile*	92	47.83	32	100.00	15	100.00
6453	1348	*Bembidion schueppeli*	22	68.18	17	100.00	6	100.00
6453	1349	*Bembidion semipunctatum*	12	66.67	6	100.00	3	100.00
6453	1350	*Bembidion stephensi*	93	64.52	52	90.38	21	90.48
6453	1351	*Bembidion testaceum*	12	41.67	6	83.33	2	100.00
6453	1352	*Bembidion tetracolum*	869	83.31	678	95.58	333	97.90
6453	1353	*Bembidion tibiale*	347	75.22	239	95.82	113	95.58
6453	1354	*Bembidion mannerheimi*	346	83.53	206	96.60	106	96.23
6453	1355	*Bembidion varium*	204	73.53	119	96.64	43	100.00
6453	1356	*Bembidion virens*	6	66.67	3	100.00	2	100.00
6453	1357	*Bembidion humerale*	3	100.00	1	100.00	1	100.00
6453	1501	*Blethisa multipunctata*	94	38.30	40	90.00	30	100.00
6453	1601	*Brachinus crepitans*	78	35.90	21	90.48	4	100.00
6453	1701	*Bradycellus collaris*	102	58.82	48	83.33	20	95.00
6453	1702	*Bradycellus csikii*	1	100.00				
6453	1703	*Bradycellus distinctus*	20	45.00	6	83.33	2	100.00
6453	1704	*Bradycellus harpalinus*	524	77.29	299	93.31	121	98.35
6453	1705	*Bradycellus ruficollis*	294	73.47	180	93.33	84	97.62
6453	1706	*Bradycellus sharpi*	191	65.45	62	93.55	25	100.00
6453	1707	*Bradycellus verbasci*	380	70.79	189	88.36	95	92.63
6453	1801	*Broscus cephalotes*	262	66.41	159	91.82	60	95.00
6453	2001	*Calathus ambiguus*	67	47.76	30	83.33	9	100.00
6453	2002	*Calathus erratus*	209	64.59	133	94.74	39	97.44
6453	2003	*Calathus fuscipes*	772	79.02	487	93.63	213	98.12
6453	2004	*Calathus melanocephalus agg.*	914	82.17	636	93.71	277	97.83
6453	2005	*Calathus micropterus*	169	66.27	96	89.58	33	96.97
6453	2006	*Calathus mollis*	242	76.86	152	92.76	47	100.00
6453	2007	*Calathus piceus*	447	78.30	290	90.00	115	94.78
6453	2008	*Calathus melanocephalus s.s.*	6	100.00	5	100.00	2	100.00
6453	2009	*Calathus cinctus*	7	100.00	4	100.00	3	100.00
6453	2101	*Callistus lunatus*	7	14.29	1	100.00	1	100.00
6453	2201	*Calosoma inquisitor*	67	25.37	27	55.56	5	80.00
6453	2202	*Calosoma sycophanta*	4	25.00	1	0.00		
6453	2301	*Carabus arvensis*	191	55.50	106	90.57	56	98.21

SPECIES	NAME	10km Number	post %70	1km Number	post %70	100m Number	post %70
6453 2302	*Carabus clatratus*	67	40.30	7	100.00	2	100.00
6453 2303	*Carabus glabratus*	175	64.57	66	84.85	24	100.00
6453 2304	*Carabus granulatus*	464	67.89	242	95.04	181	98.90
6453 2305	*Carabus intricatus*	10	20.00	2	50.00		
6453 2306	*Carabus monilis*	189	30.69	46	67.39	16	87.50
6453 2307	*Carabus nemoralis*	472	61.02	229	85.59	98	88.78
6453 2308	*Carabus nitens*	111	48.65	46	80.43	15	93.33
6453 2309	*Carabus problematicus*	721	73.93	497	93.36	266	96.99
6453 2310	*Carabus violaceus*	689	68.07	449	89.76	241	93.78
6453 2401	*Chlaenius nigricornis*	149	50.34	71	91.55	58	98.28
6453 2402	*Chlaenius nitidulus*	1	0.00				
6453 2403	*Chlaenius tristis*	4	25.00				
6453 2404	*Chlaenius vestitus*	158	61.39	90	95.56	37	100.00
6453 2501	*Cicindela campestris*	558	65.77	321	87.23	146	95.21
6453 2502	*Cicindela germanica*	12	25.00	7	71.43	3	66.67
6453 2503	*Cicindela hybrida*	15	20.00	9	77.78	3	33.33
6453 2504	*Cicindela maritima*	27	48.15	18	94.44	7	100.00
6453 2505	*Cicindela sylvatica*	31	25.81	15	73.33	4	75.00
6453 2601	*Clivina collaris*	156	53.21	71	92.96	40	100.00
6453 2602	*Clivina fossor*	720	76.53	425	94.12	202	97.03
6453 2901	*Cychrus caraboides*	693	69.84	396	90.66	193	95.34
6453 3001	*Cymindis axillaris*	25	36.00	10	90.00	4	100.00
6453 3002	*Cymindis vaporariorum*	41	56.10	17	76.47	7	100.00
6453 3003	*Cymindis macularis*	2	50.00	3	66.67		
6453 3101	*Demetrias atricapillus*	543	76.06	320	95.00	118	98.31
6453 3102	*Demetrias imperialis*	71	78.87	33	96.97	13	100.00
6453 3103	*Demetrias monostigma*	48	62.50	40	95.00	9	100.00
6453 3301	*Diachromus germanus*	4	0.00				
6453 3401	*Dicheirotrichus gustavi*	185	74.05	141	90.78	56	96.43
6453 3402	*Dicheirotrichus obsoletus*	63	66.67	27	81.48	5	100.00
6453 3501	*Dromius agilis*	165	68.48	71	94.37	16	93.75
6453 3502	*Dromius angustus*	51	72.55	18	83.33	6	83.33
6453 3503	*Dromius linearis*	675	79.70	501	95.41	223	99.10
6453 3504	*Dromius longiceps*	16	87.50	13	92.31	13	92.31
6453 3505	*Dromius melanocephalus*	483	78.47	254	95.67	86	98.84
6453 3506	*Dromius meridionalis*	231	64.94	99	86.87	33	84.85
6453 3507	*Dromius notatus*	143	69.93	79	92.41	32	100.00
6453 3508	*Dromius quadrimaculatus*	442	73.30	247	91.50	82	90.24
6453 3509	*Dromius quadrinotatus*	339	66.67	150	95.33	36	97.22
6453 3510	*Dromius quadrisignatus*	11	18.18	2	50.00	1	100.00
6453 3511	*Dromius sigma*	12	41.67	5	80.00	2	100.00
6453 3512	*Dromius vectensis*	21	38.10	7	85.71		
6453 3601	*Drypta dentata*	6	50.00	2	100.00		
6453 3701	*Dyschirius aeneus*	106	51.89	32	100.00	12	100.00
6453 3702	*Dyschirius angustatus*	5	40.00	4	100.00	3	100.00
6453 3703	*Dyschirius extensus*	6	0.00				
6453 3704	*Dyschirius globosus*	348	79.60	232	95.26	142	98.59
6453 3705	*Dyschirius impunctipennis*	36	30.56	8	100.00	3	100.00
6453 3706	*Dyschirius luedersi*	136	78.68	79	98.73	26	100.00
6453 3707	*Dyschirius nitidus*	22	36.36	4	75.00	3	100.00
6453 3708	*Dyschirius obscurus*	12	91.67	5	100.00		
6453 3709	*Dyschirius politus*	72	56.94	22	95.45	7	85.71
6453 3710	*Dyschirius salinus*	81	62.96	38	94.74	12	91.67
6453 3711	*Dyschirius thoracicus*	58	58.62	31	93.55	12	100.00

SPECIES	NAME	10km Number	post %70	1km Number	post %70	100m Number	post %70
6453 3901	*Elaphrus cupreus*	592	82.60	417	95.44	231	96.97
6453 3902	*Elaphrus lapponicus*	15	53.33	5	100.00	3	100.00
6453 3903	*Elaphrus riparius*	443	72.01	259	95.37	122	99.18
6453 3904	*Elaphrus uliginosus*	57	54.39	33	93.94	30	96.67
6453 4401	*Harpalus affinis*	615	74.96	472	93.01	224	96.88
6453 4402	*Harpalus anxius*	91	63.74	90	95.56	21	95.24
6453 4403	*Harpalus ardosiacus*	60	51.67	21	95.24	4	100.00
6453 4404	*Harpalus attenuatus*	66	57.58	34	91.18	11	100.00
6453 4405	*Harpalus azureus*	70	34.29	20	100.00	3	100.00
6453 4406	*Harpalus cordatus*	14	35.71	5	100.00		
6453 4407	*Harpalus cupreus*	2	0.00				
6453 4408	*Harpalus dimidiatus*	22	22.73	2	100.00	1	100.00
6453 4409	*Harpalus froelichi*	10	20.00	3	66.67	2	100.00
6453 4410	*Harpalus honestus*	9	0.00	2	0.00		
6453 4411	*Harpalus latus*	431	63.34	151	86.75	61	93.44
6453 4412	*Harpalus melancholicus*	13	0.00	2	0.00		
6453 4413	*Harpalus melleti*	22	27.27	5	40.00	1	100.00
6453 4414	*Harpalus neglectus*	32	59.38	28	100.00	6	100.00
6453 4415	*Harpalus obscurus*	11	9.09				
6453 4416	*Harpalus parallelus*	10	40.00	3	100.00		
6453 4417	*Harpalus punctatulus*	23	8.70	1	100.00		
6453 4418	*Harpalus puncticeps*	68	69.12	23	100.00	6	100.00
6453 4419	*Harpalus puncticollis*	28	21.43	5	60.00	4	75.00
6453 4420	*Harpalus quadripunctatus*	20	65.00	5	80.00	1	100.00
6453 4421	*Harpalus rubripes*	237	66.67	122	95.08	41	97.56
6453 4422	*Harpalus rufipes*	662	74.62	372	92.74	171	96.49
6453 4423	*Harpalus rufitarsis*	107	72.90	81	95.06	23	100.00
6453 4424	*Harpalus rupicola*	36	41.67	8	100.00	3	100.00
6453 4425	*Harpalus sabulicola*	19	36.84	1	100.00		
6453 4426	*Harpalus schaubergerianus*	45	40.00	11	100.00	4	100.00
6453 4427	*Harpalus serripes*	24	41.67	10	100.00	1	100.00
6453 4428	*Harpalus servus*	22	40.91	8	100.00	2	100.00
6453 4429	*Harpalus smaragdinus*	25	40.00	11	100.00	5	100.00
6453 4430	*Harpalus rufibarbis*	273	74.36	132	93.18	51	100.00
6453 4431	*Harpalus tardus*	194	67.01	126	96.03	39	100.00
6453 4432	*Harpalus tenebrosus*	16	68.75	6	100.00	1	100.00
6453 4433	*Harpalus vernalis*	12	75.00	11	90.91	4	100.00
6453 5401	*Laemostenus complanatus*	33	60.61	20	90.00	11	100.00
6453 5402	*Laemostenus terricola*	173	48.55	65	80.00	22	90.91
6453 5501	*Lebia chlorocephala*	94	40.43	16	75.00	5	100.00
6453 5502	*Lebia cruxminor*	10	50.00	1	100.00	1	100.00
6453 5503	*Lebia cyanocephala*	10	10.00				
6453 5601	*Leistus ferrugineus*	529	74.67	351	94.02	163	95.09
6453 5602	*Leistus fulvibarbis*	542	66.61	286	90.21	135	98.52
6453 5603	*Leistus montanus*	15	46.67	1	0.00		
6453 5604	*Leistus rufescens*	604	74.01	409	96.09	230	99.13
6453 5605	*Leistus rufomarginatus*	169	89.35	129	95.35	66	92.42
6453 5606	*Leistus spinibarbis*	334	66.17	211	91.47	104	95.19
6453 5701	*Licinus depressus*	62	54.84	23	86.96	8	100.00
6453 5702	*Licinus punctatulus*	38	42.11	11	90.91	6	100.00
6453 5801	*Lionychus quadrillum*	16	25.00	9	88.89	9	100.00
6453 5901	*Loricera pilicornis*	1139	83.58	1024	95.90	641	98.13
6453 6001	*Masoreus wetterhalli*	16	56.25	13	100.00	5	100.00
6453 6101	*Metabletus foveatus*	307	75.57	222	96.40	85	97.65

SPECIES	NAME	10km Number	post %70	1km Number	post %70	100m Number	post %70
6453 6102	*Metabletus obscuroguttatus*	122	61.48	28	96.43	11	100.00
6453 6103	*Metabletus truncatellus*	81	62.96	30	93.33	3	100.00
6453 6201	*Microlestes maurus*	166	63.25	73	93.15	25	96.00
6453 6301	*Miscodera arctica*	72	52.78	26	92.31	11	100.00
6453 6401	*Nebria brevicollis*	1285	86.61	1215	95.80	694	97.55
6453 6402	*Nebria complanata*	30	40.00	27	77.78	6	100.00
6453 6403	*Nebria gyllenhali*	391	75.96	214	93.93	100	100.00
6453 6404	*Nebria livida*	16	37.50	7	100.00	3	100.00
6453 6405	*Nebria nivalis*	20	85.00	22	90.91	17	94.12
6453 6406	*Nebria salina*	513	79.53	314	94.90	153	98.69
6453 6601	*Notiophilus aesthuans*	38	76.32	9	88.89	4	100.00
6453 6602	*Notiophilus aquaticus*	435	74.48	257	93.39	103	98.06
6453 6603	*Notiophilus biguttatus*	1179	83.63	989	94.94	466	97.64
6453 6604	*Notiophilus germinyi*	289	79.93	171	94.15	74	98.65
6453 6605	*Notiophilus palustris*	398	68.59	183	91.26	74	95.95
6453 6606	*Notiophilus quadripunctatus*	51	47.06	15	100.00	2	100.00
6453 6607	*Notiophilus rufipes*	168	65.48	79	87.34	28	100.00
6453 6608	*Notiophilus substriatus*	367	65.12	163	95.09	80	97.50
6453 6701	*Odacantha melanura*	43	65.12	32	96.88	20	100.00
6453 6801	*Olisthopus rotundatus*	384	69.01	215	93.02	92	100.00
6453 6901	*Omophron limbatum*	3	100.00	5	100.00	2	100.00
6453 7001	*Oodes helopioides*	73	45.21	32	96.88	28	100.00
6453 7301	*Panagaeus bipustulatus*	89	56.18	32	90.63	8	100.00
6453 7302	*Panagaeus cruxmajor*	17	11.76	3	100.00	2	100.00
6453 7401	*Patrobus assimilis*	212	78.30	115	93.04	55	100.00
6453 7402	*Patrobus atrorufus*	382	72.77	226	94.25	97	98.97
6453 7403	*Patrobus septentrionis*	40	67.50	15	66.67	7	100.00
6453 7501	*Pelophila borealis*	34	73.53	12	91.67	3	100.00
6453 7701	*Perigona nigriceps*	8	50.00	3	100.00	2	100.00
6453 7801	*Perileptus areolatus*	20	30.00	6	100.00	5	100.00
6453 8001	*Platyderus ruficollis*	119	70.59	59	96.61	25	100.00
6453 8101	*Pogonus chalceus*	146	69.18	100	91.00	39	97.44
6453 8102	*Pogonus littoralis*	33	57.58	14	92.86	2	100.00
6453 8103	*Pogonus luridipennis*	14	42.86	6	50.00		
6453 8201	*Polistichus connexus*	20	40.00	2	100.00		
6453 8301	*Pterostichus adstrictus*	175	77.14	100	96.00	43	97.67
6453 8302	*Pterostichus aethiops*	72	61.11	32	93.75	16	100.00
6453 8303	*Pterostichus angustatus*	61	62.30	23	91.30	12	100.00
6453 8304	*Pterostichus anthracinus*	94	56.38	31	87.10	12	100.00
6453 8305	*Pterostichus aterrimus*	7	42.86	1	100.00		
6453 8306	*Pterostichus cristatus*	55	83.64	61	96.72	18	100.00
6453 8307	*Pterostichus cupreus*	362	59.39	195	93.85	115	95.65
6453 8308	*Pterostichus diligens*	669	79.67	559	96.24	454	99.34
6453 8309	*Pterostichus gracilis*	49	53.06	21	85.71	8	100.00
6453 8310	*Pterostichus kugelanni*	20	10.00	6	33.33	2	100.00
6453 8311	*Pterostichus lepidus*	41	34.15	12	100.00	6	100.00
6453 8312	*Pterostichus longicollis*	66	37.88	10	80.00	3	66.67
6453 8313	*Pterostichus macer*	131	51.15	48	89.58	21	95.24
6453 8314	*Pterostichus madidus*	1273	87.90	1421	95.92	747	98.13
6453 8315	*Pterostichus melanarius*	885	81.69	612	93.95	333	98.50
6453 8316	*Pterostichus minor*	381	79.53	297	96.30	257	99.22
6453 8317	*Pterostichus niger*	896	82.48	700	93.71	380	98.42
6453 8318	*Pterostichus nigrita sens.lat.*	1036	82.53	864	96.41	570	98.95
6453 8319	*Pterostichus oblongopunctatus*	151	72.85	92	83.70	47	97.87

SPECIES	NAME	10km Number	post %70	1km Number	post %70	100m Number	post %70
6453 8320	*Pterostichus strenuus*	1044	84.29	772	95.34	390	96.67
6453 8321	*Pterostichus vernalis*	466	72.53	245	95.10	131	98.47
6453 8322	*Pterostichus versicolor*	318	65.72	176	94.32	91	98.90
6453 8323	*Pterostichus rhaeticus*	50	100.00	52	100.00	25	100.00
6453 8324	*Pterostichus nigrita sens.str.*	33	96.97	35	97.14	29	96.55
6453 8601	*Scybalicus oblongiusculus*	5	0.00				
6453 8701	*Sphodrus leucophthalmus*	17	17.65	2	50.00	1	100.00
6453 8801	*Stenolophus mixtus*	222	70.27	133	95.49	44	97.73
6453 8802	*Stenolophus skrimshiranus*	34	52.94	18	100.00	8	100.00
6453 8803	*Stenolophus teutonus*	32	46.88	11	90.91	3	100.00
6453 8901	*Stomis pumicatus*	366	64.75	164	93.29	66	98.48
6453 9001	*Synuchus nivalis*	235	65.96	123	92.68	63	100.00
6453 9101	*Tachys bistriatus*	36	50.00	16	81.25	6	100.00
6453 9102	*Tachys edmondsi*	1	0.00				
6453 9103	*Tachys micros*	6	50.00	7	100.00		
6453 9104	*Tachys parvulus*	15	73.33	12	91.67	5	100.00
6453 9105	*Tachys scutellaris*	16	50.00	6	83.33	1	100.00
6453 9106	*Tachys walkerianus*	3	66.67	2	50.00	1	100.00
6453 9201	*Thalassophilus longicornis*	10	60.00	4	100.00	4	100.00
6453 9301	*Trechus discus*	54	64.81	29	100.00	14	100.00
6453 9302	*Trechus fulvus*	53	37.74	18	88.89	6	100.00
6453 9303	*Trechus micros*	119	58.82	58	94.83	23	100.00
6453 9304	*Trechus obtusus*	702	83.19	437	95.88	176	98.86
6453 9305	*Trechus quadristriatus*	670	80.75	531	94.92	275	98.18
6453 9306	*Trechus rivularis*	10	90.00	10	90.00	7	100.00
6453 9307	*Trechus rubens*	78	53.85	23	95.65	7	100.00
6453 9308	*Trechus secalis*	137	59.12	67	89.55	30	100.00
6453 9309	*Trechus subnotatus*	7	57.14	4	100.00	2	100.00
6453 9401	*Trichocellus cognatus*	135	70.37	76	92.11	25	100.00
6453 9402	*Trichocellus placidus*	273	75.82	120	91.67	29	100.00
6453 9501	*Zabrus tenebrioides*	25	28.00	6	83.33	4	100.00

Table 11 Summary of data available on species distribution

Taxonomic group	**No. of Records**		**Proportion of records**			
			With locality names	**10km**	**1km**	**100M**
Woodlice	27054		100%	6%	29%	65%
Myriapoda	34330		96%	13%	29%	57%
Mollusca	114014	10km mapping data only	0%	100%	0%	0%
Opiliones	11834		98%	26%	24%	50%
Coleoptera: Cantheroidea	1135	10km mapping data only	0%	100%	0%	0%
Coleoptera: Staph	8644	10km mapping data only	0%	100%	0%	0%
Coleoptera: Carabidae	130793		94%	57%	22%	20%
Diptera: Dixidea	1463		99%	23%	21%	56%
Diptera: Brachycera	20980		99%	42%	28%	30%
Diptera: Sepsidae	6083		100%	52%	33%	14%
Amphipoda	582		96%	20%	12%	67%

4.0 ECOLOGICAL DETERMINANTS OF SOIL FAUNA DISTRIBUTION IN BRITAIN

Helaine Black, ITE, Merlewood

As shown in the previous section, current recording data can only provide very limited information about the distribution of soil faunal groups or species in Britain. Spatial and/or temporal associations and occurrence of soil faunal groups and species can only be interpreted to a limited degree amongst habitats. The data, in its present form, cannot be used to interpret a species' or group's habitat preferences and, therefore, will not address the question of what may limit its occurrence.

Distribution is a population's response to a wide range of biotic and abiotic factors, or *ecological determinants*. Some of these factors are shown in Table 12. To determine when and why soil faunal groups, species assemblages or individual species occur in particular environments or habitats, the relative importance of these various factors must be understood. Indeed, it is has been suggested that it is "futile to tackle classing of species when the complete (or main) range of ecological determinants have not been established" (David, 1990). Particular emphasis is needed on understanding species population dynamics which will alter species occurrence and subsequently, species richness in habitats over time and space.

Table 12. Biotic and abiotic factors which are the main ecological determinants of soil faunal distribution. (Abbreviations are used in subsequent) tables 13, 14 and 15.

SOIL FACTORS	abbrv.	NON-SOIL FACTORS	abbrv.	POPULATION FACTORS	abbrv.
Soil Type	TYP	Insolation (Daylight Hrs)	INSL	Diurnal Activity	DUR
Bulk Density	BD	Air Temperature	ART	Seasonal Activity	SEA
Soil Physical Properties	PHS	Aspect	ASP	Temporal Activity (> Sea)	YRS
Soil Chemical Properties	CHM	Rainfall	PPT	Depth in Soil	DPH
Soil pH	pH	Altitude	ALT	Population Aggregations	AGG
Soil or Litter Temperature	TMP	Climate Change	CC	Life-History Traits	TRT
Soil or Litter Moisture Content	MOIST	Land Use & Cultivation	LND USE	Predation	PRD.
Soil Organic matter	OM	Disturbance	DIST	Migration or Introduction	MG/IN
Litter quality/quantity	OM	Habitat (inc. vegetation)	HBT	Succession	
Soil Texture		Latitude &/Or Longitude	LL		
Soil Depth		Cultivation			

The identification of the range of ecological determinants and their level of importance in defining species distribution are essential first stages in -

a. establishing adequate sampling protocols to assess soil fauna diversity
b. defining typical soil faunal group or species assemblages for habitats.
c. predicting distribution/diversity at regional, habitat and local scales.

To determine current published data quality and quantity on the ecological determinants of soil fauna distribution in Britain, a literature review was carried out using SOILCD, BIOSIS, BIDS and NERC OPAC as the principal sources. Further references were also obtained from other literature sources.

Two main searches were carried out; one for literature directly relating to soil fauna distribution in Britain and the other for soil fauna distribution in European, Scandinavian and former USSR countries, where similar habitats to those in Britain exist. The searches were restricted to detailed field investigations where significant or clear relationships between ecological determinants and soil faunal distribution have been identified. Many texts refer to biotic and abiotic factors as potential ecological determinants but do not provide the evidence to support these claims.

Search combinations of the main sources produced just over 150 references relevant to British soil faunal groups or species. Searches for the wider region have produced over 1000 references. Complete assessment of these other data is beyond the capabilities of this study. Tables 13, 14 and 15 summarise literature records for biotic and abiotic factors identified as ecological determinants for soil fauna groups in Britain. The importance of these ecological determinants is discussed in greater detail for each group in turn.

The list of determinants given in Tables 13, 14 and 15 is not comprehensive as i. broad terms are used (encompassing several factors, i.e. soil chemical factors) and, ii. only determinants found in the literature searched are listed (some may have been missed while the importance of others may have not yet been recognised).

In the last 10 years, there has been increasing interest in the assessment of organism distribution from the relative importance of several ecological determinants. This approach has mainly been supported by the development of multivariate statistical analyses tools (e.g. computer-based ordination techniques and correspondence analysis) . As will be highlighted from the results, there have been few such studies on soil fauna in general and very few in Britain. However, the few examples that do exist suggest that future developments in determining species distributions will be made using such powerful techniques.

4.1. Soil factors

The literature review indicates that there are distinct soil type preferences for some soil faunal groups, (see Table 16 for summary). Species preferences do not necessarily correspond to "typical" soil types shown for soil fauna groups, as outlined later. There are also few studies which refer to nationally recognised soil types i.e. Soil Survey classification for British soil types. Most soil type records as presented in Table 16 are based on a broad classification using soil organic matter content (i.e. mull or mor) rather than a soil type. Soil faunal habitat preferences, occurrence or distribution, with the possible exception of earthworms and acarina, have not been examined with respect to other characteristic properties of soil types. It is also clear that there are remarkably few studies linking soil faunal distribution with regional distribution of soil types. Future identification of recognised soil types would significantly improve the capability of defining within-habitat or, at the broader scale, regional habitat differences. Specific soil properties have been identified as ecological determinants at the local (within-habitat) level. Given that these can often be a reflection of soil type, it is likely that soil type is a more important regional determinant than the literature currently suggests.

Soil texture and bulk density has been grouped together for this review. Both influence soil moisture characteristics and the ability of soil fauna to move and/or burrow in the soil; and to use the soil for construction (e.g. ants). There are several records of these influencing within-habitat distribution of burrowing species (e.g. ants, earthworms, nematodes) and ground-dwellers (e.g. soil texture is related to suitability of egg-laying sites for Orthoptera).

Table 13
Literature records of soil factors as ecological determinants of soil faunal distribution in Britain.
R = regional or habitat level; L = within habitat. Refer to Table 12 for determinants key

ECOLOGICAL	DETERMINANTS	SOIL FACTORS															
		TYP		BD		PHS		pH		CHM		TMP		MST		OM	
GROUP	COMMON NAME	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
Acarina	mites	6	31						2						2	3	6
Araneae	spiders														1	2	
Chilopoda	centipedes	9	1														
Coleoptera	ground beetles		4	1	14		2		5		5		5	1	28	3	14
Collembola	springtails		9					2						1	11	2	
Dermaptera	earwigs														1		
Diplopoda	millipedes	23													1		1
Diplura	two pronged bristletails														1		1
Diptera	flies		1											1	1	2	1
Embioptera	web spinners														1		
Enchytraeidae	potworms	2							6						1	3	2
Formicidae	ants	3	5		1	10	15		3			3	5	2	10	4	2
Gastropoda	slugs + snails	1			1		2			1					18		
Hemiptera	true bugs		1														
Hirudinae	leeches														3	1	
Isopoda	woodlice	1											2		9		
Lepidoptera	butterflies/moths												1		1	2	
Lumbricidae	earthworms	10	38	4	5			22	37		1		1		6	3	4
Mecoptera	scorpion + snow flies														1		
Microcoryphia	jumping bristletails														1		
Nematoda	nematodes	2	3					2	1					2	1	1	
Neuroptera	lacewings antlions														1		
Opiliones	harvest spiders														1		1
Orthoptera	hoppers/crickets		2				2						2		1	2	1
Pauropoda			1												1		1
Protura															1		1
Pseudoscorpionida	false scorpions														1		
Psocoptera	psocids/booklice														1		1
Raphidiidae	snakeflies														1		
Symphyla			1		1										1		1
Tardigrada	water-bears									14	14				14	3	
Thysanoptera	thrips														1		
Thysanura	bristletails silverfish														2		
Turbellaria	planarians/flatworms														2		2

Table 14
Literature records of non-soil factors as ecological determinants of soil fauna distribution in Britain. R = regional or habitat level; L = within habitat. Refer to Table 12 for determinants key

ECOLOGICAL DETERMINANTS		NON-SOIL factors																			
		INSL		ART		ASP		PPT		ALT		CC		LND		DIST		HBT		LL	
GROUP	COMMON NAME	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
Acarina	mites				2				2						1		10	43	29		
Araneae	spiders		2		2		2		2						2		2	1	1		
Chilopoda	centipedes				1				2						2		3	8	5		
Coleoptera	ground beetles		2		2						8				9		5	4	27		
Collembola	springtails								2		1		1		3			21	7		
Dermaptera	earwigs																		1		
Diplopoda	millipedes				4										1			27	12		
Diplura	two pronged bristletails																		1		
Diptera	flies					1									3		2	1	1	1	
Embioptera	web spinners																		1		
Enchytraeidae	potworms			1	5				3			1	1		1			4	4		
Formicidae	ants	4	6		3		2		3		9				5		3	10	25	8	
Gastropoda	slugs + snails		1		1	2					3				3		3	24	15	7	
Hemiptera	true bugs								2						1				1		
Hirudinae	leeches																		1		
Isopoda	woodlice				1										1		8	15	21	25	
Lepidoptera	butterflies/moths				2				2						2				3		
Lumbricidae	earthworms		2		1				2						4			23	14	1	
Mecoptera	scorpion + snow flies																		1		
Microcoryphia	jumping bristletails	1																	1		
Nematoda	nematodes								3	3	1	1			4		3		2		
Neuroptera	lacewings antlions				1														1		
Opiliones	harvest spiders																		1		
Orthoptera	hoppers/crickets				2		2		2						2		2		5		
Pauropoda																			1		
Protura																			1		
Pseudoscorionida	false scorpions				1														1		
Psocoptera	psocids/booklice														2		1		1		
Raphidiidae	snakeflies																		1		
Symphyla															1				1		
Tardigrada	water-bears								1	6	3							5	17		
Thysanoptera	thrips																		1		
Thysanura	bristletails silverfish																		1		
Turbellaria	planarians/flatworms			3				2							3			1	1		

Table 15
Literature records of population factors as ecological determinants of soil fauna distribution in Britain. R = regional or habitat level; L = within habitat. Refer to Table 12 for determinants key.

In Table 13, "soil physical properties" includes un-specified properties but are most likely be soil

ECOLOGICAL DETERMINANTS		POPULATION FACTORS																			
		DUR		SEA		YRS		DPH		AGG		PRD		MG/IN		TRT		SCC	
GROUP	COMMON NAME	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
Acarina	mites			1	37		4	13	35								18		33
Araneae	spiders													31					
Chilopoda	centipedes				1														
Coleoptera	ground beetles		5		6		5		3						5		6		10
Collembola	springtails				6			3	9		5								3
Dermaptera	earwigs				1														
Diplopoda	millipedes				3		1		4		1				1				
Diplura	two pronged bristletails						1										1		
Diptera	flies				6	1	3		3										
Embioptera	web spinners								1										
Enchytraeidae	potworms			4	5			1	2		6								
Formicidae	ants						1		1		5		5		2				2
Gastropoda	slugs + snails		6				1		3						2				
Hemiptera	true bugs				1												1		
Hirudinae	leeches																		
Isopoda	woodlice		2		3		3		3										
Lepidoptera	butterflies/moths				3				2								3		
Lumbricidae	earthworms		1		15		6	1	43		2	1	1			2	19		
Mecoptera	scorpion + snow flies				1														
Microcoryphia	jumping bristletails								1										
Nematoda	nematodes				2				1		2						1		
Neuroptera	lacewings antlions				1														
Opiliones	harvest spiders								1										
Orthoptera	hoppers/crickets		1		2				1									1	
Pauropoda									1		1								
Protura									1										
Pseudoscorionida	false scorpions				1				1										
Psocoptera	psocids/booklice								1										
Raphidiidae	snakeflies				1														
Symphyla					1				1										
Tardigrada	water-bears				2		1				1								
Thysanoptera	thrips																	1	
Thysanura	bristletails silverfish				1				1										
Turbellaria	planarians/flatworms								1		1			1			1		

faunal responses to soil texture, bulk density or particle size. There are few studies and none that show clear trends. The chemical properties listed in Table 13 include both a range of identified properties, (e.g. cations) and determinants which have not been defined. Chemical properties may link to a species mineral requirements for growth (e.g. millipedes and the requirement for calcium). Most records relate to cation content of soil e.g. base-rich or poor which is closely related to soil type and geology although neither are specified in the literature.

Soil fauna groups appear to have soil pH preferences within-habitats and across. Within these groups there are, again, species preferences which cross these categories. These are discussed later in greater detail for each soil fauna group. Soil temperature and soil moisture, both closely related to seasonal weather conditions, vegetation structure and soil type, influence local distribution in the soil (especially depth and spatial aggregation), seasonal distribution and life-history tactics (e.g. anhydrobiosis in tardigrades and aestivation/diapause in earthworms). There are indications that some species or groups may have optimum and maximum temperature and/or soil moisture ranges at the local scale to regional levels, though it is not clear how this relates to habitat species richness or occurrence.

Soil organic matter content (as percentage (%) SOM) has rarely been investigated as a determinant at the regional level in Britain, although it does link to soil type, as mentioned above. Multi-dimensional studies of other European soil faunal groups have shown percent SOM to be important in regional distribution, (see) below. Both soil organic matter and litter (quality & quantity) are important at the local level and often highlight within habitat variation due to soil properties and vegetation structure as well as food preferences of different soil faunal groups.

Table 16 Sequence of humus types and preferences of some soil faunal groups (adapted from Wallwork, 1970).

crumb formation (organo-mineral complexes) increasing --->			
pH acid	------------------------>	------------------------>	pH near neutral or slightly alkali
MOR	MODER	MULL-LIKE MODER	MODER
nematodes enchytraeidae mites collembola insect larvae myriapods isopods	mites collembola insect larvae myriapods nematodes enchytraeidae earthworms isopods	myriapods isopods earthworms nematodes insect larvae mites collembola enchytraeidae	earthworms insect larvae myriapods nematodes mites collembola

4.2 Non-soil factors

Data for non-soil factors are summarised in Table 14. Insolation appears to be particularly important for ground-active species which, locally, links to vegetation structure, desiccation and disturbance. Many ground-dwelling species are only active during the day (or night) while seasonal activity can be linked to daylight hours. At a regional level, insolation may be more important than indicated by the literature as differences in insolation with latitude may partly explain the distribution of some soil faunal groups and species, for example, ants.

Air temperature is similar in influence to soil temperature though a more indirect determinant for permanent soil-dwelling species. For many soil faunal species, there are optimal seasonal and diurnal air temperatures for local to regional occurrence which are complex interactions between latitude, season and vegetation structure (whether natural or anthropogenic).

There is surprisingly little information on rainfall as a determinant. This is likely to relate to the real lack of data than a real lack of response. Drought (i.e. a lack of rainfall) has a major impact on soil fauna distribution. During drought, there is a loss in species in the upper soil layers, some moving down to escape desiccation, others going into diapause or aestivation or simply dying-off. Research has focused on more local scale determinants e.g. soil moisture content or more obvious regional characteristics e.g. latitude, habitat type, soil type than rainfall patterns. Available data does suggest that there are lag-phase delay effects of rainfall on some soil fauna, from hours (movement in the soil) to years (reproductive rates).

Altitude is, as with many other determinants, an interaction of various local, habitat and regional scale factors, e.g. temperature, soil moisture, organic matter, habitat or vegetation structure. The relative importance of these factors with altitude differs with group and species. Distinct local distributions and/or species assemblages (e.g. mites in Yorkshire moors) have been recorded and at the regional level, habitat differences in species occurrence can be linked to altitude (e.g. ants). Aspect (e.g. southern aspect) is locally significant, as shown by ant species, and is probably a more important determinant than shown by British literature as it affects many local factors (soil moisture, insolation, vegetation growth, etc).

Climate change is included as a determinant given current environmental implications. A few experimental studies have shown changes in species behaviour and depth distribution as a result of temperature and rainfall changes mimicking climate change. Impacts on habitat and regional distribution are likely to correspond to successional determinants are already identified. However, current species distributions need to be defined before the impacts of long-term climate change can be determined.

Land-use has only been briefly examined as there are numerous texts, especially for agricultural practices, which deal with this issue. There are few studies which identify the impact of land use (and land use change) on species richness and records here mainly cover upland grazing systems of different ages. Land use type and history are important in determining species composition and abundance, however, it is not clear how clearing different habitats effects species richness.

Disturbance such as heathland burning and anthropogenic disturbance (synanthropic habitats) are factors often closely linked to succession. Some species appear to have preferences for disturbed sites (e.g. some woodlice species) while there are distinct carabid species assemblages in relation to vegetation succession after burning.

Habitat preference, in this context, mainly covers vegetation type and structure and niche preferences (see below). The former are extremely important in determining soil fauna group and species distribution. However, it is not clear how effective these preferences are in defining distribution of soil faunal groups or species across regions where there are similar habitats. One reason for this is that groups/species may bridge more than one habitat, as discussed earlier. Another reason, is the clear problem in comparing habitat data due to poor or different habitat descriptions or definitions. Some, but few, descriptions, are sufficiently detailed to link to regional and local levels (especially for mite and ant species). Others have very vague definitions, for example, deciduous woodland - but where, at what altitude or soil type?

Habitat is a simple term for a complex structure and to define it accurately, all components need to be identified. There is currently significant work being done on a working classification of British habitats (Hill et al, 1996). Wide-scale application of such a classification system will greatly assist in determining distribution patterns. Figure 3 indicates the range in population size for five soil faunal groups in four broad temperate region habitats. More detailed classification of habitats may reduce this variation to a level where population distributions can be interpreted i.e. how a populations' size relates to species richness in specific habitats. Further research is required, as mentioned above, to link land-use change with natural habitat as land-use impacts are likely to differ with habitat e.g. improved pasture established from upland moorlands and lowland grasslands are likely to differ in soil fauna species composition.

Within-habitat (local) determinants is a broad category, akin to the "niche", which includes micro-site preferences for nesting, feeding, reproduction etc., for example, bark or litter sites, under stones, plant associations, vegetation structure, etc. These are important at the local level and could be related to micro-climatic or other such variables if sufficient data was available. These determinants are often species-specific, as discussed in greater detail for individual soil groups below.

Most latitude/longitude records are for latitudinal determinants, though there are a few instances of East/ West distributions. As with altitude, these may be responses to more local environmental variables such as insolation, mean annual temperatures as well as immigration or introduction of species.

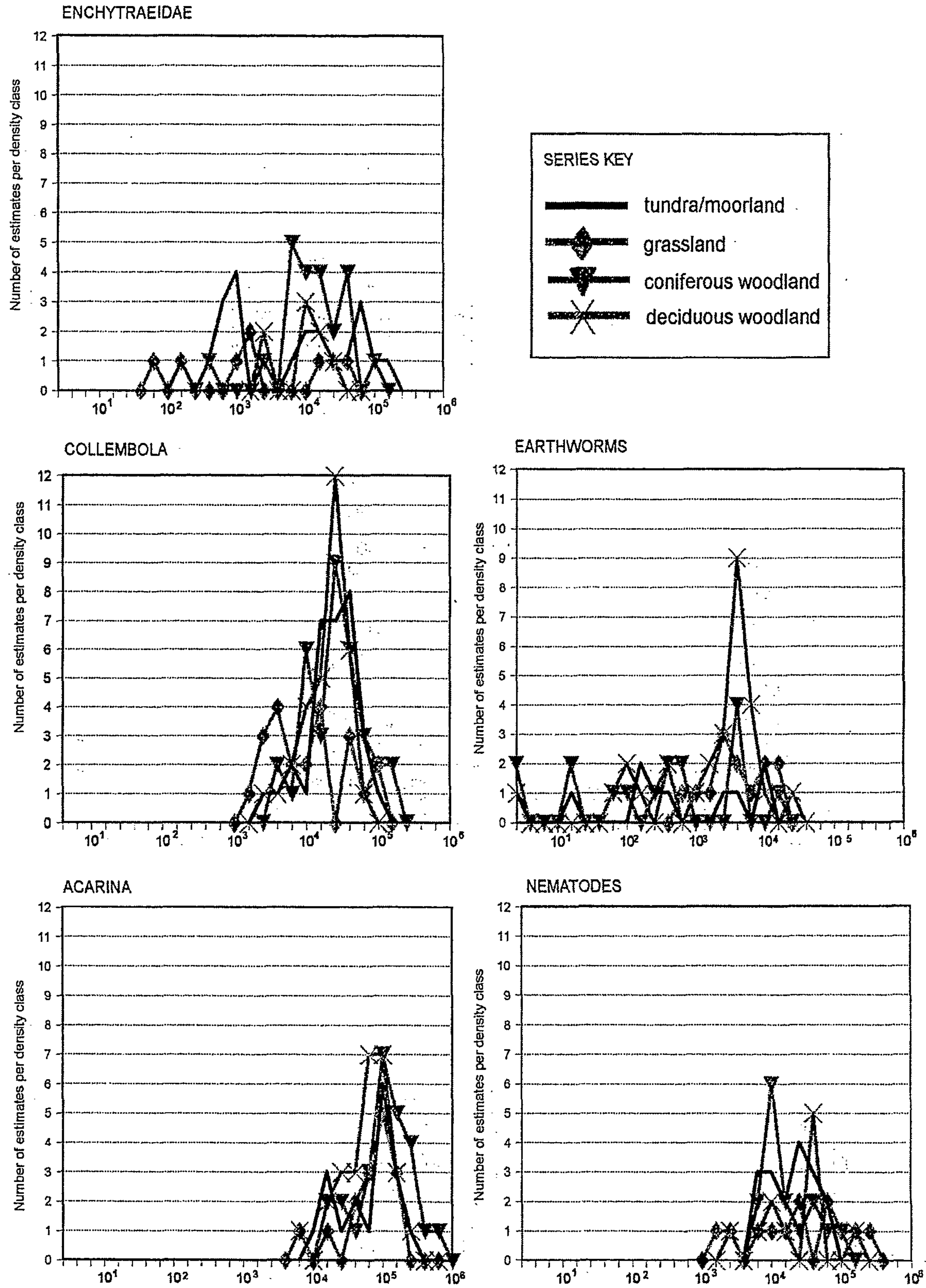
A factor that has not been highlighted by this literature review is "area". Although there is insufficient data on the importance of this determinant in soil fauna distribution, data for ants in Europe suggest that the area of a region, habitat or micro-habitat may influence species distribution.

Food quality and quantity are also basic ecological determinants for all organisms. For soil fauna, it is often closely related to soil organic matter content and/or litter quality. The heterogeneous distribution of food sources in the environment often accounts for the high degree of aggregation shown by some species. The literature is insufficient and provides only a few examples of food as a determinant of soil fauna distribution in Britain (notably for earthworms and nematodes).

Why are plant species not suitable for monitoring

Attention should be drawn to the lack of information on the potential effects of pollutants on plant communities. Little attention has been given to the effects of pollutants on plant communities in comparison to the effects shown by individual species. Hence little use has been made of the possibilities of using plant communities as biomonitors of pollution. The value of plants as monitors of pollutant levels would be dependent upon a detailed understanding and precise measurement of influential soil and plant variables. At best plants can only act as semi-quantitative monitors because of the complexity of relationships between soil and root uptake, accumulation and retention. it is extremely difficult to draw the line between

Figure 3. Frequency distributions of mean density estimates for five soil fauna groups in four temperate region habitats. Data from 62 studies in Europe, Scandinavia and USSR (adapted from Peterson & Luxton, 1982).



density class limits (logarithmically increasing class widths) advocating plants as monitors of soil contamination by for example heavy metals and accepting the gross lack of detailed knowledge that is available on the relationships between metal concentrations of vegetation and soil factors in field conditions.

4.3 Population factors

Changes in species distributions due to population dynamics must be considered to ensure that sampling strategies are adequate, (see Table 15). However, it must be stressed that current data most often refer solely to species abundance (population density) and rarely include species richness.

Peak diurnal activity (daily periods of peak activity) is often shown by litter-dwelling populations increasing overall numbers of animals in the upper soil layers or activity on the soil surface in relation to weather conditions, moisture (soil and air) as well as soil type and habitat. Some species are nocturnal (some woodlice) while others are active in early morning or evening (e.g. ant species). Seasonality, within year seasonal changes in populations, is an important determinant, especially for soil fauna that carry out a form of "hibernation" (e.g. aestivation or diapause in earthworms and cryptobiosis in tardigrades). There are also clear population fluctuations in most soil fauna, with alterations in age structure, in relation to season. Figure 3 indicates the level of population variations in common soil faunal groups for temperate region habitats. These seasonal patterns are more a response to weather conditions, soil type, habitat than predictable monthly cycles. Temporal population fluctuations over more than a year are well recognised for many species although it is not clear how this effects overall species richness. All studies have been of too short a time span to determine if there are predictable trends.

Depth in the soil is a critical ecological determinant of distribution. The majority of soil fauna, except certain earthworm species, are predominantly found in the top 10 cm of the soil. In the British Isles, depth distributions of soil fauna are greatest in dry natural grassland sites while in moorland habitats there is very strong concentration of soil fauna in the top few centimetres of soil. Distribution and species richness of soil fauna groups in forests are often related to the depth of the organic top soil. However, species depth distributions are responses to complex interactions. In particular, seasonal weather conditions strongly influence soil distribution and therefore occurrence in sampling. Soil depth distribution may also relate to soil temperature gradient thresholds (Bocock and Heath, 1967). The ability to predict depth distribution patterns of species has not been perfected. Longer-term population studies will be needed to link seasonal population fluctuations with environmental factors.

Population aggregation is well recorded in nematodes and woodlice but it is also significant in almost all soil fauna, as a result of local scale preferences in soil moisture gradients, plant associations, population cycles, etc. It introduces serious sampling problems, as discussed below. If sufficient samples can be taken, useful information on local distribution can be obtained avoiding or allowing for any inherent bias.

Predation as a determinant is unknown for most soil fauna. However, there is one significant exception which is becoming increasingly important - the predation on earthworms by the planarian worms from Australia and New Zealand. This worms future importance in determining the distribution of earthworms has been suggested by studying known habitat preferences. Migration or introduction, can both be important at a regional level and are likely to be important at the local and habitat level when introduced species expand their range. Local level migration may also be responsible for distribution especially after severe environmental stress e.g. drought or disturbance.

Detailed knowledge of species life history traits is sparse. Knowledge of life cycles of transient, temporary and periodic soil fauna is required to assess species richness. For example, seasonal distribution is closely linked to life-cycle, population age structure and size, aestivation, presence of larvae etc. Life-form (functional group) has been used to define species assemblages at a local level (for example, in mites on moorland soils) but the usefulness at habitat or regional level in unknown.

There are few data on soil faunal succession (mainly due to the short-term nature of many ecological studies; typically <3 years). A few studies in both natural and anthropogenic regenerating sites indicate species assemblages can be associated with different stages of vegetation or soil succession. This in turn is linked to a species ability to migrate, as well as area of disturbance. There is evidence of adventitious and pioneering groups or species likely to recolonize perturbed areas.

4.4 Soil fauna groups in Britain

Brief summaries of the literature are given for soil fauna groups to extend the information in Tables 13, 14 and 15 and to examine species information, where possible. Some groups, notably earthworms, are dealt with in greater detail due to the quantity and quality of literature available.

EARTHWORMS

There are approximately 30 species of earthworms in Britain of which 10 are common. Ecological research has focused on these 10 species. Relatively little is known about the ecology of the remaining species. Although there is a wealth of data on earthworm populations, total earthworm species richness for a range of habitats, fluctuations or changes in these numbers at any given time in the year can not be defined from the literature. Population characteristics (e.g. abundance and species richness) of earthworms have been recorded by various researchers (most pre 1970) but many studies have concentrated on specific functional groups, often related to sampling methods. Earthworm functional groups have been defined in terms of soil use and location (Bouché, 1977).

Dispersal of earthworms may be important in regional and habitat distribution, especially where it concerns introduced species. Predation is a key determinant at local habitat and regional levels given the recent introduction and spread of the New Zealand flatworm, *Artioposthia triangulata*. The spread of this worm is predicted to have a catastrophic impact on earthworm abundance and distribution (Boag, pers. comm.).

There are generally fewer earthworms in acid, mor, fallow and moorland soils than in mull soils. Coniferous woodland populations tend to be smaller than deciduous woodlands and grasslands seem to support higher populations than other habitats. Species associations can also be related to soil type (at a broad level) and habitat (see Table 17). *A. calignosa*, *A. longa*, *O. cyaneum* and *L. terrestris* are typical pasture species in Britain. *L. rubellus* and *A. chlorotica* are often associated with these species and others in arable sites. There are rarely more than four species in peaty soils. *Calluna* heath and coniferous mor soils often contain only two species (*D. octedra* and *B. eiseni*) which reside in the litter layer. In woodland mull soils, *A. chlorotica, A. calignosa, A. rosea, A. longa, O. cyaneum* and *L. terrestris, L. castaneus* and *L. rubellus* are commonly found together. Most habitat studies cannot be extended to indicate distribution in various habitats across Britain; habitat classifications are too broad and there has been insufficient comparison of habitat types.

Soil texture can limit distribution. Earthworms are rare in very coarse texture soils or high clay content soils in areas of high rainfall. In a survey of pastures in Scotland, population differences were attributed to soil texture (Guild, 1951), as indicated in Table 18. Light and medium loam soils had the highest populations and species richness. *Allolobophora calignosa* was dominant in all soil types and *A. longa* was less abundant in gravelly and alluvial soils. The highest number of earthworm species found in pasture was 10 and the lowest was 4 species. This highlights the problem shown by most data - there is high variation within habitat/land use type. The determinants of this variation may only be identified by greater "resolution" of habitat and species characteristics e.g. soil pH, texture, season, aestivation period, etc, as outlined below. There seemed to be little relationship between the age of the pasture and species in Guild's study. However, Evans & Guild (1947) showed *Allolobophora chlorotica* is often dominant in arable systems and remains so for many years after arable land is re-seeded for pasture.

Table 17. Earthworm species in four woodland habitats in Oxfordshire (adapted from Phillipson et al., 1976).

earthworm species	mixed woodland on clay	mixed woodland limestone	beechwood on clay	beechwood on limestone
L. castaneus	+	+	+	+
L. rubellus	+	+		
S. mammalis	+	+		+
D. rubida		+		+
E. tetaedra	+			
E. eiseni	+			
L. terrestris	+	+		+
A. longa				+
A. calignosa	+	+	+	+
A. chlorotica	+	+		+
A. rosea	+	+	+	+
A. muldali	+	+	+	+
O. cyaneum	+	+		+

Table 18. Earthworm species richness and abundance in pasture soils in Scotland (From Guild, 1951).

SOIL TYPE	POPULATION (nm^{-2})	SPECIES RICHNESS
shallow acid peaty soil	5	5
natural hill pasture (brown earth ?)	14	5
peaty acid	14	6
gravelly loam	36	9
clay	40	9
alluvium	44	9
medium loam	56	9
light sandy	57	10
light loam	63	8

Several reports indicate that most earthworm species prefer soils with a neutral pH. Satchell (1955) compiled a list of pH related preferences or tolerances (Table19). Most species occur in soils of pH 6.0 and least in pH 5.0 (Piearce, 1972; Edwards and Lofty, 1977). The data rarely indicate a direct relationship between pH and population size, except where in cases of extreme pH and no direct relationship between pH and species richness has been shown in natural habitats. In arable systems, earthworm numbers and weight positively correlated with soil pH (Standen, 1984). Soil pH may also effect diapause; the more acid the soil for basophilic species then the earlier and longer is diapause.

Table 19. Classification of earthworm species according to soil or litter pH (adapted from Satchell, 1955).

pH	ACID TOLERANT			UBIQUITOUS					ACID INTOLERANT				
3.5	1	2	3	4	5		7						
4.0	1	2	3	4	5	6	7						
4.5	1	2	3	4	5	6	7	8					
5.0	1	2		4	5	6	7	8	9	10	11	12	13
5.5				4	5	6	7	8	9	10	11	12	13
6.0				4	5	6	7	8	9	10	11	12	13
6.5				4	5	6	7	8	9	10	11	12	13
7.0				4	5	6	7	8	9	10	11	12	13

1 = E. eiseni
2 = D. octaedra
3 = D. rubida

4 = L. rubellus
5 = L. terrestris
6 = L. castaneus
7 = O. cyaneum
8 = D. rubida

9 = A. caliginosa
10 = A. nocturna
11 = A. chloritica
12 = A. longa
13 = A. rosea

Soil and air temperatures and soil moisture content, which are often inversely related, are important factors influencing population dynamics; low temperature and high soil moisture are less limiting than dry soil and high temperatures. Prevention of water loss is a major factor in earthworm survival. Prolonged drought can reduce populations markedly and it may take several months for them to recover. Most earthworms are more active in moist soils than dry ones and during periods of considerable rain, some may come on to the soil surface. In hot, dry periods, most species are active deeper in the soil e.g. *A. chlorotica*, *A. calignosa* and *A. rosea* usually occur above 10 cm in the soil but when soil temperature goes below 5°C or the soil becomes very dry (no moisture content status recorded) then these species move down (Gerard, 1967). *A. chlorotica*, *A. calignosa, A. rosea, A. nocturna* and *L. terrestris* are generally most active in an English pasture between August and December and April to May with cocoons produced in late spring and early summer (Evans & Guild, 1947). Satchell (1967) concluded that the most suitable conditions for earthworm activity on the soil surface were nights when soil temperature did not exceed 10.5°C, grass and air temperature. were above 2°C and there had been some rain during the previous 4 days. However, temperature ranges are unknown for most species. Maximum diurnal activity is generally from 6 am to 7 pm in Europe, which probably relates to the optimum activity temperatures defined by Satchell (1967). The range of activity time may also vary with habitat/land use as well as species. In pasture, peak diurnal activity was recorded between 6 am to 6 pm (Evans & Guild, 1947).

Species inhabit different zones in the soil which can be attributed to functional group (Table 20) but depth can change considerably throughout the year. For example, Gerard (1967) showed that, in pasture, most earthworms are found below 7.5 cm in January and February. When the soil temperature was above 5°C at 10 cm depth, most individuals of *A. chlorotica, A. calignosa* and *A. rosea.* and smaller individuals of *A. longa, A. nocturna* and *L. terrestris* were above 7.5 cm in the soil. Nearly all cocoons were found between 0 and 15 cm in the soil.

Table 20. Depth categories and associated functional groups for 12 common earthworm species in Britain.

deep burrowers	horizontal burrowers	litter dwellers
anecic	endogeic	epigeic
L. terrestris	*O. cyaneum*	*S. mammalis*
A. nocturna	*A. calignosa*	*L. rubellus*
A. longa	*O. lacteum*	*L. castaneus*
	A. rosea	*D. octaedra*
		D. rubida

Food quality and quantity (e.g. particle size and C:N) is a key determinant of local distribution but it is not known how it effects habitat or regional distribution. Phillipson *et al.* (1976) showed a strong positive association between numbers of *A. calignosa* and eight species of ground flora in beechwood in England. Food availability also aggregates earthworm populations e.g. dung pats, increasing the heterogeneity of population distribution. No direct relationships have been established between food preferences, food availability and species richness.

Other life-history traits are likely to have a limited influence on distribution. Earthworm life span is potentially 4-8 years but more likely measured in months due to predation and parasitism. Life cycles of earthworms are semi-continuous or continuous (Edwards & Bohlen, 1996). However, peak annual population densities occur, mainly from spring and early summer, possibly extending into winter. This may be due to change in depth distribution as well as population turnover. Little is known of seasonal changes in population structure i.e. ratios of adult to immature, which can vary in some species (*c.f.* Gerard, 1960). Annual population size and distribution may be related to the previous year's weather conditions. Cocoons are produced and deposited near the soil surface, depending on soil moisture content and/or soil temperature. In drier and warmer periods, cocoons will be deposited at greater depth. Cocoon numbers depend on species and climate (*c.f.* Evans & Guild, 1948; Satchell, 1967). Cocoons are produced by many species during peak periods in spring or early summer in the northern hemisphere. Air temperature may restrict distribution as below 3°C, egg laying is much reduced (Evans & Guild, 1948).

Seasonal quiescence/hibernation is a key determinant of local distribution and is a direct response to harsh conditions (drought and high temperature especially). It can be facultative, occurring during adverse environmental conditions or obligatory, occurring at certain times each year, independent of current environmental conditions but usually in response to changes or internal mechanism. Facultative earthworms pass the summer or dry months in a dormant state. In temperate regions, such as Britain, this is usually in warm spells (e.g. immatures of *Aporrectodea caliginosa, Allolobophora chlorotica, A. rosea* - when soil is too dry or cold). Temperature and moisture are the most important soil conditions dictating the estivation stage. Obligatory aestivation/diapause is typically May to October for *A. nocturna* and *A. longa.*

Within-habitat aggregation may occur but the ecological determinants of this behaviour have not been determined (Phillipson et al., 1976). Adults may be randomly dispersed but immatures may be aggregated as they have lower powers of dispersal so build up areas of aggregation. Possible factors for spatial variation in horizontal distribution are (1) physio-chemical soil and micro-climatic conditions (especially soil moisture content), (2) food availability, (3) reproductive potential and dispersive powers and (4) historical factors (Guild, 1952; Murchie, 1958; Edwards and Bohlen, 1996). For earthworms in Britain, interactions between determinants have not been extensively studied and there are few multivariate investigations. Much of this is due to the fact that most earthworm studies in Britain were carried out before multivariate techniques were available. A notable exception is Phillipson et al. (1976) who studied earthworm distribution within an Oxfordshire beechwood. The importance of select ecological determinants differed with species and functional group but the variance explained was less than 45%. It was concluded that species distribution could not be totally explained by the limited number of ecological determinants they used (see Table 21). Boag et al. (1994) studied 13 species in Scottish arable and pasture land and found that only one species showed a regional distribution bias; *L. festivus* was restricted to South and West of Scotland. The determinants of this distribution and for other species have not been defined, though some are clear introductions (e.g. *M. phosporeus* and *S. tamesis*).

Table 21. Results from the multiple regression analysis of earthworm numbers and various site characteristics (adapted from Phillipson et al., 1976)

Earthworm species	Functional group	Ecological determinant within habitat in order of significance	Percentage of variance explained (P<0.01 or 0.05)
all earthworms	all	soil depth soil density max. water content litter standing crop	42.4
D. mammalis	epigeic	soil depth drying out litter standing crop	28.7
L. castaneus	epigeic	soil depth soil density	32.1
D. rubida	epigeic	drying out	10.5
L. terrestris	anecic	soil depth	21.8
A. longa	anecic	drying out	12.1
A. calignosa	endogeic	litter standing crop	11.3
A. rosea	endogeic	soil depth soil density	32.5
A. muldali	endogeic	litter standing crop	26.3
O. cyaneum	endogeic	drying out	10.6
A. chlorotica	intermediate	none	

Research in Europe and Scandinavia indicates that multivariate analyses of ecological determinants can clearly define species preferences and assemblages to habitats. In Swedish forest, heath and pasture, earthworm species were related to soil clay content; *A. calignosa, A. longea* and *L. terrestris* distribution all correlated positively with clay at 60 cm depth (Nordstrom & Rundgren, 1974). From a detailed regional and habitat study, Briones et al. (1992) show that the group of species *A. caligNosa, D. mamalis, L. rubellus, E. tetraedra* and *E. rubida* could be separated by preferences for organic matter, soil texture and moisture content.

ENCHYTRAEIDAE

These worms are typically much smaller than earthworms, (10 to 25 mm in length) and very slender. There are approximately 21 genera, of which 8 are common. This group's taxonomy is poorly known and is in much need of revision. Enchytraeids have a wide range in population size within, as well as, among habitats. This is principally due to their highly aggregated distribution within the soil, probably in response to micro-conditions in the soil. This behaviour differs with species (O'Connor, 1967). Sampling needs to account for this aggregation as well as seasonal population cycles.

These worms have a high tolerance to stress although populations are highest in soils with high organic matter content and high soil moisture (typically acid soils of moors and coniferous woodland than deciduous woodland). Habitat preferences in the three genera, Cognettia, Mesenchytraeus and Lumbricillus, are recorded as bog/fen for the first two and marine littoral for the third. Habitat preferences and known ecological determinants for species in woodland are summarised in Table 22. One species, *Cognettia sphagnetorum*, tends to dominate oligotrophic soils. In grasslands, populations size and production of enchytraeids were negatively correlated with soil pH, phosphorus additions and number of grass species (Standen, 1984). Springett (1963) reported that species richness was greater in grassland than woodland. This is the only record of species richness distribution for Enchytraeids in Britain.

Table 22. Habitat preferences and known ecological determinants for select Enchytraeid species (adapted from O'Connor, 1967).

Species	Woodland habitat	Layer in moder soil
Cognettia cognetti	douglas fir	litter
Cognettia glandulosa	oak	litter
Cognettia spagnetorum	beech	litter
Marionina cambrensis	douglas fir, oak, beech	humus
Achaeta eiseni	douglas fir	humus
Achaeta camerani	oak	mineral
Achaeta bohemica	beech	mineral

COLEOPTERA - beetles and weevils

These are often the most abundant ground-dwelling insects. There are 13 super-families containing over 4,000 species in Britain. Over 300 species, in six families, are commonly associated with the soil while 100's of species from the remaining families can be found. Adults are ground-dwelling, but may use the soil for burrows, while larvae are, in many cases, soil-dwelling.

Distribution and occurrence of Coleoptera is highly dependent on life-cycle as well as soil, seasonal weather conditions and adult species distributions. Many beetles have a greater than one year cycle (e.g. carabids) and eggs and larvae can develop in the soil for several years before pupation. Life cycle varies not only with species but also with food supply and in periods of abundant food supply, life cycles for some species may be completed more quickly. Species life-cycles may also be slower with increasing latitude. In Britain, most beetles have a single or double activity peak, one caused by species coming out of hibernation and the other through population growth. There is little data on the distribution of beetle species larvae among or within habitats. Data from upland moorlands show that most larvae are found within the top 5 cm of the soil and there is some vertical migration with soil and weather conditions (Coulson and Whittacker, 1978).

COLEOPTERAN SUPER FAMILIES

Caraboidae	**Scarabaeoidae**
Dascilloidae	**Elateroidae**
Cantharoidae	**Dermestoidae**
Chrysomelidae	**Curculioniodae**
Byrrhoidae	**Cucujoidae**
Staphylinoidae	**Eucinetoidae**
Histeroidae	

Scarabaeoidae (including scarab beetles) have wide food and habitat ranges; from wood, roots to litter and animal carcasses. Life cycles vary with species and range from 1 to several years. Life cycles of the most common soil pest species (whitegrubs) are well documented. Elateroidae, including click beetles (wireworms as larvae), have both ground and soil dwelling adults while larvae are amongst the most serious agricultural soil pests. There are approximately 65 click beetles species. Data from Central Russia (Penev, 1992) highlight how "macro-environmental changes" caused by climate can influence beetle distribution. The presence or absence of wireworm species were investigated in oak forests along an altitudinal gradient. Species abundance and richness were affected by climatic trends and local habitat characterisations. From 26 species, two species occurred in most sites. *Athous haemorrhoidalis,* correlated positively with temperature and negatively with increasing rainfall and humidity i.e. abundance increased with warmer and drier local climates. *A. vittatus* was found in much wetter and colder areas. Five species assemblages were determined from environmental conditions i.e. ordination to soil type and habitat (soddy podzol, sandy-loams, grey forest soils, chernozems, forest-steppe boundary, floodland oak, meadow chernozems). Significant correlations were obtained for longitude, latitude, days of frost, rainfall, humidity, soil conditions and humus. It is possible to use these factors to predict geographical distribution, however, biogeographical zonation patterns are "typological" categories explained by latitudinal climatic gradients. However, local conditions - relief, exposition, soil type and composition - may support communities atypical of a zone.

Staphylinoidae, includes the rove beetles which is one of the largest families of beetles. Adults and larvae are commonly found in the upper soil horizon. There is at least one generation per year but may be several depending on species. Soil staphylinids are generally found in uncompacted, moist forest soils which is high in organic matter. Several species are restricted to saline soils and deep mineral soils are preferred by some species (e.g. Leptotyphilinae). Larvae of most species can be found in the soil and occurrence will relate to individual species life cycles. Caraboidae, including the carabids (ground-dwelling beetles) typically have one generation per year with breeding during spring or autumn. Seasonal migration can occur with movement for overwintering in more sheltered areas. Select studies of ground beetle distribution using multivariate techniques to identify habitat preferences, species assemblages and distribution are presented below to highlight the level of information that is needed and that can be derived from a multi-dimensional approach. Stork (1990) provides further details on the use of ground beetles in environmental studies.

Eyre & Luff (1990) identified 14 ground beetle assemblages associated with British grasslands. Soil moisture content was identified as the main variable effecting distribution. This was investigated further by Foster et al. (1995) using ordination techniques. Within habitat preferences were determined for 41 species of ground beetles in wet grassland in Ayrshire. The main determinants appeared to be the requirement for shade and moisture conditions which recognised 6 within-habitat areas with separate beetle species assemblages. Using DECORANA and fuzzy clustering, habitat preferences of 37 beetle species in an upland moorland grazing system were identified by 5 species assemblages. These correlated with sedges & moss species, soil moisture content, soil dry bulk density and cover of non-woody dicots and grass spp. (McCracken, 1994). In a *Calluna* dominated upland heath in the North York moors, 54 ground beetle species were collected from 62 sites (Gardner, 1991). Thirtysix occurred at five or more sites, 19 were common and 3 were common to all. Ordination indicated that distribution of carabid species was influenced by site wetness and vegetation development (e.g. succession). Twinspan and fuzzy clustering classifications indicate a separation between species from wet sites and *Calluna*-dominated sites. Fuzzy-clustering appeared to be more sensitive to site differences (see Table 23). However, Gardner also stressed that information on the distribution of carabid species would have to be included in the classification of vegetation types before any assessment of the characteristic carabid communities associated with them could be made.

Table 23. Ground beetle species habitat preferences and species assemblages identified from TWINSPAN and fuzzy clustering (adapted from Gardner, 1991).

SPECIES	HABITAT PREFERENCES	SPECIES	HABITAT PREFERENCES
Agonum fulginosum	hyrophilus	*Nebria salina*	sparse/short vegetation
Pterostichus nigrita	hyrophilus	*Calathus micropterus*	well developed vegetation
Cicindela campestris	xerophilic	*Pterostichus niger*	well developed vegetation
Calathus erratus	xerophilic sparse/short vegetation	*Techus obtusus*	well developed vegetation
TWINSPAN ASSEMBLAGES	**HABITAT PREFERENCES**	**FUZZY-CLUSTERING ASSEMBLAGES**	**HABITAT PREFERENCES**
GROUP A *Agonum fulginosum* *Pterostichus diligens* *Pterostichus nigrita*	boggy ground, damp heath *Spagnum* = bog *Spagnum*	**GROUP A** *Agonum fulginosum* *Pterostichus nigrita*	bog with Spagnum, *J. effusus* & *A. canina*
GROUP B	*Calluna* dominated well developed vegetation; damp/ shady ground in early pioneer/ early growth	**GROUP B** *Nebria salina* *Pterostichus diligens* *Dyschirius globosus*	damp *Calluna* heath in early pioneer/early growth
Bembidion unicolor *Calathus micropterus* *Calathus violaceus* *Pterostichus diligens*	damp or shady ground	**GROUP C** *Calathus micropterus* *Techus obtusus*	*Calluna* heath: late mature/ early degenerative phase
Bradycellus ruficollis *Olisthopus rotundatus* *Techus obtusus*	*Calluna*	**GROUP D** *Trichocellus cognatus* *Notiophilu aquaticus*	*Calluna* heath in building/ mature phase
GROUP C *Bembidion nigricorne* *Calathus erratus*	*Calluna* dominated, dry ground & poor vegetation cover recently burnt or in pioneer/ early growth	**GROUP E** *Bradycellus harpalinus* *Calathus erratus*	dry *Calluna* heath recently burnt or in pioneer/ early growth

WOODLICE

There are currently 37 species recognised in the British Isles and there are good keys available for species identification. Woodlice brood numbers and life-span differ with species and are influenced by geographical location. It is widely recognised that temperature thresholds and relative humidity interactions dictate distribution (Hopkin, 1991). However, relatively little is known about habitat preferences or ecological determinants of individual species (see Table 24). Harding & Sutton (1985) give distribution maps and detailed habitat descriptions for all UK terrestrial isopod species.

Depth distribution can be important. Davies et al. (1977) studied the vertical distribution of isopods and a diplopod in a dune grassland at Spurn Head, East Yorkshire (*Porcellio scaber*, *Philoscia muscorum*, *Armadillidium vulgare* and *Cylindroiulus latestriatus*). Maximum soil depths were in winter and summer and minimum depths in spring and autumn in order to sample all species would require sampling to a depth of 6 cm.

Table 24. Distribution and habitat ranges of British woodlice species.

WOODLOUSE species	DISTRIBUTION	HABITAT	description and notes
Trichoniscoides sarsi	?	?	soil dwelling
Armadillidium pictum	rare (NW England & mid Wales)	selective	ancient woodland, screes and upland limestone areas
Armadillidium album	rare (SW Scot to S Eng)	selective	drift line on sandy beaches & salt marshes
Porcellio laevis		rare; s eng	selective ? synanthropic sites
Stenophiliscia zosterae	rare; SE eng	selective	shingle, shingle/mud beaches
Buddelundiella cataractae	restricted ? coastal S Wales, N Norfolk & Cardiff	selective ?	shingle banks and under stones in gardens
Porcellionides cingendus	restricted ? s/w eng & wales; extending range	selective ? ?	grassland, scrub, open woodland. grass tussocks and leaf litter
Trichoniscoides helveticus	restricted; SE england	selective ?	ancient woodlands, soil dwelling
Halophthalmus montivagus	restricted; central S Eng	selective	ancient woodlands, rotting wood under stones
Armadillidium nasatum	restricted; common below Hull/ Aberystwyth	?	sunny & exposed spots (gardens, quarries to grasslands)
Armadillidium vulgare	restricted; common S/E Eng. coastal further north/west. absent from N Eng/Scot ?	wide	
Armadillidium depressum	restricted; common SW Eng/ S Wales	?	coastal cliffs & synanthropic sites (gardens)
Platyarthrus hoffmannseggi	restricted; common Wales & S eng; not in scot	selective	ants nests
Eluma purpurascens	restricted; Kent/Norfolk (SE Eng ?) increasing range ?	selective ?	coastal cliffs & synanthropic sites inland
Ligidium hypnorum	restricted; locally common S/E eng	selective	damp leaf litter in fens and deciduous woods
Halophiloscia couchi	restricted; S & W coasts of Eng/Wales	selective	coastal; shingle/boulder beaches, tidal rivers. night
Trachelipus rathkei	restricted; SE eng + midlands	wide	
Metatrichoniscoides leydigi	unknown	?	under stones
Halophthalmus mengei	unknown, widespread ?	selective	rotting wood, humus, rubbish tips and damp sites
Porcellio dilatatus	widespread - locally common ? under-recorded ?	wide ?	natural & synanthropic sites; inland ?
Ligia oceanica	widespread	selective	coastal only; rocky shores
Androniscus dentiger	widespread	wide	
Oniscus asellus	widespread	wide	
Philoscia muscorum	widespread	wide ?	grasslands hedgerows gardens
Trichoniscus pusillus	widespread	wide ?	damp soil and leaf litter
Trichoniscus pygmaeus	widespread	wide ?	damp soil and leaf litter
Trichoniscoides saeroeensis	widespread ?	selective	coastal, seashore only
Miktoniscus patiencei	widespread ? coastal	selective	coastal salt marshes, cliff bases shingle
Cylisticus convexus	widespread ? locally common	selective ?	disturbed coastal sites e.g. cliff bottoms, synanthropic sites inland
Armadillidium pulchellum	widespread ? Wales, S Scot, N Eng ?	natural ?	grassland, limestone areas, coastal cliffs (Wales)
Trichoniscoides albidus	widespread ?; E/S/central Eng . + Cumbria ?	selective	wet sites, under stones in natural and synanthropic sites
Porcellio scaber	widespread and common	wide	
Metatrichoniscoides celticus	widespread coastal ? wales & w eng	selective ?	strandline debris under stones
Halophthalmus danicus	widespread S of Humber and Mersey	selective	rotting wood, humus, rubbish tips and damp sites
Porcellio spinicornis	widespread; less so on western coasts	selective ?	walls, buildings, limestone, lime rich mortar
Porcellionides pruinosus	widespread; more common E than W	selective ?	dung/decaying bark in pasture synanrthopic sites

ACARINA (Mites)

There are four orders of Acari, each with different functional characteristics. Their taxonomy is difficult and there are no published keys to British species. The oribatid mites (Cyptostigmata) are the most abundant and diverse in soil and, given their dominance, should ideally be treated individually. Most mites are concentrated in the top 3 cm of the soil and exhibit vertical migration in response to seasonal soil conditions. Species appear to differ in tolerance or preference to environmental conditions and research in Finland has shown that oribatid mite species distributions are closely related to soil moisture content, pH and humus content (Strenzke, 1952; Karppinen, 1955). Ecological preferences identified from detailed field studies are summarised briefly below.

Most mite species are dependant on relatively high humidity to survive. Prostigmata and Mesostigmata are usually the most active and are often not restricted to soil; many of these are predatory. Astigmata have been little studied and considered relatively unimportant in the soil. More typical of drier soil, Astigmata may be locally abundant in pasture and arable soils (Wallwork, 1970). Cryptostigmata are most abundant in forest mor soils, especially under oak, beech, Douglas fir, hemlock and pine. Cultivated soils are relatively sparse in Cryptostigmata. Many species are limited in their distribution with few ubiquitous species (e.g. *Oppia nova* and *Tectocepheus velatus*). Sixtyseven species being recorded from seven British woodland soils by Evans et al. (1961). Of these, 26 species were restricted to one or two soils. It would appear that land use is also important in determining species richness with fewer Cryptostigmata species in pasture and arable. It has been suggested by Wallwork (1970) that associations of species can only be identified for restricted habitats with a small number of species.

There are either one or two seasonal peaks of activity depending on habitat; November-December and February-March in mixed (oak and sycamore) woodland, with similar trends in moss and rendzina on limestone, cliff edge soil, grassland. In *Mollinia* fen, mites were most abundant in February and least abundant in August (MacFayden, 1952). Sheals (1957) showed that Cryptostigmata were most abundant in October and February and least so in December.

The rapid seasonal fluctuations are not likely to be as a result of food supply due to the time-gap in breeding cycles. Soil moisture has been identified as a significant factor; in salt-marsh, highest mite abundance equates with lowest soil moisture content (as a combination of rainfall and tidal levels). This was determined in Luxton's (1967) study of the ecology of saltmarsh acarina in South Wales. The following five determinants were examined (1) rainfall and moisture levels; (2) breeding cycles (3) food supply (4) effects of predators (5) temperature and climatic conditions. Of these determinant, one was the most important for the distribution of salt-marsh acarina. Differences in species composition was noted by changes in dominant species in seaward and land-ward plots, seaward plots showed a more closely associated community, perhaps due to a greater clumping of vegetation. Vegetation succession has been demonstrated to effect species distribution. Prostigmata are often the first colonisers, especially in soils of low organic matter content.

Wood (1967a,b&c) studied acari and Collembola in the Yorkshire moors. One hundred and fifty-five acari species and 45 collembolan species were identified. Two species occurred in almost all sites; moss, *Sesleria*, *Festuca-Agrostis* and *Nardus* sites. Lowest species richness for both mites and collembola were shown in moss sites and the highest in *Sesleria*. No differences in population densities were recorded for different habitats. Habitat and season were important for Collembola, Mesostigmata, Prostigmata and Astigmata species richness. No soil or botanical determinants could be identified for the species assemblages. The potential for using species-area curves to see differences in habitats was explored. This paper included extensive species lists with abundance classes for this region. Wood (1967b) also examined vertical distribution of Collembola and mites in these sites. Most populations were found in the top 4 cm though both mites and Collembola were found deeper in mull and gleyed podzol than brown-earth or mor. Depth distributions related to functional group and life-form.

Habitat species assemblages were identified by Wood (1967c) using presence or absence data of Collembola and mite species and soil and vegetation characteristics of 11 sites in Northern England. Lichens and moss sites on limestone boulders have a simple and specialised fauna of low species richness. Greater numbers of dominant species (ca 3) were found in grasslands. Overall, 8 Collembola, 11 Prostigmata, 18 Cryptostigmata, 1 Astigmata, 1 Mesostigmata species were dominant in different habitats. Results again showed that species assemblages could be identified for habitats. However, these cannot be transferred to other regions where the relative importance of ecological determinants may be different.

COLLEMBOLA (Springtails)

There is no key to British species of Collembola and Collembola taxonomy is in dire need of revision (Hopkin, pers. comm.). Long-term ecosystem studies have recorded 13 to 25 species in upland soils at Moor House and 43 (see section 5.0) in mixed deciduous woodland at Meathop Wood) in Cumbria as part of the IGBP in the 1960's-70's. Until species taxonomy is revised, there can be little constructive comparison of habitat data.

Collembola also show seasonal activity peaks, typically two in similar months to mites, and these peaks also differ with habitat (Sheals, 1957). Moore and Luxton (1988) recorded population peaks in late spring, early summer in Lancashire. Low summer populations may occur in periods of drought and high summer temps. Some species showed no seasonal trends (7 out of 14). Wind dispersion and short breeding cycles resulted in rapid increases in populations while populations density may also relate to soil structure. Some species prefer less moist soils (e.g. *Isotoma notabilis*), see Table 25. Successional species distribution may occur with *T. krausbaueri* being the first dominant species which is superseded by *I. notabilis* after time. The rate of succession is dependent upon the acidity of sites - at more acidic sites, there is a longer dominance of *T. krausbaueri*.

Population numbers typically range from 5,000 to 50,000 m^{-2} in coniferous and deciduous woodland and tundra/moorland while grassland populations show a much greater range (*cf.* Peterson & Luxton, 1982). In general, Collembola are more abundant in woodland than grassland. Populations are generally higher in mesic soils than wet or dry soils but wet soils tend to have a much wider range of population estimates. Both positive and negative relationships have been shown between Collembola and soil moisture. This may be due to the controlling factors being more complex than just solely soil moisture content (e.g. pF values). Soils with accumulated organic matter tend to have higher populations than mineral soils while soil pH (linked to organic matter content) itself also influences densities and colonisation. Murphy (1955) studied long-term changes in Collembola in moorland soils in Scotland and found no clear association of species with plant species, unlike Wood's research in Yorkshire (Wood 1967b). There were distinct species associations within moorland sites related to hummocks and hollows, which may be a form of succession.

Table 25. Collembola species and habitat preferences in Britain

Collembola	Habitat	Soil moisture preferences
Isotomurus sp.	heath/moor bog	hydrophilous
Isotoma sp. aff. *plumosus*	heath/moor bog	hydrophilous
Isotoma sensibilis	heath/moor	?
Sminthurides malmgreni	heath/moor bog	hydrophilous
Tetrcanthella wahlgreni	heath/moor Calluna-Cladonia,	xerophil
Friesea mirabilis	heath/moor Sphagnum	mesophil, cavernicolous
Isotoma notabilis	heath/moor	?
Folsomia brevicauda	heath/moor Calluna-Cladonia ?	mesophil, cavernicolous
Hypogastrura scotica	heath/moor Calluna-Cladonia,	xerophil ?
Arrhopalites principalis	heath/moor Calluna-Cladonia ?	xerophil ?
Sminthurides schotti	heath/moor Calluna-Cladonia ?	xerophil ?
Ballistura crassicauda	heath/moor Sphagnum	mesophil, cavernicolous
Tetrcanthella brachyura	heath/moor bog	hydrophilous

Wallwork (1970) stated that Collembola species show different degrees of tolerance to environmental factors and, consequently, species composition may be a good indicator of microhabitat conditions. Studies outside Britain have shown that there is some correspondence between vegetation structure and Collembola species (Christiansen, 1964). Population peaks may also correlate with vertical movement up in the soil while depth distribution itself can differ with species. Most species are found in the top 15 cm of the soil. Typically, larger species are found nearer the soil surface and this has been attributed to soil pore size.

NEMATODA

Nematode taxonomy is unresolved and there are extreme difficulties in identifying species, especially for natural habitats. Nematoda are major pests and disease carriers as well as being important in nutrient cycling in soils with most terrestrial forms being less than 4 mm in length. They are commonly divided into five trophic groups:

1. Phytophages
    - a. Endoparasites
        - migratory
        - sedentary
    - b. Ectoparasites
        - migratory
        - sedentary
2. Microbivores (bacteria & microflora)
3. Fungivores (fungal mycelia)
4. Omnivores (several sources)
5. Predators

Soil particle size (e.g. small clay particles) can limit nematode distribution while organic matter amendments can both increase or decrease nematode species abundance. After soil structure, soil moisture content is the most important ecological determinant, limiting dispersal and life-cycle. Some nematode species enter diapause when soil moisture levels drop below a threshold level. Nematodes are also effected by a range of chemicals, generally transported in soil water, especially root exudates but species appear to be tolerant of a wide range of pH. Temperature effects life processes and species exhibit a wide range of tolerances. Diapause (cyptobiosis) occurs with low O_2 concentrations, dehydration, high salt concentrations and freezing conditions. Some nematode species can exist in this state for several years.

In the temperate region, nematodes are more abundant in deciduous woodland than coniferous or tundra sites. Populations in grasslands vary considerably (Peterson and Luxton, 1982, Figure 3). Non-wooded habitats classified as mesic have larger nematode populations than either wet or dry habitats, with dry habitats showing the smallest populations. Mineral soils have larger populations than mor/peat soils. Biomass of individuals may be larger in grasslands than in woodlands and larger in coniferous woodland than deciduous woodland, moorland has the lowest of all. Species richness is highest for all soil fauna with highest species richness in mull soils compared to acidic soils. However, these distributions need to be substantiated for Britain.

Boag & Neilson (1996) studied the distribution of six species of *Rotylenchus* and *Paratylenchus* plant parasitic nematodes (Table 26). *Rotylenchus robustus*, the most common species. and *Rotylenchus goodeyi* showed marked seasonality in population activity (max. March-April) and various habitat preferences (also see Bongers, 1988).

Table 26. Summary of plant parasitic nematode species distribution in Britain.

NEMATODA	DISTRIBUTION	HABITAT	
Rotylenchus robustus	widespread and common	various	higher altitudes, wetter soils, arable, scrubland, grassland and deciduous woods (light sandy soils)
Rotylenchus goodeyi	widespread; most common	unknown	soils with higher pH, low altitudes, scots pine. E Scot. not in Orkney and Shetlands
Rotylenchus uniformis	widespread	unknown	
Rotylenchus buxophilus	restricted; SE Eng except 1 E Scot	unknown	
Rotylenchus pumilis	restricted; S Eng. and Wales	unknown	(light sandy soils)
Pararotylenchus ouensensis	unknown	selective ?	coniferous woodland

Data are extremely scarce on non-economically important nematodes. European studies indicate possible soil types preferences (Bongers, 1988). Most species are found in the top 10 cm of the soil, though this varies with species and habitat (Overgaard Nielsen, 1949). Nematodes may increase soil depth in areas of greatest disturbance or minimum vegetation cover. Species are commonly aggregated in distribution. Webster and Boag (1992) examined aggregation in cyst nematodes and found spatial variation to occur over 5 m to 50 m. Recent use of krigging techniques to examine spatial patterns, shows that spatial distribution can be linked to environmental factors such as soil nitrate or organic matter "hot-spots" (Ettema et al., in press).

Hodda and Wanless (1994) surveyed Chalk grasslands at Porton Down, comparing nematode species between the flat valley bottom and hill top (alt. 160 m). One hundred and fifty-four species were recorded (44 unassigned), most were new records. Eighty-nine common enough for analysis. Forty-nine showed no difference in site preference, 22 were more abundant in the valley, 11 in the hill site and 3 restricted to just the hill site and another 3 to the valley site. There were two seasonal activity peaks (January and June). In the June peak, Dorylaimida predominated and in the January peak, Rhabditida, Araeolaimida or Tylenchida. Significant time differences were also shown. Thirty-six species altered their distribution over the study period.

TARDIGRADA

Some 74 species have been recorded in Britain (Morgan and King, 1976). Kinchin (1994) states there is much confusion over taxonomy and there may be a need to revise the current key to British species. These soil fauna are most found in surface water of mosses, lichens, liverworts and some angiosperms. Life span is typically 3 to 30 months with approximately 12 moults during the lifetime. The peak of reproduction is typically between April/May with smaller peaks throughout the year (e.g. October and January). Cyptobiosis (also known as anabiosis or anhydrobiosis) can be triggered in tardigrades, usually as a response to environmental stress of either chemical or physical nature. Many species are widespread and cosmopolitan. *Dispascon* species occur more commonly in the north and at high altitudes in southern Britain. *Echiniscus testudo* is the commonest *Echiniscus* species in the south whilst in Scotland three species are predominant (*Echiniscus testudo, E. merokensis* & *E. wendti*). Scottish moss also has a greater overall species richness in *Echiniscus* species than other parts of Britain. *Macrobiotus islandicus* is found only in the highest peaks of Scotland and *Macrobiotus orcadensis* occurs extensively in Scotland but rarely further south. Records of distribution are incomplete and many parts of the country have not been surveyed.

Habitat preferences are noted, though tardigrades are considered bryophilos species. Button and erect mosses generally contain more tardigrades than creeping mosses. Sphagnum contains fewer tardigrades than moss species in sandy areas. Too little is known of British species to say whether they may be host-specific. There appears to be no direct correlation between particular moss species and tardigrade species but moisture regime is important in determining the composition of the fauna. The growth form of a moss and the rate of water loss from this form appears to be an important factor in determining community structure. This is in turn dependent upon exposure of the moss to sunlight and wind, nature of substratum, depth of rhizoid layer, habit of moss and outline of moss cushion. Species assemblages have been recorded for different layers within a moss cushion; a-layer (green leaves on top of cushion) = *Macrobiotus hufelandi* and *Minibiotus intermedius*, b-layer (stem/litter layer) = *Hypsibius dujardini* and *Isohypsibius prosostomus* and c-layer (rhizoid/soil later) = *Diphascon scoticum* and *Macrobiotus harmsworthi* (after Overgaard-Nielson, 1948 and Kinchin, 1989).

Tardigrades are also common in soil and leaf-litter though population estimates vary greatly. They generally have an aggregated distribution in soil (Mihelcic, 1963). They are often found around plant roots and in the top few centimetres of soil. Soil communities are composed of a different species than that occurring in moss. In coastal habitats there are species restricted to organic slime on algae and interstitial species living between the small gaps in sand and silt. In the top few centimetres of sand (mesopsammic species) e.g. *Batillipes* spp. exist. There is a possible zonation due to feeding differences and seasonal fluctuations with peaks in spring and autumn and ultimately deep-sea benthic species. Substratum pH may be a significant ecological determinant (Table 27) though it may be less important in drier habitats (e.g. moss group 5).

Table 27. Environmental preferences for some of the more common tardigrades (Adapted from Dastych, 1988).

Tardigrade spp.	moisture regime (moss group)	geology
Dactylobiotus spp.	hydrophilous (group 1)	?
Pseudobiotus spp.	hydrophilous (group 1)	?
Hypsibius dujardini	hygrophilous (group 2/3)	mesocalciphil (no preferences)
Minibiotus intermedius	hygrophilous (group 2/3)	mesocalciphil (no preferences)
Echiniscius spp.	xerophilous group 4/5)	various
E. granulatus	xerophilous (group 4/5)	eucalciphil (exclusive to carbonate/alkaline rock)
E. testudo	xerophilous (group 4/5)	eucalciphil (exclusive to carbonate/alkaline rock)
E. blumi	xerophilous (group 4/5)	acalciphil (exclusive to non-carbonate/acidic rock)
Ramazzottius cf. *oberhaeuseri*	xerophilous (group 4/5)	polycalciphil (usually on carbonate/alkaline rock)
Milnesium tardigradum	xerophilous (group 4/5)	mesocalciphil (no preferences)
Macrobiotus cf. *hufelandi*	euryhydric (group 1-5)	mesocalciphil (no preferences)
Macrobiotus cf. *harmsworthi*	euryhydric (group 1-5)	mesocalciphil (no preferences)
Isohypsibius elegans	?	eucalciphil (exclusive to carbonate/alkaline rock)
Richtersius coronifer	?	eucalciphil (exclusive to carbonate/alkaline rock)
Macrobiotus areolatus	?	polycalciphil (usually on carbonate/alkaline rock)
Calohypsibius ornatus	?	oligocalciphil (usually non-carbonate/acidic rock)
Diphascon scoticum	?	oligocalciphil (usually non-carbonate/acidic rock)
Hebesuncus conjungens	?	acalciphil (exclusive to non-carbonate/acidic rock)
Diphascon angustatum	?	acalciphil (exclusive to non-carbonate/acidic rock)
Macrobiotus spectabilis	?	acalciphil (exclusive to non-carbonate/acidic rock)

Tardigrades show limited dispersal which is mainly passive, usually by water or wind movement of sand/soil particles and likely over short distances only. Some species are more common at certain altitudes and may have a restricted range, (see Table 28). Altitudinal distribution is likely to be primarily determined by abiotic factors associated with microhabitat (e.g. humidity or temperature) rather than altitude *per se*. The precise controlling factors are as yet unknown. Some species are extremely euryplastic in environmental requirements. Abundance varies greatly with year and season, as well as spatially. Annual density in a Swedish pine forest ranged from 9,000 m^{-2} in August to 97,000 m^{-2} individuals in December (Persson et al., 1980). Food availability affects some tardigrade populations while climate has a strong effect but this is poorly understood.

Table 28: Altitudinal distribution of tardigrades (adapted from Dastych, 1987, 1988)

Altitudinal group	Height above sea level	Example species
Lowland species	below 200 m	*Ramazzottius anomalus*
Upland species	201 - 500 m	*Echiniscius testudo*
Foreland species	501 - 1000 m	*Brydelphax weglarskae*
Montane species	above 1000 m	
sub-alpine	in mountain forest	*Brydelphax parvulus*
mesoalpine	below tree line	*Richtersius coronifer*
eualpine	above tree line	*Calohypsibius ornatus*
Tychoalpine	all altitudinal zones	*Macrobiotus* cf. *hufelandi*
		Macrobiotus cf. *harmsworthi*
		Ramazzottius cf. *oberhaeuseri*
		Milnesium tardigradum
		Diphascon scoticum

DIPLOPODA (Millipedes)

There are over 21 species of millipedes in Britain. Table 29 summarises available data on species habitat preferences in Britain. Seasonal activity influences distribution e.g. moulting periods which coincides with appropriate weather conditions. In temperate regions, many species hibernate in winter with some species moving down into the soil to hibernate, e.g. *Blaniulus guttulatus* in British woodland (Brookes & Willoughby, 1978). Complex migration patterns also dictate distribution e.g. *Cylindroiulus punctatus* moves from leaf-litter to rotting logs as weather warms up in spring and moves to mineral soil in autumn (Banerjee, 1967a,b). In dune grasslands, lowest depth occurs when air temperature is less than 8°C. *Cylindroiulus latestriatus* is found at 2 cm depth in late autumn and 8 cm in winter; below woodlice and mainly in the rooting zone (Davies et al., 1977).

Glomeris balcanica egg laying typically occurs from May to August and field maturation takes up to three years. For *Julus scandinavicus* in Cheshire wood, there is a new generation in June, egg laying possibly in April. However, variations in life cycles commonly occur which may be due to micro-habitat preferences or predictability of habitat (Blower, 1969, 1970; Calow, 1978). Meyer (1990) has shown factors that effect life cycles in millipedes in the central Alps; with an increase in altitude, decrease in snow-free days and decrease in temperature there is a corresponding increase in time to maturity, longevity and slow down in life cycles (see also Read, 1985 - Madeira). In Holland, *Polydesmus* is active in spring and summer, *Cylindroiulus* peaks in spring and autumn. *Polydesmus denticulatus* is active over a wide range of temperatures (9-20°C) whereas *Cylindroiulus frisius* (= *latestriatus*) has two activity periods more closely tied to temperature as opposed to rainfall. There are also species differences in generation times; *Julus scandinavicus* = 3 years to maturity & *Ophyiulus pilosus* = 2 years.

Millipedes frequently have an aggregated distribution which may vary with soil depth, humidity, sex ratios, etc. In France, maximum density is typically in early summer with recruitment from the new generations (David, 1984). Species are most active at night with peaks just before sunrise and after sunset and often peaks in the breeding season. Dispersal is limited and species richness declines with increasing altitude (Hopkin & Read, 1992). Barlow (1960) concluded that humidity was the major

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Table 29. Millipede and centipede habitats, within-habitat and soil preferences.

Millipede species	habitat preferences	soils	within-habitat preferences	notes
Glomeris balcanica		(calcareous)		
Glomeris marginata	deciduous woods	(calcareous)		dominant of climax oak (ash)
Polymicrodon polydesmoides	deciduous woods	(calcareous)		
Julus scandinavicus	coniferous + deciduous woods	mor/sandy		mixed woodland, beech
Blaniulus guttulatus	grass/arable			
Cylindroiulus punctatus	coniferous + deciduous woods		floor of oakwoods, bark	dominant of climax oak
Cylindroiulus britannicus			bark, rotten wood	
Cylindroiulus parisiorum			bark, rotten wood	
Ophyiulus pilosus	deciduous woods			mixed woodland, beech
Polydesmus angustus	deciduous woods			
Polydesmus denticulatus	deciduous woods	(calcareous)		often more abundant than *P. angustus*
Cylindroiulus latestriatus (frisius)	coastal, inland sandy soils	sandy		
Schizophyllum (Ommatoiulus) sabulosus	coniferous	sandy		esp. Scotland
Brachydesmus superus	deciduous woods, grass/arable			
Cylindroiulus londinesis var. caeruleocintus		calcareous		
Archeboreoiulus pallidus		calcareous		
Brachyiulus pusillus	coastal, arable			
Tachypodoiulus niger			ground + aerial	
Schizophyllum sabulosum			ground + aerial	
Isobates varicornis			bark, rotten wood	
Proteroiulus fuscus			bark, rotten wood, litter	

Centipede species	habitat preferences	soils	within-habitat preferences	notes
Necrophloeophaggus longicornis	grassland (arable)	mull	not often in woodland soils	
Lithobius duboscqui	grass/arable	mull	soil/litter	
Brachygeophilus truncorum	wood/heath/moor	mor + poorer mull		
Geophilus carpophagus	wood/heath/moor	mor + poorer mull		
Lithobius calcaratus	wood/heath/moor	mor		
Lithobius lapidicola	wood/heath/moor	mor		
Lithobius variegatus	wood/heath/moor	mor	soil	
Geophilus insculptus		richer mull		
Geophilus electricus		richer mull		
Lithobius crassipes			soil/litter	
Lithobius forficatus			ground + aerial	

CHILOPODA (Ccentipedes)

There are approximately 47 species of centipedes in Britain, however, centipedes have not been well studied and details on their distribution or ecology are scarce in the literature (Table 29). There are three distinct groups; Geophilomorpha (burrowing species), Lithbiomorpha (surface hunters) and Scolopendromorpha (also surface hunters). Centipedes are pre-eminently woodland species (Blower, 1955) which can adapt to non-forested conditions. A few species are typical of arable, grassland *e.g.*

Necrophloeophagus longicornis and *Lithobius duboscqui.* Typical moorland species are *Brachygeophilus truncorus, Geophilus carpophagus, L. variegatus, L. calcaratus* and *L. lapidicola.* Moorland species are generally linked to more acidic (mor) soils while grassland/arable species are linked to more alkali (mull) soils. There is a distinction between soil, litter and ground dwellers. The larger lithobiids are ground-dwellers. In general lithobiids are most frequent in litter while geophilomorphs mainly live in the soil and are found at depth in colder periods of the year. Species also often aggregate in preferred micro-habitats e.g. under bark. Centipedes are more susceptible to desiccation than millipedes, however, excess water can be just as detrimental (preventing oxygen uptake). Susceptibility to "drowning" varies with species and is linked to habitat preferences. Distribution and activities depend largely on body form and water relations (Raw, 1967).

FORMICIDAE (Ants)

There are 4 sub-families of ants in Britain with, approximately, 42 native species. Table 30 summarises data on distribution and habitat preferences. The greatest species richness is in the southern regions e.g. 33 in Dorset, 31 in Hampshire, 29 in Surrey, 27 in Isle of Wight, 26 in East Kent and South Devon, 24 in Berkshire. But, the literature suggests it is difficult to generalise about the geographical distribution of species (*cf.* Wallwork, 1970), especially as these social insects can maintain their own micro-environment which concentrates populations. On a European scale, species richness declines, including the 35 or so British species, with increasing altitude and decreasing regional area (Cushman et al., 1993). Species occurrence also increases with habitat area. Another European wide study shows that sun-light hours, July temperatures, length of growing season and distance to coast are key ecological determinants (Baroni-Urbani and Collingwood, 1976, 1977).

Once, or twice, a year winged reproductives (alates) leave colonies to found new ones; typically in autumn in response to humidity and/or temperature stimuli. However, species often have specific requirements. Formicinae favour sandy soils while others, e.g. *Myrmica* spp. and *Ponera* spp. favour organic soils in damp environments e.g. woodlands. Elmes and Wardlaw (1982) have shown that *Myrmica* spp. distribution in chalk grassland is related to insolation and vegetation structure (Table 20). Comparisons of local habitat preferences and life forms of two *Myrmica* species can be used to indicate regional, and to some degree, habitat distribution. But there are exceptions, especially at higher altitudes.

Table 30 : Distribution and habitats of the majority of ant species in Britain (principally compiled from Brian, 1982).

Species	Main habitat	Regional distribution	Local habitat/niche
Anergates atratulus	heath and grassland	mid-south England	*T. caespitum* nests
Formica aquilonia	woodland	almost confined to Scottish Highlands.	surface/subterranean mounds
Formica cuniularia	heathland	rare; England	small mounds
Formica exsecta	woodland and heath	similar distribution to *Formica sanguinea*	nests in scrub and heath
Formica fusca	heath and grassland	widespread in England, absent from Scotland except Western Isles.	subterranean
Formica lemani	scrubland	widespread; further north than *F. fusca* and only Formica in Northern Isles.	subterranean
Formica lugubris	woodland	ranges from Wales, N. England to Scotland; Highlands but not in Lowlands. Altitude restricted ?	surface/subterranean mounds
Formica picea	woodland	v. rare.; New Forest	black bog ant.
Formica polyctena	woodland and grassland	rare	surface/subterranean mounds
Formica pratensis	woodland	rare	surface/subterranean mounds
Formica rufa	woodland	most of eastern and western england, rare north and absent from Scotland and Ireland.	surface/subterranean mounds
Formica rufibarbis	heathland	rare; southern england.	
Formica sanguinea	woodland	patchy but wide distribution; in Scotland, s. England but not n. England, Wales or Ireland.	
Formica transkaucasica	peat bogs	rare	specialist bog dweller.
Formicoxenus nitidulus	woodland	similar to wood ant, *F. rufa*	lives in *F. rufa* nests.
Formicoxenus nitidulus	woodland	rare; but widespread ?	rarer guest ant. only in nests of wood or hairy wood ant.
Hypoponera punctatissima	?	isolated places in England but widespread	glasshouses and rarely outside, in sunny situations
Lasius alienus	limestone/chalk heathland	southern distribution and coastal distribution in north	subterranean; warm soils of heathland, limestone or chalk
Lasius brunneus	woodland	rare; oak woodlands	nests in old trees
Lasius flavus	heath and grassland	widespread ex. N. Scotland and Ireland; dominant in lowland heath/ grassland in England	subterranean; small hillocks, meadows or hillsides.
Lasius fuliginosus	woodland	sporadically in southern england	near trees, nest at foot of trees.
Lasius niger	scrubland	widely distributed but absent from some areas in Ireland and Scotland.	Bushy scrubland, cultivated areas and gardens, wet places
Lasius umbratus	woodland	widespread but sporadic ?	subterranean; obligate social parasite of *L. niger*
Leptothorax acervorum	heath and scrubland	widely distributed (but patchy)	nests in hard wood, twigs or soil surface crust
Leptothorax tuberum	woodland	rare; restricted to southern England	rotting wood or under moss in shade
Monomorium pharaonis		not native, though common in houses	common in houses
Myrmecina graminicola	heath and grassland	southern England	deep in soil in sunny places.
Myrmica rubra	heath and grassland	fairly common	under stones
Myrmica ruginodis	various	widespread	grassland predominant with *M.scabrinodis*
Myrmica sabuleti	heath and grassland	widespread	drier grasslands
Myrmica scabrinodis	heath and grassland	widespread	subterranean; shorter vegetation, drier/shallow soils
Myrmica speciodes		only in Kent and Sussex	
Myrmica sulcinodis	heath and grassland	widely distributed. common in lowland heath in southern england.	under stones
Ponera coarctata	woodland	southern England	nests under stones and moss
Sifolinia karavajevi	?	v. rare; in *Myrmica sabuleti* colony	in *Myrmica sabuleti* colonies
Solenopsis fugax	coastal	restricted to south; coastal distribution	near *Lasius* or *Formica* nests.
Stenamma westwoodii	heath and grassland ?	rare; in the south.	under stones. galls or twigs. damp places
Strongylognathus testaceus	heath and grassland	rare; Dorset and Hampshire	
Tapinoma erracticum	heathland	confined to central southern England; common in sandy soils of New Forest.	surface/subterranean nests.
Tetramorium caespitum	heath and grass	Restricted to the south (lowland heath and grassland)and coastal zones in the north. Temp. restricted ?	subterranean; upper soil surface

Table 31. Habitat preferences in *Myrmica* species in chalk grassland.

Vegetation structure	long vegetation		short vegetation	
Insolation/microclimate	low cool	high warm	low cool	high warm
Myrmica spp.				
M. ruginodis macrogyna		(+)	+	
M. rubra		+	+	
M. sabuletti		(+)		+
M. scabrinodis		+		

after Elmes & Wardlaw (1982)

TURBELLARIA (Flat worms)

Flatworms are normally present in woodland soils (Kuhnelt, 1955) except where soils are waterlogged. All but one species are restricted to soil, living in the water film surrounding decomposing litter, and all species encyst when conditions are dry. Distribution data are insufficient for species except the New Zealand flatworm. Certain habitat characteristics are known for the New Zealand distribution of the predatory land planarian, *Artioposthia triangulata,* e.g. a soil temperature range which does not exceed 20°C and relatively humid, damp microclimate. These are now being used to predict its potential range throughout Britain using bioclimatographs and data already available (30 year data from three different habitats as reference sites; monthly temperature, rainfall, relative humidity and rainfall patterns). However, it is unknown how closely the determinants in New Zealand will match the British environment (Boag et al., 1995).

DIPLURA

There is one family, including approximately 7 species, of two pronged bristletails in Britain; Campodea. Little is known of their life-history traits although they are known to breed in the summer months. They are believed to be widely distributed although there is no data available on British distribution. Dipluran life-cycle is approximately two years in Europe and these cryptic animals generally live in damp humus or soil, in litter or under stones and in caves.

MICROCORYPHIA (Jumping bristletails)

Jumping bristletails live in forest litter, under bark, in rock crevices and under stones (Ferguson, 1990). Regional distribution data are unavailable although they are considered widespread.

PAUROPODA

Five families of pauropoda, containing more than 5000 species, are currently recognised worldwide (Dindal, 1990), however, the number of species in the UK is unknown. In most environments, occurrence is patchy and populations are sparse. These animals are unable to bury into soil, so live in tunnels and crevices in the soil. They are also found in humus and litter layers, under bark and stones and in moss carpets. They inhabit a range of soil types and most often occur in high organic soils which are moist; not wet or dry, and in deciduous rather than coniferous litter. Regional distribution data are unavailable although they are considered widespread.

SYMPHYLA

This is a cosmopolitan faunal group of which relatively little is known (Edwards, 1970). There are two common genera in Britain, *Scutigerella* (saprozoic and pests) and *Symphylella* (saprozoic). Symphylids are white, soil myriapods and are well distributed in upper soil layers and go to depth via soil pores, cracks, burrows etc (Edwards, 1955). They can penetrate deep into the soil and may only be found at the surface when seeking food and when environmental conditions are suitable. They are most abundant in soils with open structure and high organic matter content, where they can be found at depth (> 2 m), and rarely occur in heavy clay or acid peat soils i.e. they are most abundant in loam soils followed by clay loams and sandy clay loams with species least abundant on sands and clays. They are also more abundant in cultivated soil than forest litter, moorland or permanent grassland (arable>forest/moorland/ permanent pasture). A life cycle in Britain is at least 3 months while seasonal changes in populations and vertical migration are known to occur; down in summer and closer to surface in spring. Regional distribution data are sparse although they are considered widespread.

PSOCOPTERA (Booklice or barklice)

There are approximately 90 species in Britain with the majority living off fungi and algae on litter, seeds and bark but there are only a few truly soil-dwelling species associated with decomposing litter. Regional distribution data are unavailable although they are considered widespread.

PROTURA

Little is known about these common soil fauna which are often abundant in humus but not in the presence of fungi. Nosek (1976) summarised species distribution for Europe. They occur in all regions and live principally in forest humus and litter under bark and stones, in peat bogs, pasture and arable fields and in moss and lichens. They are especially abundant in forest soils. In forest soils, they are often found at depth greater than 25 cm. There are indications, from European studies, that some species have wide ecological ranges while others may be very narrow. There are 12 species recorded for Britain, where they are most common in leaf litter and moist soil with high organic matter. Regional distribution data are unavailable although they are considered widespread.

THYSANURA (Three-tailed bristletails)

Bristletails (also known as silverfish) are found in litter, humus and under stones and bark. They are most abundant in forest soils but are found in a wide range of habitats. Regional distribution data are unavailable although they are considered widespread. Nine species are recognised in Britain

OPILIONES (Harvest spiders)

Approximately 20 species are found in Britain. Several are widespread in distribution with distinct habitat preferences for some species (Phillipson, 1959). Few species live in litter layers while other are ground-dwellers preying on other soil fauna. Populations are often highest in woodland and open fields. Association with the soil differs with life-history traits as well as species. Members of the family Trogulidae may be restricted to chalky soils. Peak diurnal activity occurs at night. Species which are prone to desiccation feed solely at night, are more closely associated with the soil and are active over winter. Some species also feed during daylight and these tend to be more active in the vegetation above the soil and less active over the winter.

PSEUDOSCORPIONIDA (False scorpions)

Restricted in distribution, *Neobiscum muscorum* is the most common species (deciduous and coniferous woodlands) followed by *N. silvatorum* (drier woods), *N. fuscimanum* (wetter woods) and *N. brevifemoratum* (peat bogs). There is also a provisional distribution atlas.

ARANEAE (Spiders)

There are almost 600 spider species in Britain with true soil-dwelling spiders widespread. Within-habitat distribution may be regulated by soil moisture content and vegetation structure as well as by sex. Peak activity is generally greatest in summer and autumn as a combination of increased foraging activity and population turnover while latitude, altitude and climate influence life-history traits. Data on species distributions in different habitats are relatively scarce. There is a Biological Recording Centre scheme in operation.

GASTROPODS (Snails and slugs)

There are over 110 species of snails and slugs in Britain, with all but 2 species in the Order Pulmonata (pulmonates). Snails and slugs have been little studied outside pest management; some species are well-known pests of vegetable crops, in particular. Data from Europe suggests that they are not common in heavily structured soils or where vegetation is sparse (van der Drift, 1951) while species distribution may be indirectly related to soil substrate material (geology). Species associations have also been shown on calcareous soils and basic silicate derived soils (Lozek, 1962). Soil moisture may also be a key determinant, with most species preferring moist soil environments while some species live in cracks in the soil in drier, warmer periods. Species dependency for calcium can be used to characterize species assemblages (Lozek, 1962). Differences in depth distribution in the soil may be a response to temperature and moisture with species moving down in the soil profile in arable soils in the winter (Hunter, 1966). Soil-dwellers also show nocturnal peaks in activity (South, 1965). In Britain, species richness is highest in woodlands with few pasture species.

HEMIPTERA (True bugs)

This Order is formed from two sub-Orders, Homoptera and Heteroptera, and contains over 1600 British species. There is a wide range of habitat preferences and distributions for this Order. Some families are very localised (Cicadidae) while other are cosmopolitan (e.g. Miridae). A comprehensive summary of family or species distributions is outside the scope of this study. Ground-dwelling species are mainly found between spring and autumn while some species may be found in litter or upper soil layers during hibernation. Most ground-dwellers are found in the drier areas of the south and east of Britain on well-drained soils of chalk and sandstone areas, or coastal dunes. It has been suggested that temperature may also restrict regional distribution.

ORTHOPTERA (Crickets, grasshoppers and ground hoppers)

There are only 30 or so species in Britain, with a distinct southern bias; only 7 are found in Scotland. Southern heathland supports the highest species richness. Table 32 briefly outlines broad habitat preferences. Adults of all species are most common in the summer. Diurnal activity patterns differ with species but relate to (soil/air) temperatures and relative humidity; grasshoppers and ground hoppers are most active during the day while bush crickets are most active at night. Most species have an annual life cycle, with adults dying out in the autumn having laid eggs (often in the soil in egg cases) for the following year. Some grasshoppers and bush crickets, with two year life-cycles, overwinter while some groundhoppers and crickets may hibernate as late stage nymphs in the soil. Marshall and Haes (1988) provides a detailed breakdown of species habitat preferences and species richness in broad British habitat categories.

Table 32. Distribution and broad habitat preferences of Orthoperan groups in Britain.

SPECIES	species N	Distribution	Broad habitat preferences
cave crickets	1	rare, restricted to market gardens in south	caves - introduction from Asia
mole crickets	1	rare, restricted to few sites in S. England	damp ground, chalk heaths
grasshoppers	11	widespread, most common in south	grassy and low-growing vegetation
groundhoppers	3	mainly restricted to S. England	where grass cover not too extensive, edges of streams and ponds
bush crickets	10	rare, mainly restricted to S. England	bushes and scrubby vegetation
true crickets	4	rare, restricted to extreme S. England	depends on species; wood, open grass or coastal

DERMAPTERA (Earwigs)

There are seven species in Britain, with only two common species (*Forficula auricularia* and *Labia minor*), (see Table 33). They are nocturnal animals and found in crevices and under stones during the day. Some species, typically *Forficula ricularia*, may burrow into the soil. Mating occurs in late autumn and winter after which adults hibernate in the soil and under stones and bark. Eggs are laid in earthen burrows/nests and nymphs mainly hatch in early spring.

Table 33. Distribution and broad habitat preferences of Dermapteran groups in Britain.

SPECIES	DISTRIBUTION	HABITAT
Forficula lesnei	confined to S. England	damp sites
Apterygida media	confined to S. England	damp sites
Forficula auricularia	widespread	damp sites
Labia minor	widespread	compost heaps, dung and manure
Euborellia annupiles	localised, ports and rubbish sites. Immigrant	damp sites
Labidura riparia	rare, coastal areas and by rivers (extinct ?)	damp sites; sandy soils
Labidura sp.	?	damp sites

THYSANOPTERA (Thrips)

There are over 150 species in Britain, with most plant sap feeders. Some adults are associated with the soil, living on vegetation, under stones and bark and in litter while most thrip species pupate in the soil or in litter debris. Many species over winter as adults or pupae in the soil.

MEGALOPTERA (Principally snake flies)

Four species of the snake flies family, Raphidiidae, live in Britain, although they are not common. Larvae of these species can be found under loose bark and in litter and are most frequently found in oak and pine forest during the summer.

DIPTERA (Two winged flies)

This is a huge group containing over 5,000 British species in three sub-Orders; Nematocera, Brachycera and Cyclorrhyapa. It is impossible to summarise these data effectively within this review. Various families have larvae which are well documented soil fauna e.g. Tipulidae, Trichoceridae, Bibionidae, Mycetophilidae, Rhagionidae, Tabinidae and Therevidae. Larvae of Tipulidae (crane-flies), of which there are over 300 British species, soem of which have been studied in some detail in moorland soils as part of the IGBP Moorhouse study. There are several species found in the range of moorland soils with *Tipulida paludosa* the most abundant.

4.5 METHODS

4.5.1. Soil fauna sampling

The efficiency of assessing soil fauna distribution is closely linked to the effectiveness of sampling and soil extraction methods. This also presents difficulties in assessing the literature, as different methods have been used to sample soil faunal groups and species. At present, there is no one method which can be used to sample all soil fauna, with each method having its own benefits and drawbacks. These pros and cons have been extensively reviewed (Phillipson, 1971; Dindal, 1990; Gormy and Grum, 1993). Methods for sampling some ground-dwelling soil fauna in Britain have been assessed in McKeever (unpubl. ITE report). This provides a useful framework to consider selectivity, seasonal usefulness and efficiency of both sampling and sorting techniques as well as likely financial costs in terms of both time and labour.

For example, earthworm sampling strategies must consider distribution determinants given that there are distinct soil depth groupings in earthworms, a large size range (typically from 2 - 30 cm), see Arthur (1965) for British species, and hibernation patterns. There are various chemical and mechanical sorting methods. It is generally considered that hand-sorting of soil is sufficient but a combination of both is recommended to ensure complete sampling of species richness. A range of techniques recommended by various European researchers is outlined below. Hand sorting recommendations are 16 sample units/ha. to a depth of 20 cm (Zicsi, 1958). Persson & Lohm (1977) suggested a soil depth of 30 cm in summer and 60 cm in winter. Lavelle (1978) suggests sampling the top 50 cm of soil in 10 cm layers in 1 m^2 quadrats supplemented by washing and sieving 20 x 20 cm samples. Satchell (1969) recommends three applications of 9 l of 0.165-0.55% formalin/0.5 m^{-2}. It is clear that all methods are very time consuming and labour intensive. Future research must consider if there are alternative sampling methods to determine distribution across region or habitat or within-habitat.

All present, methods for assessing soil populations of invertebrates cause site disturbance (e.g. soil sampling or chemical extraction) and require a sufficient number of samples to be taken to reduce variations in populations and ensure all species are collected. The number of samples required will depend on study area and factors which effect local distribution especially species aggregation in response to environmental conditions or life-cycle stage. Most soil animals have an aggregated distribution (Peterson & Luxton, 1982) therefore a high number of sample units is required to obtain a degree of accuracy in population estimates. Recommendations range from as low as 5 to over 30 samples, depending on the groups and habitats being assessed. Sampling units (size/no.), sampling period and sampling frequency must be carried out in relation to fluctuations in population size and/or distribution. In general, species with greater population variations (see Figure 1), will require more intensive sampling. The level of intensity will vary from within-habitat to regional scale and over temporal scale. Bouché estimated earthworm populations in the French IGBP sites from two samples per year (spring and autumn) over several years. He suggests that this sampling may characterise the site better than a mean obtained from more frequent sampling for just one year. But it is clear that the method of sampling depends on what the information is required for. If species distribution needs to be predicted on a monthly basis, both accurate seasonal and annual data is required.

The efficiency of various soil extraction techniques has been covered in the reviews of Phillipson (1971) and Peterson and Luxton (1982) and Gorny and Grum (1994). Efficient extraction techniques are critical if examining abundance of species. In general, species richness increases with the greater number of individual collected and with number of samples.

There are various non-destructive sampling methods and the most commonly used is the pitfall trap. Fauna sampled from these are typically those which have only part of their life-cycle in the soil and fauna which are on the ground or near-ground vegetation. There are also problems with interpreting the data as it reflects activity and not population size. However, given the time, cost and expense of soil sampling techniques, it may be worthwhile investigating the potential for alternative non-destructive techniques to sample below ground as well as above ground fauna

Another aspect of scale is which level of assessment is required for soil fauna; occurrence or abundance. For the purposes of this study, both have been examined in the literature. For the information to date, it is not possible to state whether occurrence is too simplistic or abundance too complex. These will have to be determined for individual groups or species in individual habitats and will depend greatly on availability of efficient sampling techniques.

4.5.2. Soil fauna identification

As mentioned above, there is a significant problem in interpreting the literature or assessing field data as species taxonomy for most soil fauna is woefully inadequate. It is currently difficult to determine which species are being discussed in the literature as species names cited have often been revised. Studies of groups which have not been adequately revised or have no clear method of identification are almost meaningless at a species level. For the purposes of this assessment, species names are listed as given by the authors and revised only when recent taxonomic revisions are available (both published and revised names are generally listed). Table 34 summarises taxonomic requirements for individual soil faunal groups. Much of these data are derived from Tilling (1987), available literature and taxonomic groups specialists. There are few taxonomic services available from the National Museums and, where available, specialist taxonomists (professional or non-professional) are rarely able to spend the time (or be able to afford the time) to carry out numerous identifications. The cost of numerous identifications can also restrict interpretations since taxonomic services typically cost from £35 a specimen.

Table 34. The majority of soil fauna groups of Britain; their affinity with soil, availability of identification keys and requirements for updating keys.

Phylum	class	sub-class/order	sub-order/ family	soil	litter	ground	species	key	revision	common name
Arthropoda	Insecta	Hymenoptera	**Formicidae**	+	+	+	42	yes	yes	ants
Arthropoda	Crustacea	Malacostraca	**Isopoda**	+	+	+	37	yes	no	woodlice
Arthropoda	Insecta	**Psocoptera**		+	+	+	~90	?	yes	psocids/ booklice
Arthropoda	**Chilopoda**			+	+	+	47	yes	yes	centipedes
Arthropoda	**Diplopoda**			+	+	+	52	yes	no	millipedes
Mollusca	**Gastropoda**			+	+	+	115	yes	yes	slugs + snails
Arthropoda	Arachnida	**Acarina**	Astigmata	+	+		?	no	yes	mites
Arthropoda	Arachnida	**Acarina**	Prostigmata	+	+		2000 ?	no	yes	mites
Arthropoda	Arachnida	**Acarina**	Mesostigmata	+	+		?	no	yes	mites
Arthropoda	Arachnida	**Acarina**	Cryptostigmata	+	+		> 300	no	yes	moss/beetle mites
Platyhelminth	**Turbellaria**		e.g. Tricladida	+	+		>7	?	yes	planarians/ flatworms
Arthropoda	Insecta	**Collembola**		+	+		40 ?	no	yes	springtails
Arthropoda	Insecta	**Diplura**	Campodeidae	+	+		11	yes	yes	two pronged bristletails
Arthropoda	Insecta	**Microcoryphia**		+	+		?	?	yes	jumping bristletails
Arthropoda	Insecta	**Pauropoda**		+	+		?	?	yes	
Arthropoda	Insecta	**Protura**		+	+		12	no	yes	
Arthropoda	Insecta	**Thysanura**	Machilidae	+	+		9	no	yes	bristletails silverfish
Ascelminthes	**Nematoda**			+	+		>100?	no	yes	nematodes
Annelida	Oligochaeta		**Lumbricidae**	+	+		25	yes	yes	earthworms
Annelida	Oligochaeta		**Enchytraeidae**	+	+		>100	no	yes	potworms
Arthropoda	**Symphyla**			+	+		?	yes	yes	
Arthropoda	**Tardigrada**			+	+		>20	yes	yes	water-bears
Arthropoda	Insecta	Coleoptera	**Caraboidae**	(+)	+	+	~ 400	yes	yes	ground beetles
Arthropoda	Insecta	Coleoptera	**Scarabaeoidae**	(+)	+	+	250	yes	yes	dung beetles+chafers
Arthropoda	Insecta	Coleoptera	**Dascilloidae**	(+)	+	+	1	yes	?	
Arthropoda	Insecta	Coleoptera	**Elateroidae**	(+)	+	+	~70	yes	yes	click beetles
Arthropoda	Insecta	Coleoptera	**Cantharoidae**	(+)	+	+	~45	yes	yes	
Arthropoda	Insecta	Coleoptera	**Dermestoidae**	(+)	+	+	~30	yes	yes	
Arthropoda	Insecta	Coleoptera	**Chrysomeloidae**	(+)	+	+	~300	yes	yes	eg chrysomelids
Arthropoda	Insecta	Coleoptera	**Curculionoidae**	(+)	+	+	~1000	yes	yes	weevils
Arthropoda	Insecta	Coleoptera	**Byrrhoidae**	(+)	+	+	10	yes	?	
Arthropoda	Insecta	Coleoptera	**Cucujoidae**	(+)	+	+	~330	yes	yes	eg darkling beetles
Arthropoda	Insecta	Coleoptera	**Staphylinoidae**	(+)	+	+	~3500	yes	yes	eg carrion beetles
Arthropoda	Insecta	Coleoptera	**Eucinetoidae**	(+)	+	+	26	yes	yes	
Arthropoda	Insecta	Coleoptera	**Histeroidae**	(+)	+	+	~40	yes	yes	
Arthropoda	Insecta	**Dermaptera**		(+)	+	+	7	yes	no	earwigs
Arthropoda	Insecta	Hemiptera	**Homoptera**	(+)	+	+	<450	yes	yes	eg cicadas + hoppers

5.0 A CASE STUDY IN THE VICINITY OF THE AVONMOUTH SMELTING WORKS; USE OF EXISTING DATA

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5.1. Introduction

As part of the SOILPACS feasibility study, it was felt appropriate to examine an existing data set relating to the region around the primary zinc-cadmium-lead smelting works at Avonmouth, SouthWest England. This is one of the best-studied contaminated terrestrial ecosystems in the world where the effects of aerial metal pollution on the biota have been studied since the early 1970s. The report below concentrates on recent work on biodiversity in the vicinity of the factory (measured by number of species or abundance of particular taxonomic groups) and is intended to highlight some of the factors which will need to be considered if a working SOILPACS programme is to be established. Effects on invertebrates at the species level are important to quantify in the context of setting soil quality criteria, especially with regard to the concept of '95% protection levels' for metals advanced by Van Straalen (1993) and others (for a critique of the method, see Hopkin 1993*c*).

A description is given of a detailed survey of the biodiversity of soil invertebrates conducted in the vicinity of the Avonmouth primary zinc, cadmium and lead smelting works near Bristol, UK. Although some groups of organisms such as millipedes, woodlice and earthworms were present in lower numbers near the factory, others such as carabid and staphylinid beetles, centipedes, and linyphiid spiders showed no obvious differences between sampling sites. In addition, some invertebrates such as lycosid spiders, grasshoppers, and a species of bug (*C. vulnerata*) were much more abundant close to the factory. Overall, Collembola and mites were generally less abundant near the factory. However, preliminary identification of the Collembola samples showed clear differences in responses at the species level with some taxa being more abundant near to the smelter while populations of others were clearly being reduced by the very heavy metal contamination. However, diversity indices were impossible to calculate for Collembola and mites due to a lack of published identification keys to these groups.

Following a detailed survey of literature records, a new checklist for Collembola of Britain and Ireland is presented. It is shown however, that uncritical use of such a list can be very misleading due to the taxonomic confusion that exists. Detailed notes are given of how such confusion can arise within a few selected genera of Collembola.

It is concluded that the most promising groups to include in a SOILPACS scheme with present knowledge are those showing the clearest reductions in species diversity in the most contaminated sites, i.e. woodlice, millipedes and earthworms for which good identification keys are available. Collembola and mites show great promise as indicator organisms but only at the species level. Development of modern identification keys to these groups is essential if their potential is to be fully realised.

5.2. The Avonmouth Site

Before the First World War, Britain's primary source of zinc bullion was Belgium. During and after the War, it became extremely difficult to obtain zinc from this source and it was decided for strategic reasons that a primary zinc smelting works was required in Britain. The first smelting works at Avonmouth was commissioned in 1929 and this produced both lead and zinc. The current smelter was constructed in 1969 and was of the Imperial Smelting Furnace No. 4 design which was able also to produce cadmium. It was, at the time, a new and revolutionary procedure which became known as the Imperial Smelting Process.

The annual output of the factory is approximately 100,000 tonnes of zinc, 40,000 tonnes of lead and 300 tonnes of cadmium, although the exact quantities produced depend on demand and international metal prices. Several devices are fitted to the chimneys of the plant to reduce pollutant emissions. Nevertheless, considerable quantities of metal-containing particles are released (Table 35, Appendix A) and these settle over a wide area on the surrounding soils and vegetation where they have the potential to directly affect the biota, and to enter food chains. For example, concentrations of cadmium significantly above background can be detected more than 25 km downwind of the factory in surface soils, vegetation and woodlice (Hopkin *et al.* 1986).

Numerous papers have been published on the concentrations and effects of metals derived from the smelting works on particular species of soil invertebrates (for reviews Hopkin 1989; Martin & Bullock 1994). There is quite detailed knowledge on the dynamics of metals in earthworms (Spurgeon *et al.* 1994; Spurgeon & Hopkin 1995, 1996*a*, 1996*b*, 1996*c*, 1996*d*), snails (Laskowski & Hopkin 1996*a*, 1996*b*), woodlice (Drobne & Hopkin 1994, 1995; Hopkin 1990*a*, 1990*b*, 1993*b*; Hopkin & Martin 1982*a*, 1982*b*, 1984; Hopkin *et al.* 1986, 1989, 1993; Jones & Hopkin 1996), centipedes (Hopkin & Martin 1983, 1984) and spiders (Hopkin & Martin 1985). When the *relative* toxicities of individual metals to primary consumers are examined in the laboratory, it is clear that cadmium is about ten times more toxic than zinc (on a weight basis). However, because zinc is invariably present at concentrations of at least 60 times greater than cadmium in soils and leaf litter, it is almost certain that deleterious effects of pollution from the smelter on woodlice (Hopkin & Hames 1994), snails (Laskowski & Hopkin 1996*a*, 1996*b*), Collembola (Sandifer & Hopkin 1996) and earthworms (Spurgeon *et al.* 1994; Spurgeon & Hopkin 1995, 1996*a*, 1996*b*, 1996*c*, 1996*d*) are due to zinc and not cadmium. Lead toxicity is not considered to be a problem relative to the other metals, although all elements may be important in the context of food chain transfer (not considered here).

Table 35. Total monthly and annual aerial emissions of lead, zinc and cadmium from the Avonmouth smelting works during 1993 from values supplied by Britannia Zinc Ltd. (see Appendix A for full details). Cu emissions are not measured by the factory.

	Pb	Zn	Cd
Jan	2.4	13.5	0.4
Feb	2.7	6.1	0.2
Mar	2.5	6.9	0.2
Apr	2.7	4.9	0.2
May	2.7	7.6	0.3
Jun	2.0	4.7	0.1
Jul	1.8	5.4	0.2
Aug	2.1	9.3	0.2
Sep	3.0	16.6	0.3
Oct	2.4	6.9	0.2
Nov	1.7	9.8	0.2
Dec	1.8	5.4	0.3
Mean	2.3	8.1	0.2
Tonnes yr^{-1}	20.3	70.9	2.1

One of the most obvious effects of the pollution in the vicinity of the smelting works is a large build up of undecomposed leaf-litter on the soil surface (Hopkin *et al.* 1985; Martin & Bullock 1994). The most likely explanation of this phenomenon would be absence of earthworms which, if present, would help to degrade much of this material. However, other soil invertebrates are also involved in the decomposition process and it was decided in 1993 to conduct a detailed survey of the distribution and abundance of these animals to see whether the metal pollution of the soils was reducing biodiversity.

5.3. Why Monitor Biodiversity at Avonmouth?

Hopkin (1993*a*) and Walker *et al.* (1996) recognise four main types of *in situ* biological monitoring of pollution. *Type 1 biomonitoring* measures effects on communities looking for changes in species abundance and diversity in comparison to 'control' unimpacted sites. *Type 2 biomonitoring* measures concentrations of pollutants in organisms. *Type 3 biomonitoring* determines effects of contaminants which at the biochemical level are often known as 'biomarkers'. *Type 4 biomonitoring* studies the evolution of genetic resistance to pollutants. It is envisaged that SOILPACS will concentrate almost exclusively on Type 1 biomonitoring, and this is the approach adopted in the survey described in this report.

It is important to monitor biodiversity and abundance of soil invertebrates because many are intimately involved in major soil processes. The absence of 'keystone' species may result in disruption of ecosystem processes such as litter decomposition and nutrient cycling. From the conservation point of view, loss of biodiversity of any species is considered a 'bad thing' and should clearly be prevented wherever possible. The expectation might be that pollution will result in decreased diversity and abundance but as is shown below, this is not necessarily the case for all organisms.

There are three main approaches to Type 1 biomonitoring of the responses of soil organisms to pollution:

- Follow changes in biodiversity with time (i.e. before, during and after a pollution incident). The main problem with this approach is that much monitoring is reactive rather than proactive and it is not possible to predict where pollution is likely to take place (e.g. Chernobyl), unless the site of a new factory or road is known before it is built.
- Compare biodiversity at impacted sites with that which would be expected if the site were clean. This approach needs extensive knowledge of soil biodiversity on a local and national scale for the species included in any SOILPACS scheme (e.g. local ecological surveys, BRC distribution maps etc.).
- Compare biodiversity along a gradient of pollution from clean to the most polluted. This approach was used in the case study at Avonmouth which is described below.

5.4. Methodology of the Case Study

5.4.1 Digging for earthworms

Twenty two sites were surveyed for earthworms in October 1993 including one 'control' site on the Reading University campus (Fig. 4). All sites were from permanent grassland verges adjacent to minor roads at least 1 metre from the kerb. At each site, four separate quadrats (25 cm x 25 cm) were marked on the soil surface. Soil was dug out to a depth of 40 cm from within each quadrat, hand sorted and all earthworms found returned to the laboratory for identification. This method of collection was preferred due to practical problems with other techniques such as formalin extraction.

5.4.2 Pitfall trapping for surface active arthropods

Five permanent grassland sites were chosen for a study of the seasonal differences in abundances of surface-active invertebrates in the vicinity of the smelting works between March and September 1994 (Fig. 5) (permission was kindly granted by Britannia Zinc Ltd. to use sites 1 and 2). It was not possible to include all the sites that were surveyed for earthworms due to limitations of time and manpower. Soil cores were taken from each site and acid digests were analysed for cadmium, copper, lead and zinc by flame atomic absorption spectrometry. These results (Figs. 6 to 10) show three main features.

- There is a clear decline in metal concentrations with distance from the smelting works from Site 1 to Site 5.
- The levels of metals are much higher at the surface than at depth due to the aerial source of the contamination (with the exception of Site 1 where old smelter slag has been covered with a capping layer at some time in the past).
- Concentrations of metals in the litter at Site 1 are incredibly high. Indeed, the combined amounts of zinc and lead constitute almost 10% of the dry weight of the dead plant material! (Fig. 6).

At each site, six pitfall traps were established at 1 metre intervals, each comprising a plastic vending machine cup filled to a depth of about 4 cm with commercial antifreeze (ethylene glycol). The traps were emptied at monthly intervals and their contents returned to the laboratory for sorting and identification. The sampling occasions were 21 March, 18 April, 16 May, 13 June, 18 July, 15 August and 19 September 1994.

5.4.3 Heat extraction of organisms from soil and litter using Tullgren funnels Two 20 cm x 20 cm quadrats were positioned close to the pitfall traps on each sampling occasion and all the leaf litter, and soil to a depth of 10 cm, were removed from within them and returned to the laboratory. Each sample was placed in a Tullgren funnel consisting of a heat source above (light bulb), and a 1 mm wire mesh over a funnel above a glass beaker containing 70% alcohol. It took about 1 week for all the invertebrates to be extracted from the samples.

5.5. Results

A huge quantity of data was generated during the survey. Indeed it took at least two years with the resources available to sort and identify all the samples. Even then, it was not possible to identify some groups to species due to the lack of identification keys to the UK fauna. The main omissions for faunal keys reside with the mites and Collembola. Both groups were abundant in the samples and there were clearly major differences in the responses of different species to the pollution. However, it was not possible to put specific names to most of the morphotypes due to the ambiguity of many species descriptions in the literature.

It is not possible to include more than a small proportion of the data generated but a few selected examples will be presented to illustrate the main conclusions of the survey.

5.5.1 Earthworms

The results show clear evidence of both reduced abundance and diversity of earthworms near the factory in comparison to more distant sites (Table 36; Fig. 11). There is also evidence of differential sensitivity with species such as *Lumbricus. rubellus* surviving much closer to the smelter than for example *A. caliginosa.*

5.5.2 Orthoptera (grasshoppers and crickets)

Interestingly, far more Orthoptera were collected in the pitfall traps at sites 1 and 2 than in the 'cleaner' sites (Fig.12). Almost all the animals collected were of the grasshopper *Chorthippus albomarginatus*. It is also clear that their abundance was markedly seasonal with almost none appearing until 13 June.

5.5.3 Hemiptera (bugs)

Most bugs showed no obvious relationship with distance from the smelter, except for the conspicuous red and black *Cercopis vulnerata* which was much more common near to the factory (Fig. 13). However, this species was only found between 16 May and 18 July.

5.5.4 Beetles

Ground beetles (Carabidae, Fig. 14) and rove beetles (Staphylinidae, Fig 15) showed no clear trends although there is a suggestion that the carabids were more common at intermediate sites. The lack of any obvious species-specific responses suggests that beetles may not be suitable for a SOILPACS programme.

5.5.5 Spiders

Almost all the spiders which fell into the pitfall traps were money spiders (Linyphiidae, Fig. 16) or wolf spiders (Lycosidae, Fig. 17). While the money spiders had similar abundances at all sites, it is clear that the wolf spiders were much more common near the factory. It is possible that this increased abundance was an indirect response to the metal pollution which suppresses vegetation growth, hence providing open areas with greater insolation in which the spiders can hunt more successfully.

5.5.6 Woodlice

No woodlice were collected in pitfall traps at site 1, and very few at site 2 (Fig. 18). They were quite common at sites 3 and 5 but at site 4, there were fewer individuals than might have been expected. The reason for their relative absence at site 4 is not known. The overall trend, however, is for a reduction as one approaches the smelter (also seen by Hopkin *et al.* 1986).

5.5.7 Myriapoda (centipedes and millipedes)

Centipedes manage to survive in similar abundances at all sites, but millipedes were not present at sites 1 and 2 (Fig. 19). Most of the centipedes collected were the small *Lithobius microps* although at site 1, the dominant species was the large *Cryptops parisi*, a characteristic species of urbanised habitats.

5.5.8 Mites

Due to the taxonomic problems outlined above, mites were only sorted into oribatids and 'the rest'. In the Tullgren funnel litter samples (Fig. 20), there is a suggestion of reduced numbers near the factory and this is clearer in the Tullgren funnel soil samples (Fig. 21). However, close examination of the mites in each sample showed that there were clearly differences in species composition which would repay more detailed analysis if an identification key were available.

5.5.9 Collembola (springtails)

The pooled samples of Collembola show evidence of an overall reduction in numbers as one approaches the smelter (Figs. 22, 24, 26). However, preliminary identification of a few of the more easily recognisable species show clear evidence of species-specific responses to the pollution. Thus while *Lepidocyrtus lanuginosus* manages to survive in quite high numbers at site 1, *Orchesella villosa* is absent (Fig. 23). *Isotomurus palustris* was very abundant at site 3 but only until 16 May when it 'died out' (Figs. 22, 24). There were many specimens in the soil and leaf litter which could be assigned to the genus Protaphorura, but these could not be given a specific name due to the taxonomic problems outlined in Table 37. Similar taxonomic problems were encountered with specimens of *Ceratophysella* and *Hypogastrura* (see appendix B, C).

5.6. Discussion

5.6.1 Sampling methodology

While digging might be regarded as a relatively crude sampling technique, it has proved to be very effective at Avonmouth allowing a large number of sites to be surveyed in a single day. There is no sorting, and identification of earthworms is relatively straightforward.

Setting up and collection of the pitfall trap samples was quite easy. However the traps need to be placed in an inconspicuous positions to avoid vandalism. We have encountered considerable problems at Avonmouth with a farmer who has taken exception to our fieldwork, even though none of it is conducted on his land. Nevertheless, due to careful positioning of the traps, we only lost a single sample throughout the whole survey (it was run over by a tractor at site 1). The samples themselves require three stages of sorting 1) removal of soil, fragments of vegetation, and other unwanted material, 2) sorting to major taxonomic groups and 3) specific identification. A huge number of samples were generated and it has taken the equivalent of approximately one 'man year' for the task to be completed. However, this time period would be much reduced in subsequent surveys as much of the time was taken up with acquisition of identification skills. The samples also take up quite a volume if they are to be permanently stored.

Collecting the soil and leaf litter samples was very straightforward and could be accomplished at the same time as attending to the pitfall traps. However Tullgren funnels take up quite a lot of space in a laboratory where they have to be set up for at least a week to ensure full extraction of the invertebrates. Although there is no preliminary sorting stage (the samples below the funnels remain quite 'clean'), the organisms in soil and litter tend to be much smaller and difficult to identify than the material which falls into the pitfall traps. There are similar problems with storage as are encountered with pitfall trap samples. This part of the project also took about one 'man year' to accomplish.

5.6.2 Frequency of sampling

In any SOILPACS scheme, it is important that account be taken of the seasonal variation in the abundances of some groups. At the very minimum, sampling should take place in Spring, Summer and Autumn. Preliminary observations on populations of earthworms since October 1993 has shown that they are quite difficult to find during the late Autumn, Winter, early Spring, and during the hottest summer months.

5.6.3 Which organisms to monitor?

The organisms that SOILPACS should focus on are those which show a clear negative response to pollution. From this survey, the most promising candidates would appear to be woodlice, millipedes, earthworms, and mites and Collembola assuming the taxonomic problems are resolved. These are all primary consumers and their absence from a site would be expected to result in reduced decomposition and possible disruption of other soil processes. The taxonomic problems in Collembola are illustrated below.

5.6.4 Taxonomic problems with Collembola

Collembola (springtails) are widespread and abundant wingless insects which occur in soils and leaf litter in densities of 20,000 m^{-2} or more (Hopkin 1997). A typical UK woodland or permanent grassland would be expected to support 30 to 40 species so they have great potential as components of a SOILPACS scheme. However, there is no identification key to the group in Britain and foreign guides are either out-of-date, or omit many of our species. As part of this feasibility study, a new checklist of Collembola was prepared based on all literature records from the 19th century to the present day (this database was also used for the preparation of preliminary distribution maps included in the following section). There are 392 names on the list, but only 92 of these have been recorded more than 15 times from Britain. For example, there are 38 'species' of *Protaphorura* on the checklist (Table 37) but some taxonomists consider that almost all of these are varieties of a much smaller number of species, possibly as few as one or two!

In order to further illustrate the problems, a detailed study of the genera *Brachystomella*, *Ceratophysella* and *Hypogastrura* was undertaken in the light of recent taxonomic developments. Of the 24 species on the British list, only six can unequivocally be regarded as present in the UK with another four as probable residents. The presence of a further ten species needs to be confirmed and the remaining four are synonyms of other species. There are similar, if not worse taxonomic problems in other Collembola genera (e.g. *Protaphorura*, Table 37).

5.7. Conclusions and Recommendations

Details of an extensive study of the arthropod fauna at the sites of increasing distance from the primary cadmium, lead and zinc smelter in Avonmouth was provided as part of this report to show the overall community effects of extreme metal contamination. Contrary to expectations although there was a general reduction in the diversity of different taxonomic groups, not all were absent from the most polluted sites. Indeed, some, for example, the grasshoppers and lycosid spiders, were actually found in greatly increased numbers closest to the smelter. Explanations for this phenomenon differ between the groups, but a major factor in all increased occurrences is the effect of reduced competition. Species one would expect to be dominant are unable to tolerate the high metal concentrations making it possible for those species that are less effective competitors, but more metal tolerant, to be dominant. However, some groups did show clear reductions in abundance at or even total absence from the most contaminated localities, for example, millipedes, oribatid mites and woodlice. The effects of metals pollution on the arthropod communities are highly complex. It appears that the groups most severely affected by contamination are all primary consumers. Clearly, this has serious implications for the decomposition processes at localities such as Avonmouth.

- Hand searching, pitfall trapping and Tullgren funnels have been successfully used at Avonmouth to demonstrate effects of metal pollution from the smelter on soil biodiversity. However the number of replicates, frequency of sampling and density of sites have not been examined in relation to their ability to reflect the total composition of the fauna. Some sort of pilot scheme would need to be conducted to determine say, what level of sampling intensity would be needed to sample X% of the fauna (X depending on the level of available resources)
- The study has taken a total of about two man years to carry out. By far the greatest time was taken in sorting and identification of material. Fieldwork was relatively labour unintensive. While the sorting could be carried out by relative non-experts (i.e. casual labour), the identification needs some expertise and it would be much more cost-effective to employ such staff on longer term contracts. As a rough guide, it takes approximately one man day to deal with one sample (single earthworm sample, single pitfall trap, single Tullgren funnel sample) from collection through to sorting and identification.
- Single site monitoring is not recommended as it would not take account of the natural background variations in invertebrate populations that occurs between clean sites.

- Single occasion sampling is also not to be recommended as it does not take account of seasonal variations.
- It needs to be recognised that some organisms seem to be unaffected by aerial metal pollution at Avonmouth, indeed lycosid spiders in particular appear to prosper near the factory. SOILPACS 'indicators' need to be chosen with this in mind. Responses are also likely to be pollutant-specific; some organic chemicals may seriously affect lycosid spiders even though they appear insensitive to metals.
- The most promising organisms to include in a SOIPACS 'suite' of indicator organisms would appear to be primary consumers namely earthworms, woodlice and millipedes. Full interpretation of the effects of pollutants on two of the most promising indicator groups, mites and Collembola, is inhibited by the lack of identification keys, lack of national distribution maps and out of date taxonomy. These problems need to be resolved before their potential use as SOILPACS indicators can be confirmed.

Table 36 Total number of earthworms collected from four 0.25m x 0.25m quadrats at 22 sites. SD of mean given in brackets. Asterisk indicate sites significantly different from the control at * $p < 0.05$ ** $p < 0.02$ (n.s. = not significant). Sites in **bold** type were used for the field soil toxicity tests (see Section 4.2 and Chapter 6).

	Total Number (No/m²)	*L. terrestris* (No/m²)	*L. rubellus* (No/m²)	*L. castaneus* (No/m²)	*A. chlorotica* (No/m²)	*A. rosea* (No/m²)	*A. caliginosa* (No/m²)	*O. t. tytyrtaeum* (No/m²)
Site 1	0**	0	0	0	0	0	0	0
Site 2	0**	0	0	0	0	0	0	0
Site 3	0**	0	0	0	0	0	0	0
Site 4	0**	0	0	0	0	0	0	0
Site 5	0**	0	0	0	0	0	0	0
Site 6	18* (± 5.2)	3 (± 3.8)	15 (± 6.8)	0	0	0	0	0
Site 7	10* (± 5.2)	0	1 (± 2)	9 (± 5)	0	0	0	0
Site 8	0**	0	0	0	0	0	0	0
Site 9	32 n.s. (± 16.3)	4 (± 4.6)	13 (± 8.3)	10 (± 5.2)	5 (± 5)	0	0	0
Site 10	11* (± 6.7)	1 (± 2)	2 (± 4)	8 (± 5.7)	0	0	0	0
Site 11	10* (± 5.7)	2 (± 4)	2 (± 4)	1 (± 2)	1 (± 2)	4 (± 3.3)	0	0
Site 12	9 (± 13.2)	1 (± 2)	2 (± 2.3)	1 (± 2)	3 (± 6)	2 (± 4)	0	0
Site 13	53 n.s. (± 19.7)	2 (± 4)	6 (± 7)	4 (± 5.7)	40 (± 20)	1 (± 2)	0	0
Site 14	42 n.s. (± 22)	3 (± 2)	5 (± 7.6)	3 (± 3.8)	5 (± 6)	9 (± 10.5)	16 (± 5.7)	4 (± 2)
Site 15	18 n.s. (± 4)	4 (± 4.6)	4 (± 0)	1 (± 2)	7 (± 9.5)	1 (± 2)	1 (± 2)	0
Site 16	48 n.s. (± 5.7)	10 (± 9.5)	2 (± 2.3)	6 (± 5.2)	20 (± 11.8)	4 (± 3.3)	6 (± 6.9)	0
Site 17	58 n.s. (± 41.9)	3 (± 3.8)	5 (± 3.8)	14 (± 5.2)	29 (± 33.5)	7 (± 5)	0	0
Site 18	39 n.s. (± 17.4)	15 (± 6)	2 (± 4)	1 (± 2)	0	10 (± 5.2)	11 (± 8.9)	0
Site 19	68 n.s. (± 22.9)	23 (± 10.5)	15 (± 11.5)	3 (± 2)	16 (± 11.8)	10 (± 9.5)	1 (± 2)	0
Site 20	56 n.s. (± 13.9)	1 (± 2)	6 (± 4)	0	3 (± 2)	10 (± 5.2)	36 (± 11)	0
Site 21	34 n.s. (± 11.5)	3 (± 2)	4 (± 3.3)	2 (± 4)	14 (± 13.3)	8 (± 7.3)	3 (± 3.8)	0
Site 22 (control)	45 n.s. (± 25)	12 (± 11.3)	5 (± 6)	0	4 (± 5.7)	16 (± 7.3)	8 (± 7.3)	0

Table 37 : Species of Genus *Protaphorura* Absolon, 1901 (Onychiuridae) recorded from Britain in the check list for Collembola of Kloet and Hinks (1964) and the update of Gough (1978). The 22 species regarded as valid by Bellinger & Christiansen in their world list available over the Internet are shown in bold type. Those not shown in bold are probable synonyms, however, there is no widespread agreement among taxonomists as to how many of the 38 'species' on this list should be considered as true biological species. Some authors go as far as to suggest that there may only be a few variable species and that all the other morphotypes should be considered as varieties.

1. ***Protaphorura alborufescens* (Vogler, 1895)**
2. ***Protaphorura armata* (Tullberg, 1869)**
3. ***Protaphorura aurantiaca* (Ridley, 1880)**
4. ***Protaphorura bagnalli* Salmon, 1959**
5. ***Protaphorura bicampata* Gisin, 1956**
6. ***Protaphorura caledonica* Bagnall, 1935**
7. ***Protaphorura campata* Gisin, 1952**
8. ***Protaphorura debilis* (Moniez, 1890)**
9. ***Protaphorura evansi* Bagnall, 1935**
10. ***Protaphorura fimata* Gisin, 1952**
11. *Protaphorura flavidula* Bagnall, 1939
12. ***Protaphorura furcifera* (Börner, 1901)**
13. ***Protaphorura halophila* Bagnall, 1937**
14. ***Protaphorura hortensis* Gisin, 1949**
15. *Protaphorura humata* Gisin, 1952
16. *Protaphorura imminuta* Bagnall, 1937
17. *Protaphorura lata* Gisin, 1956
18. *Protaphorura magnicornis* Bagnall, 1937
19. *Protaphorura meridiata* Gisin, 1952
20. *Protaphorura nemorata* Gisin, 1952
21. ***Protaphorura octopunctata* (Tullberg, 1876)**
22. *Protaphorura procampata* Gisin, 1956
23. *Protaphorura prolata* Gisin, 1956
24. ***Protaphorura pseudocellata* Naglitsch, 1962**
25. *Protaphorura pulvinata* Gisin, 1954
26. ***Protaphorura quadriocellata* Gisin 1943**
27. ***Protaphorura stachi* Bagnall, 1935**
28. ***Protaphorura subaequalis* Bagnall, 1937**
29. *Protaphorura subarmata* Gisin, 1957
30. *Protaphorura sublata* Gisin, 1957
31. ***Protaphorura subuliginata* Gisin, 1956**
32. ***Protaphorura s-vontoerneri* Gisin, 1957**
33. ***Protaphorura thalassophila* Bagnall, 1937**
34. *Protaphorura tricampata* Gisin, 1956
35. *Protaphorura trinotata* Gisin 1961
36. ***Protaphorura tullbergi* Bagnall, 1935**
37. *Protaphorura uliginata* Gisin, 1952
38. *Protaphorura waterstoni* Bagnall, 1937

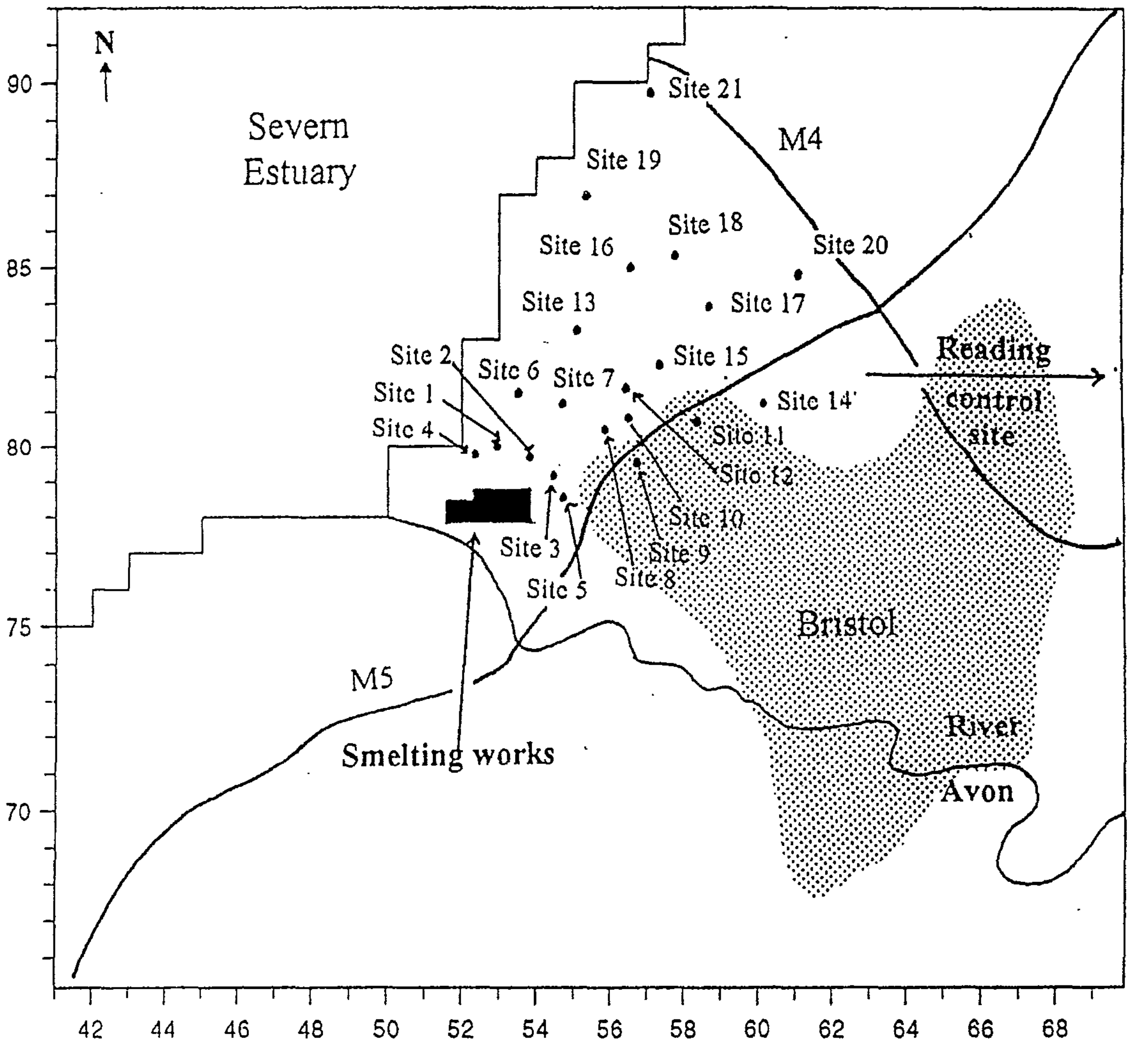


Fig 4 Location of the 22 sites surveyed for earthworms in October 1993 including one control site on the Reading University Campus. Source: Spurgeon & Hopkin (1996c).

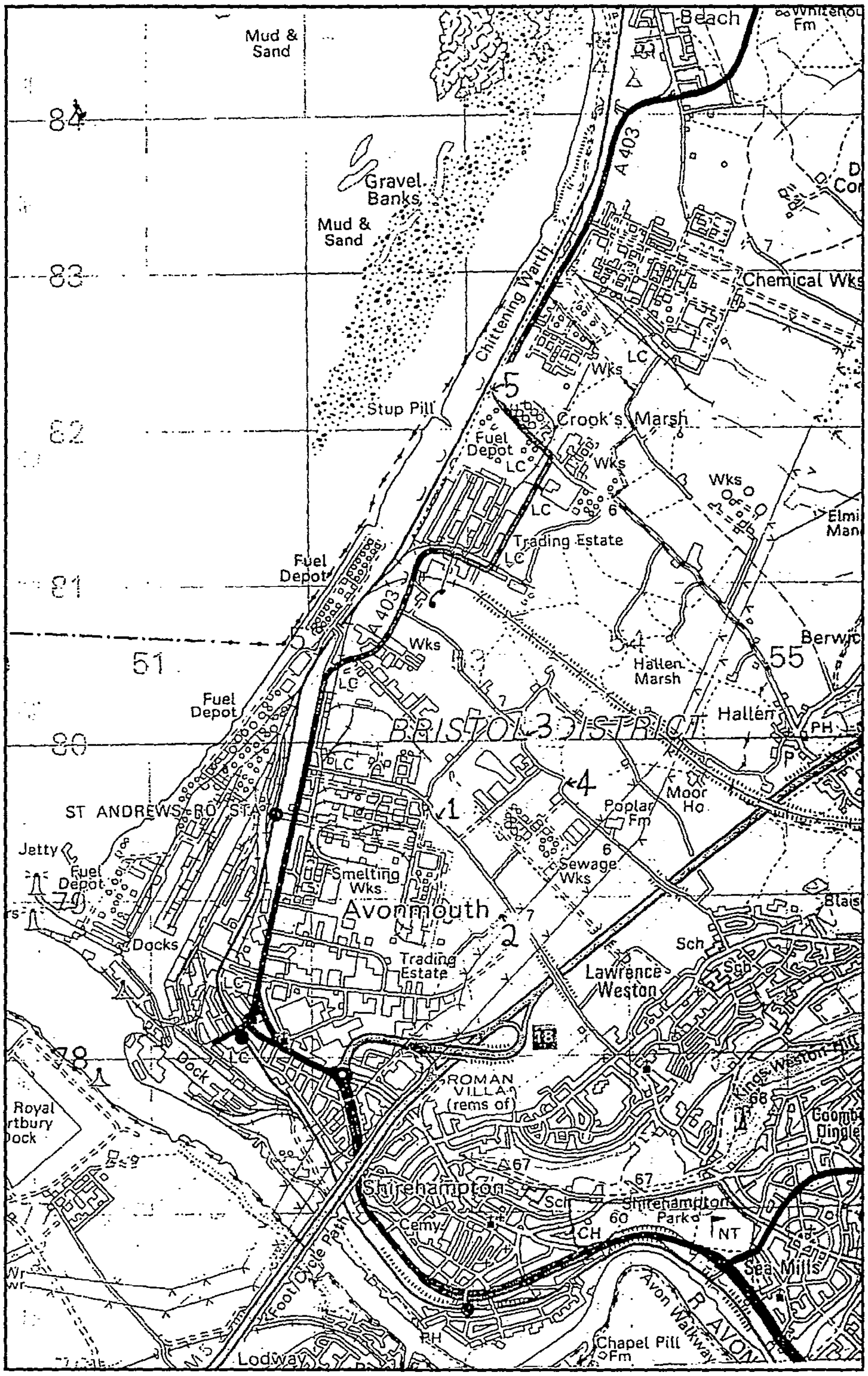


Fig 5. Ordnance Survey map showing sampling area and sites.

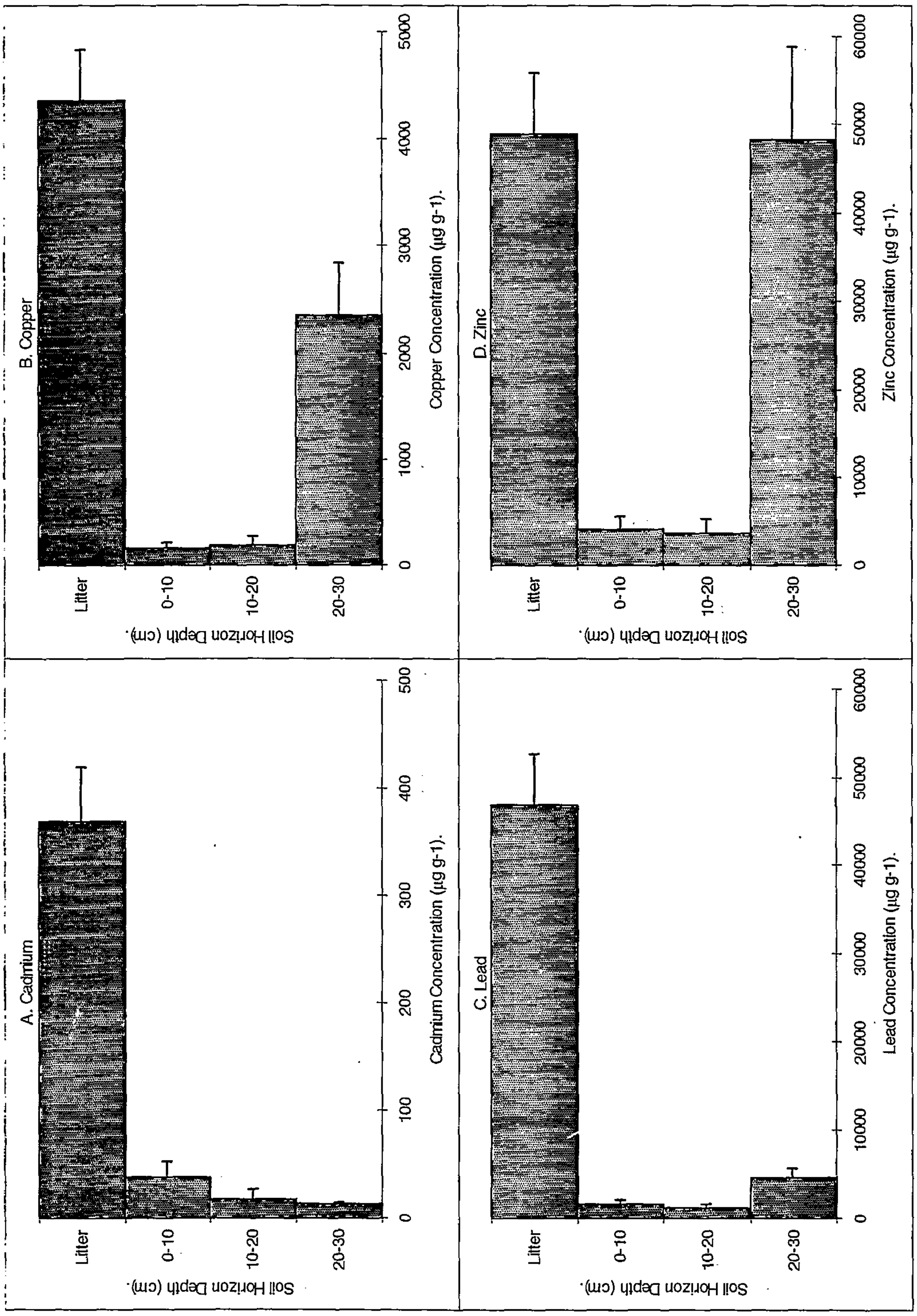


Fig 6. Cadmium, copper, lead and zinc concentrations in soil horizons at site 1 (± standard errors, n=5)

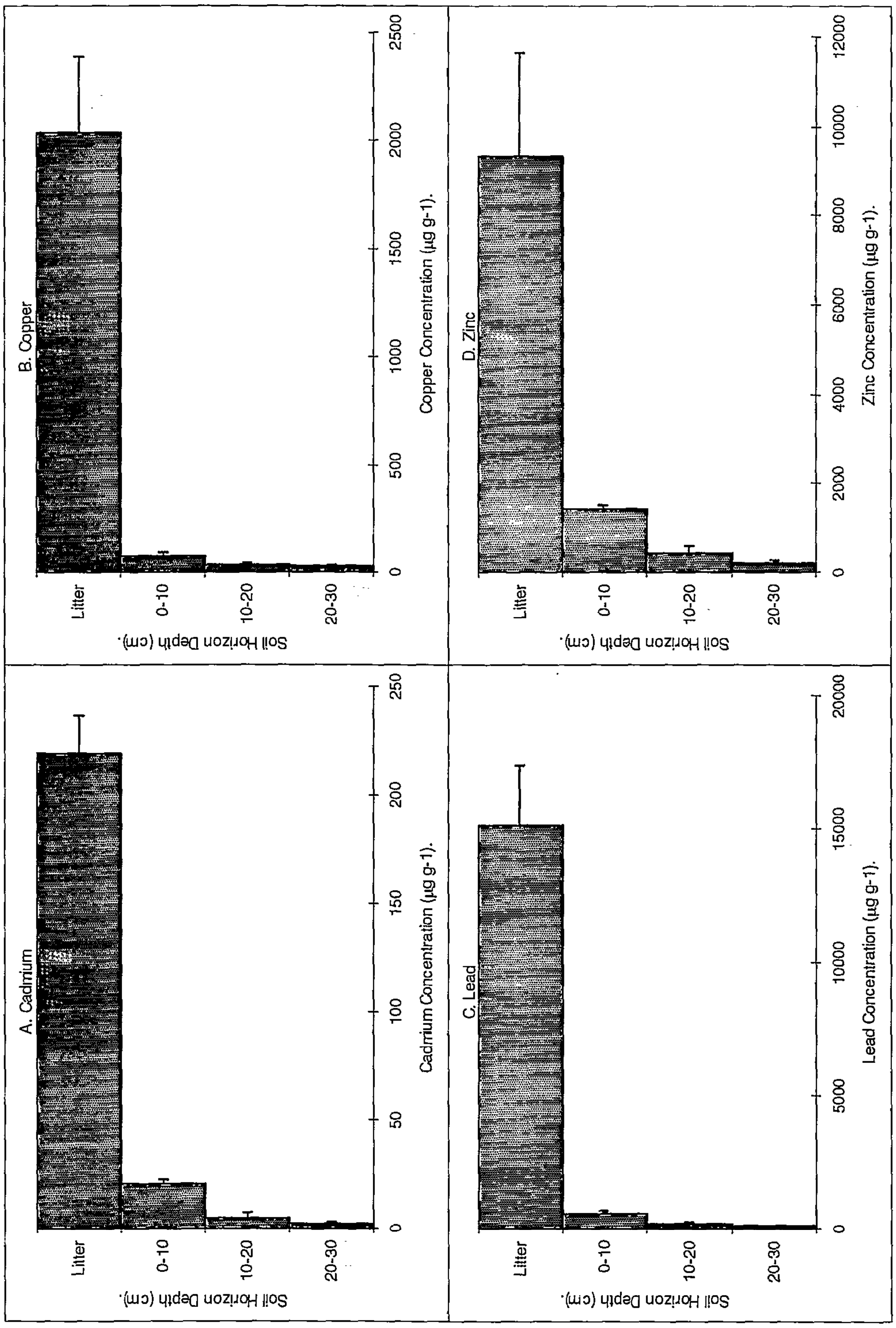


Fig 7. Cadmium, copper, lead and zinc concentrations in soil horizons at site 2 (± standard errors, n=5)

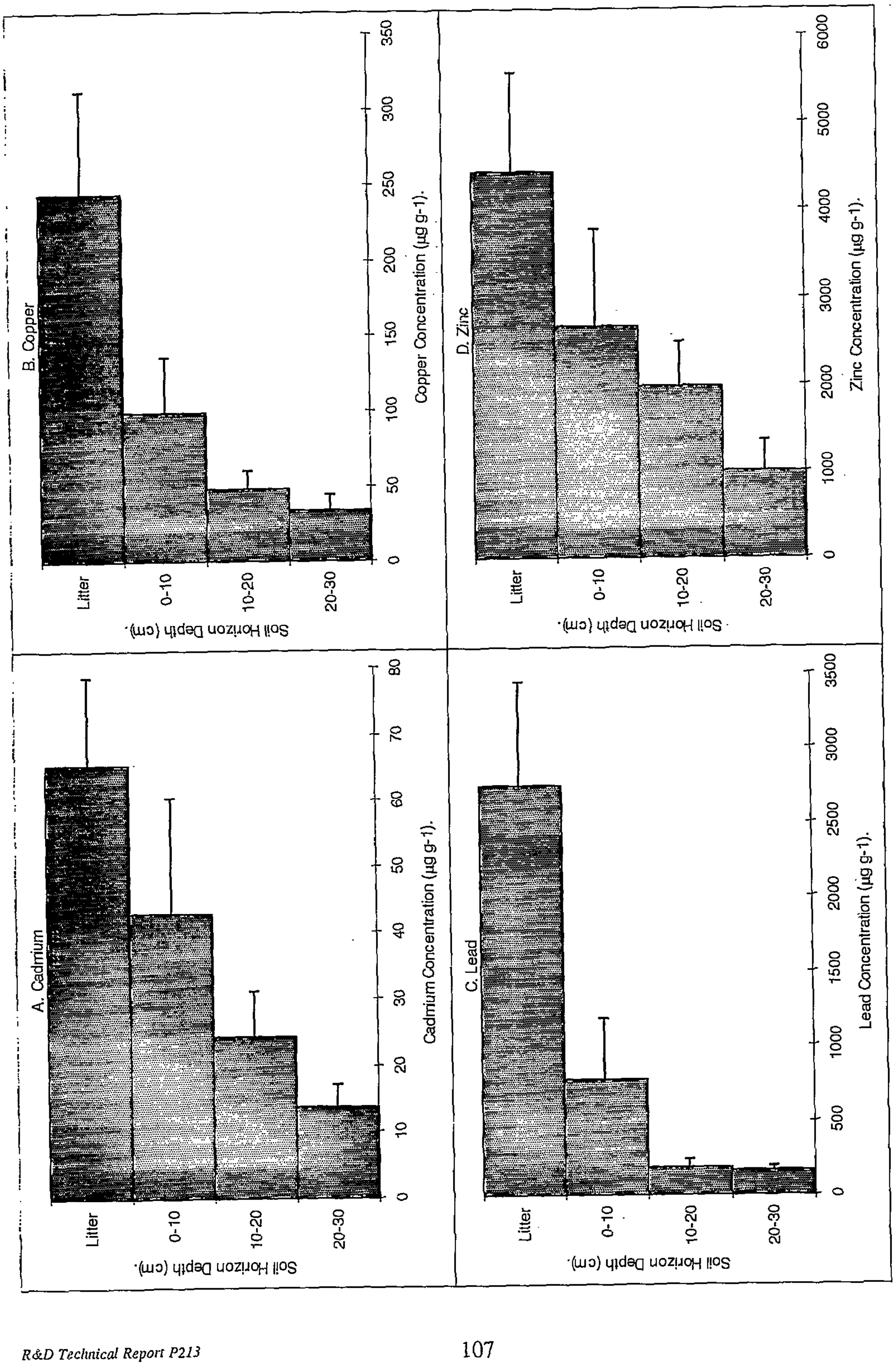


Fig 8. Cadmium, copper, lead and zinc concentrations in soil horizons at site 3 (± standard errors, n=5)

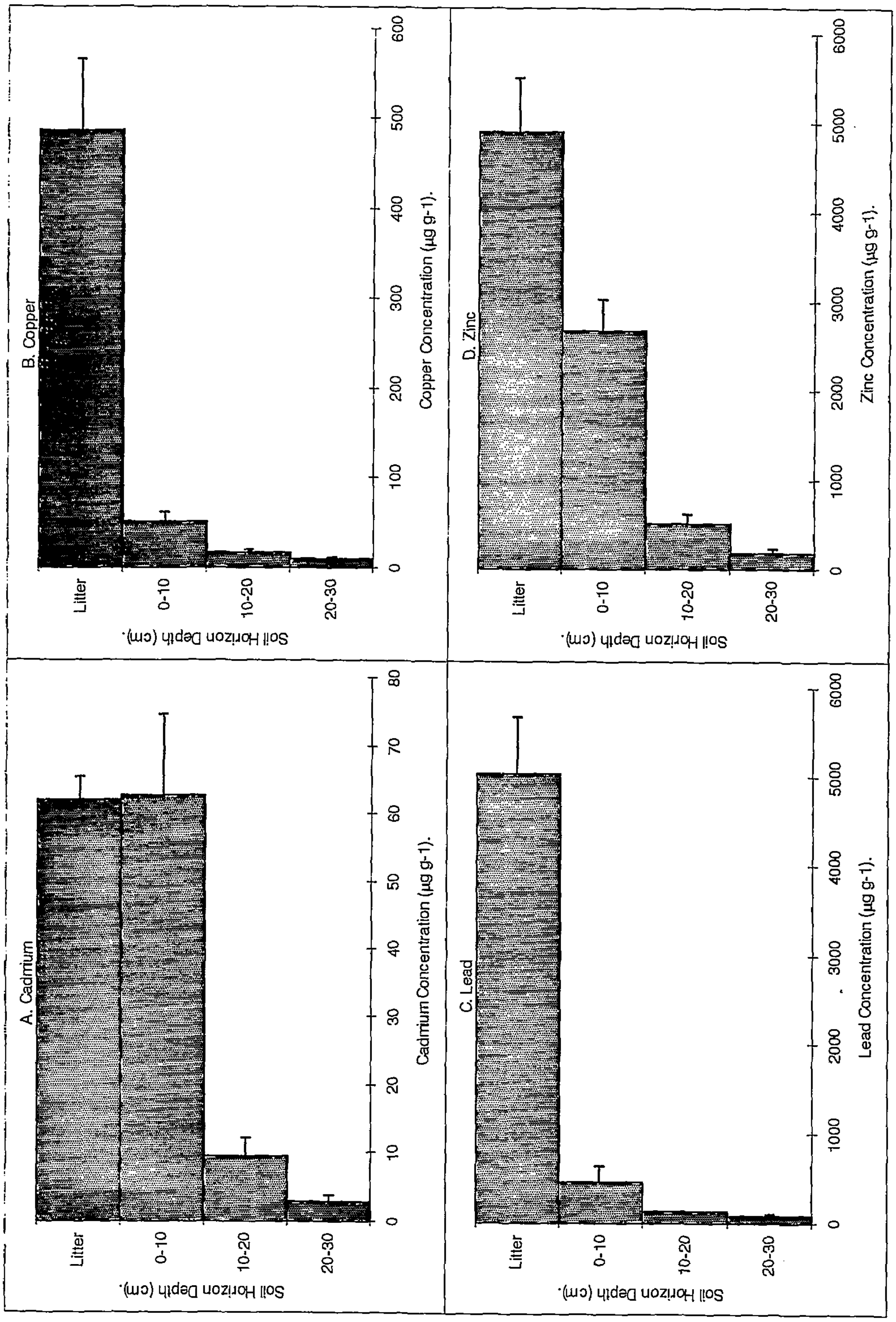


Fig 9. Cadmium, copper, lead and zinc concentrations in soil horizons at site 4 (± standard errors, n=5)

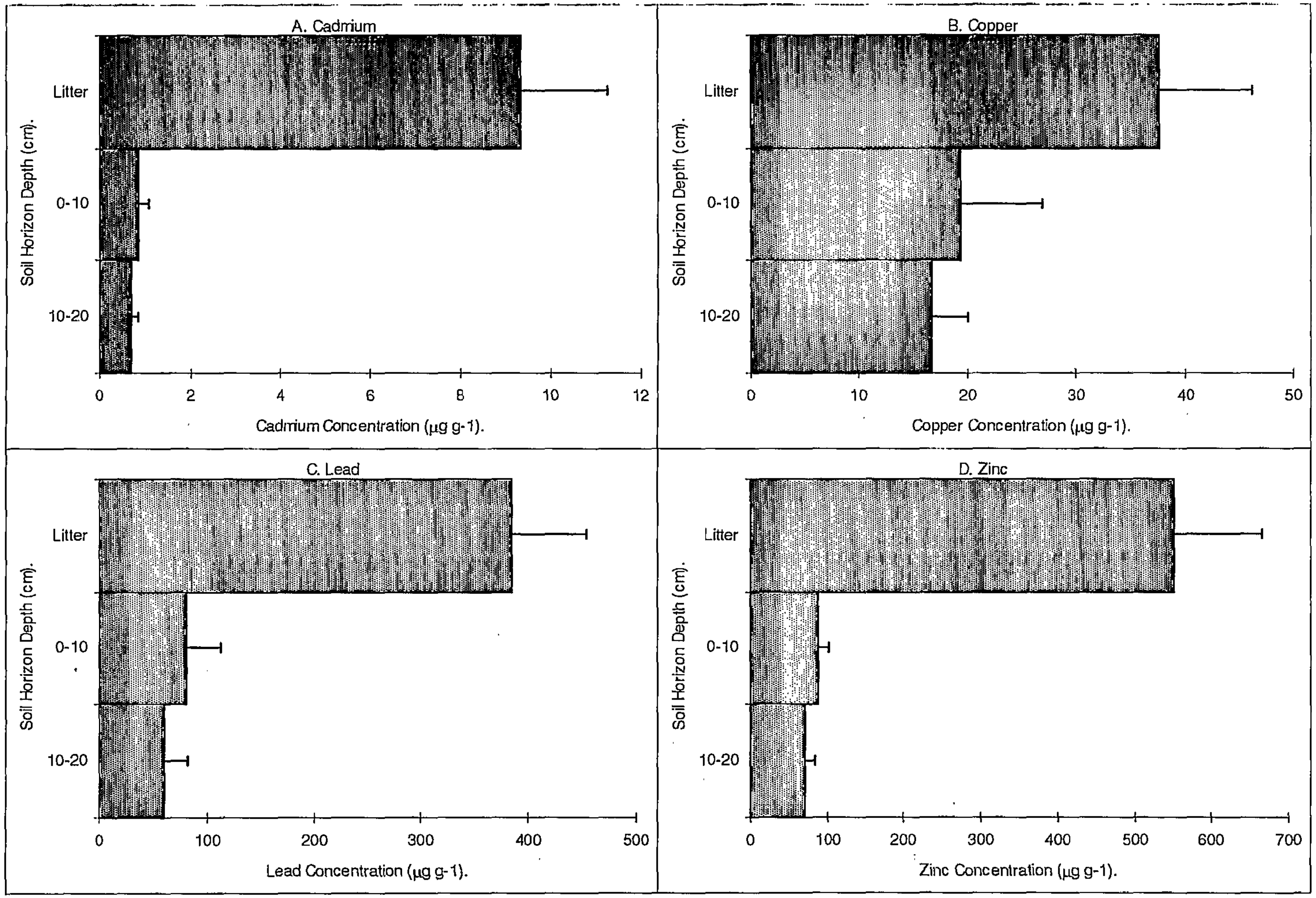


Fig 10. Cadmium, copper, lead and zinc concentrations in soil horizons at site 5 (± standard errors, n=5)

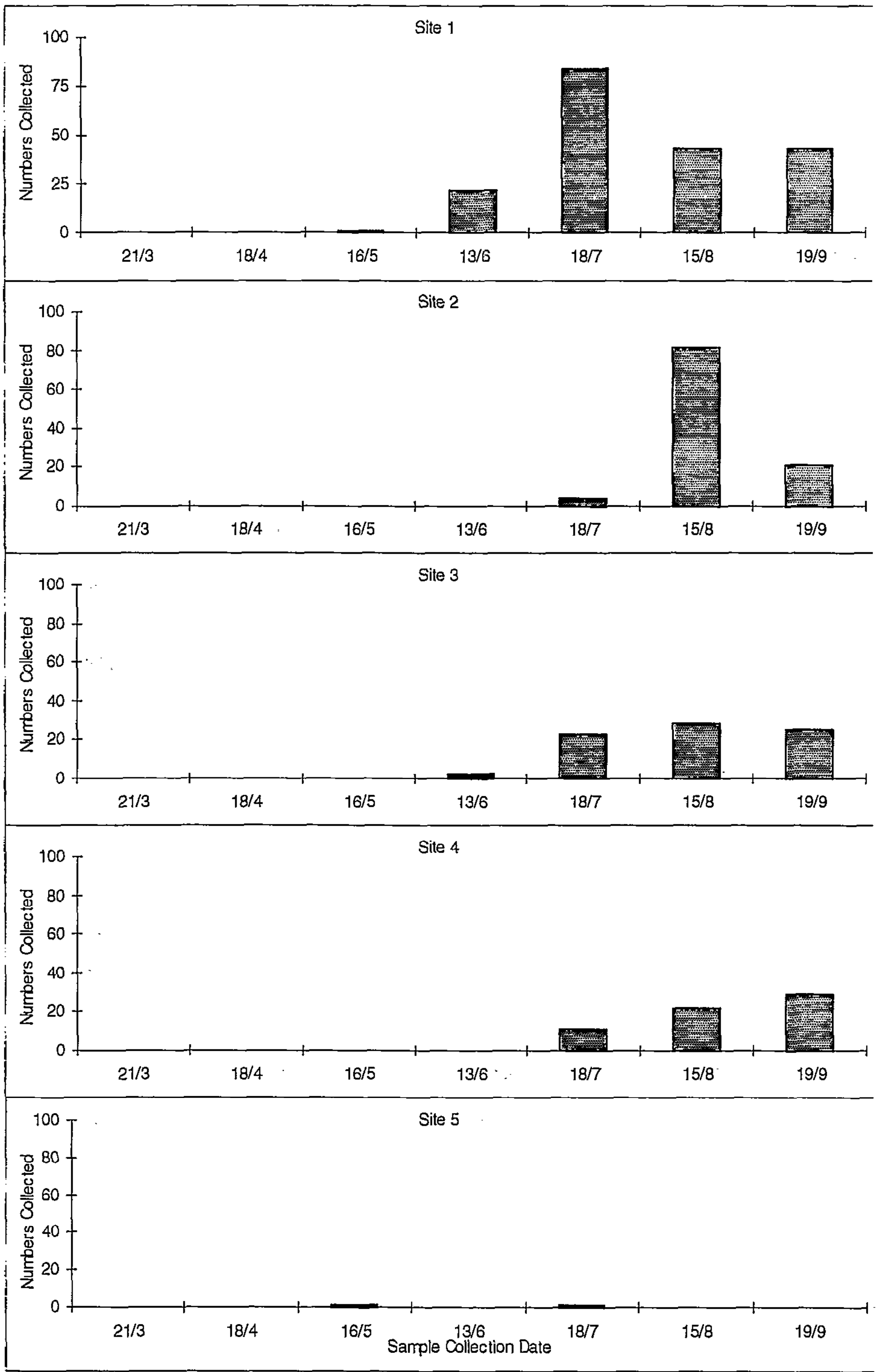


Fig 11. Total numbers of grasshoppers and crickets in pitfall traps at sites 1-5 during 1994.

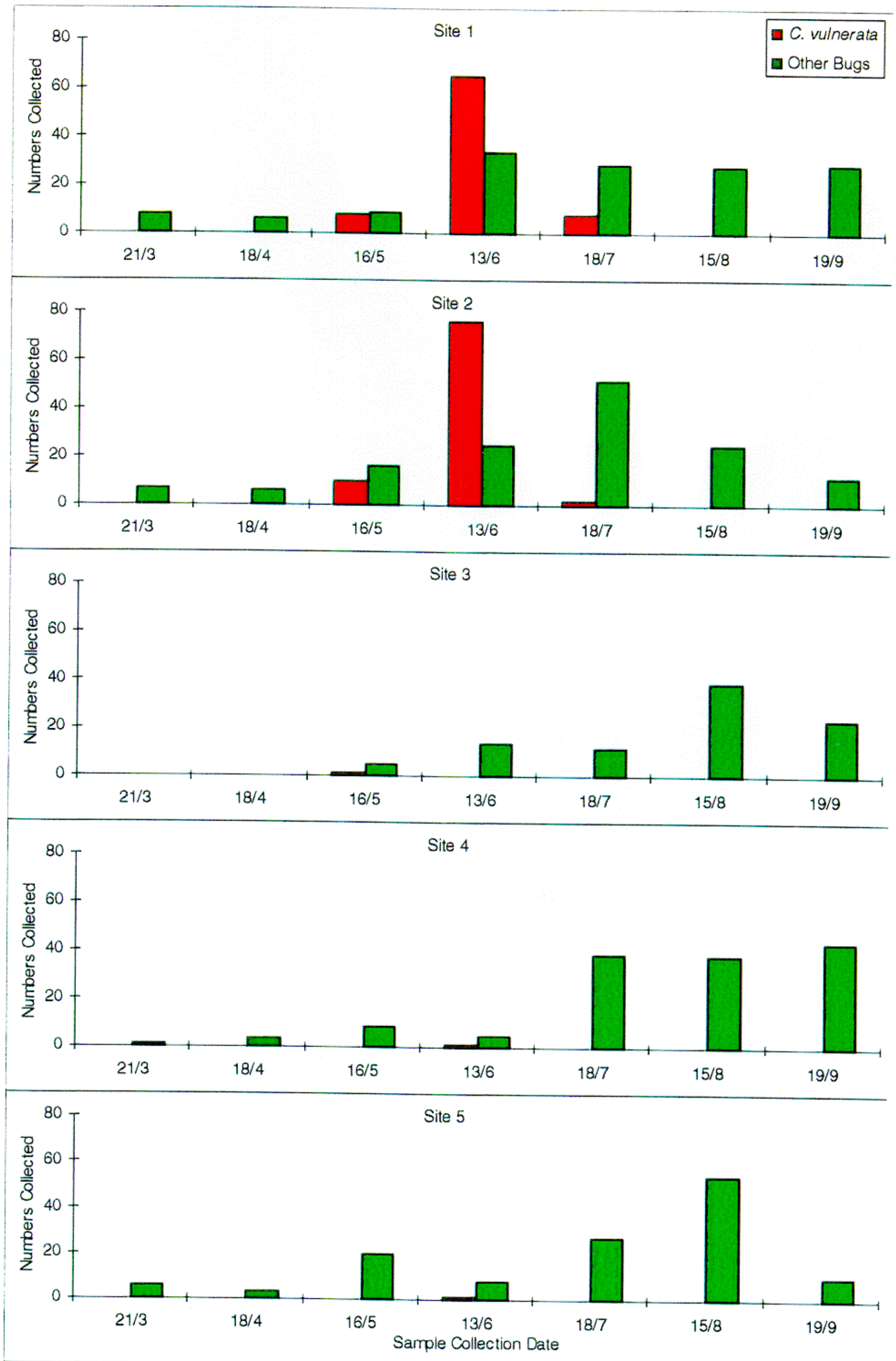


Fig 12. Total numbers of Hemiptera in pitfall traps at sites 1-5 during 1994, showing *Cercopis vulnerata* separately.

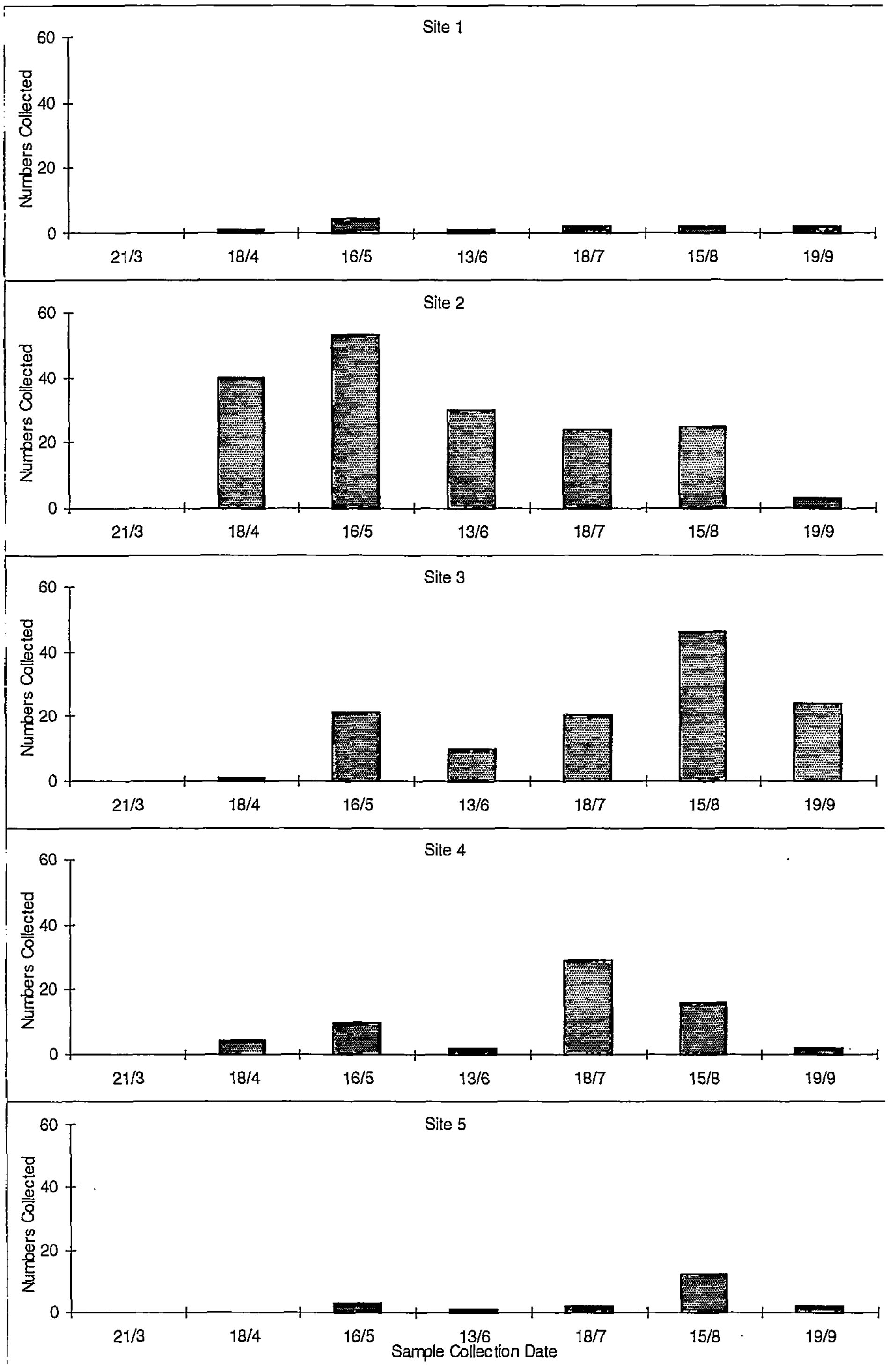


Fig 13. Total numbers of Carabidae in pitfall traps at sites 1-5 during 1994.

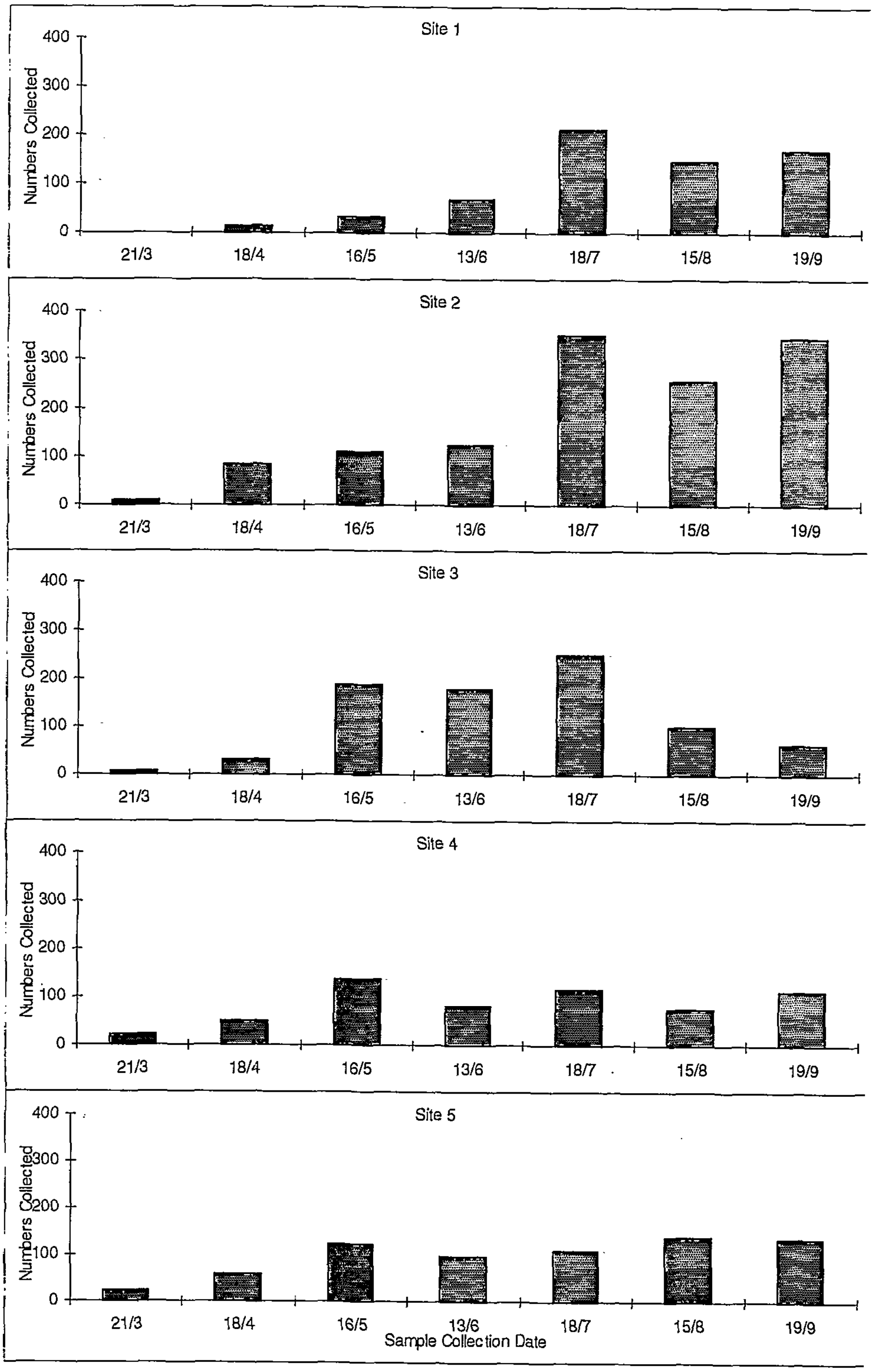


Fig 14. Total numbers of Staphylinidae in pitfall traps at sites 1-5 during 1994.

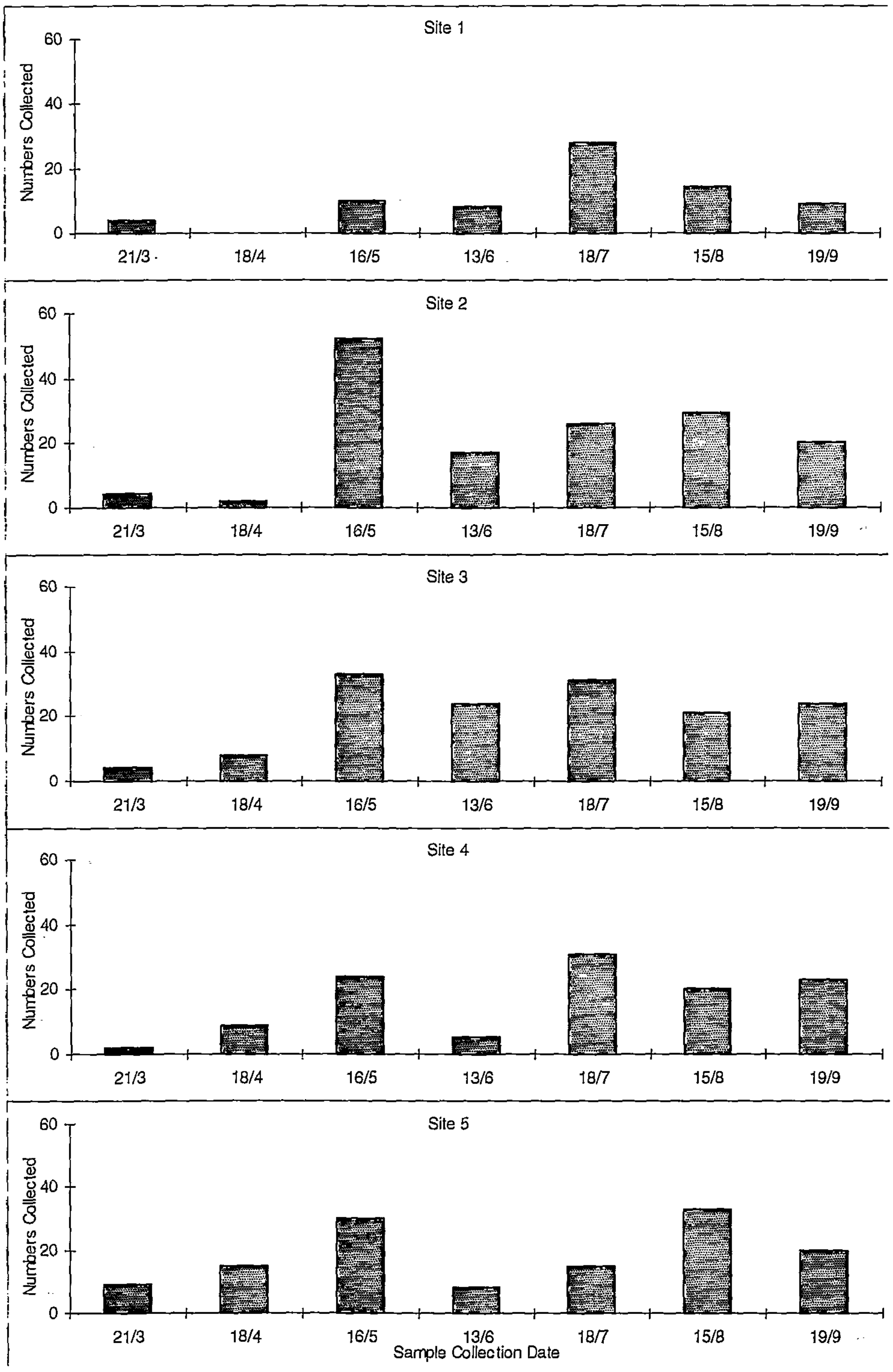


Fig 15. Total numbers of Linyphiidae in pitfall traps at sites 1-5 during 1994.

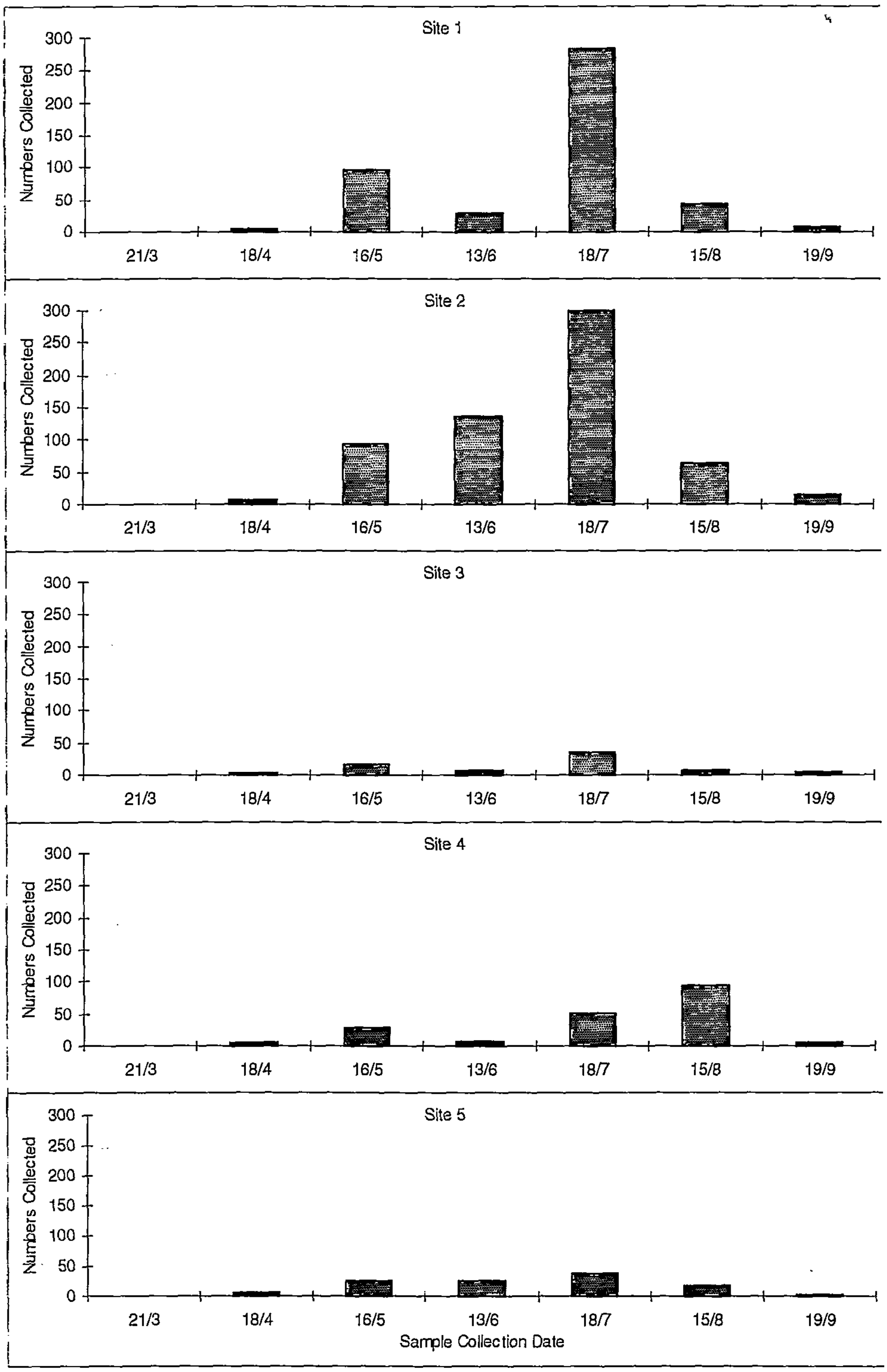


Fig 16. Total numbers of Lycosidae in pitfall traps at sites 1-5 during 1994.

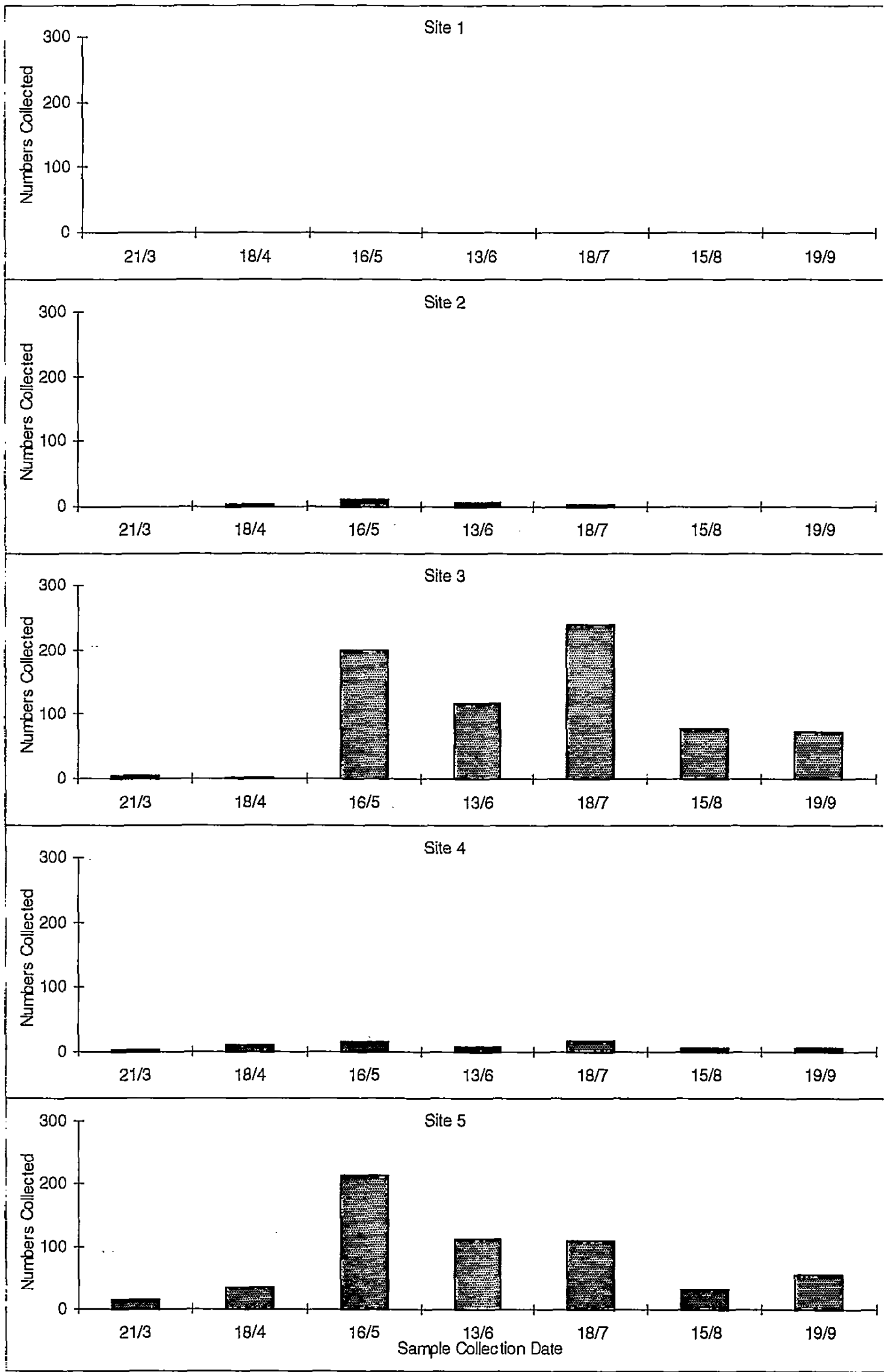


Fig 17. Total numbers of woodlice in pitfall traps at sites 1-5 during 1994.

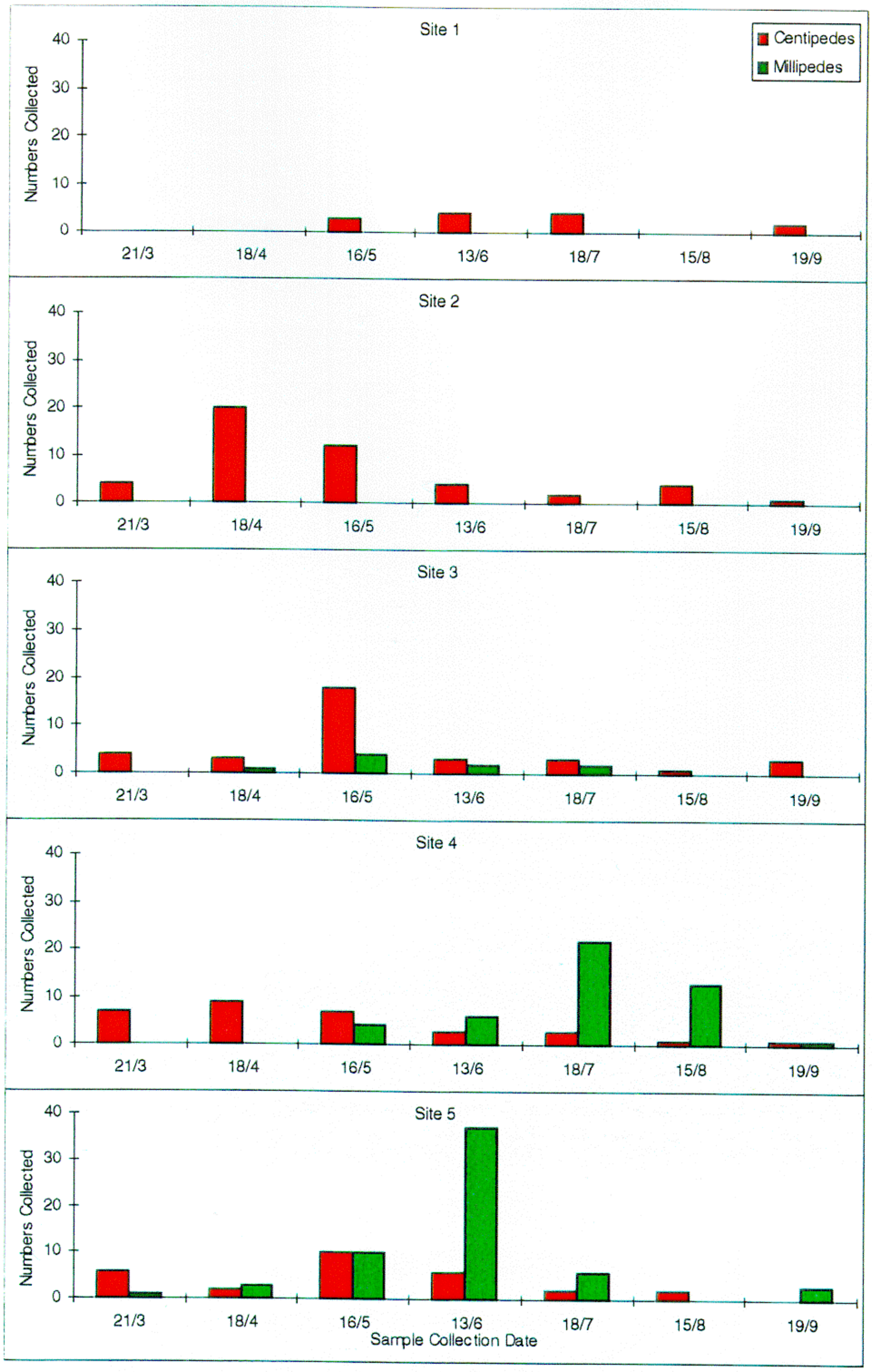


Fig 18. Total numbers of centipedes and millipedes in pitfall traps at sites 1-5 during 1994.

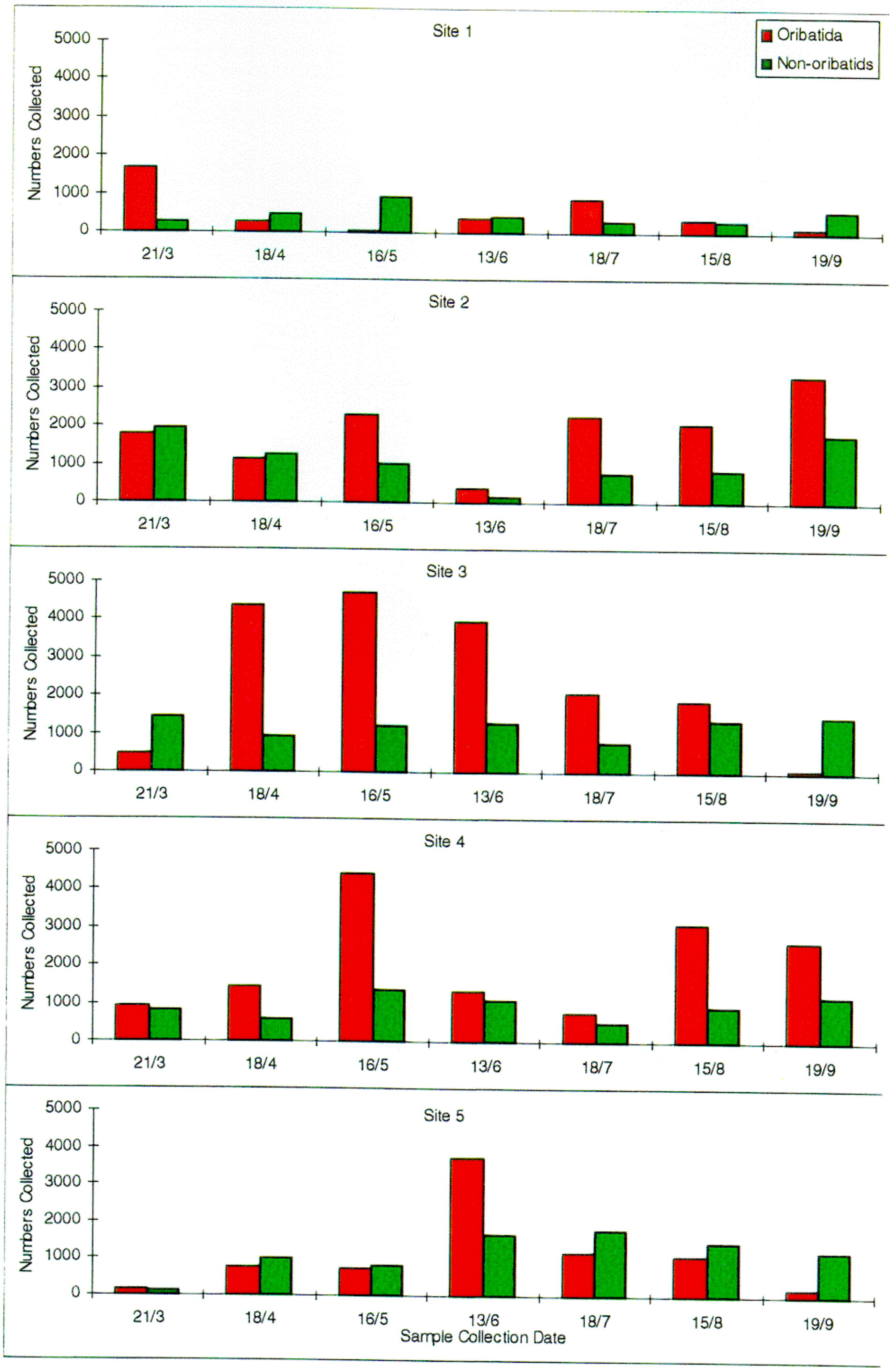


Fig 19. Total numbers of mites in Tullgren funnel litter samples at sites 1-5 during 1994.

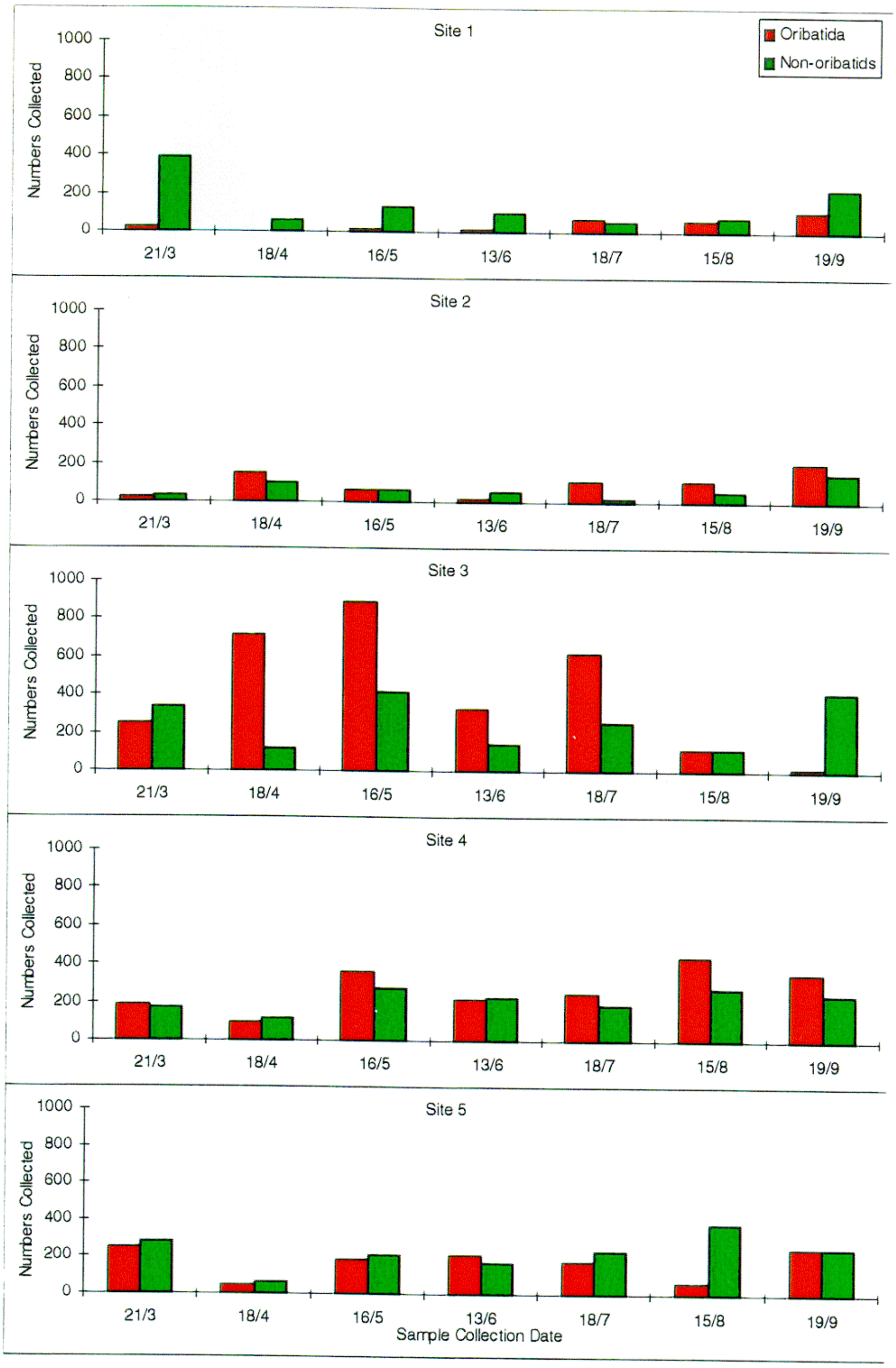


Fig 20. Total numbers of mites in Tullgren funnel soil samples at sites 1-5 during 1994.

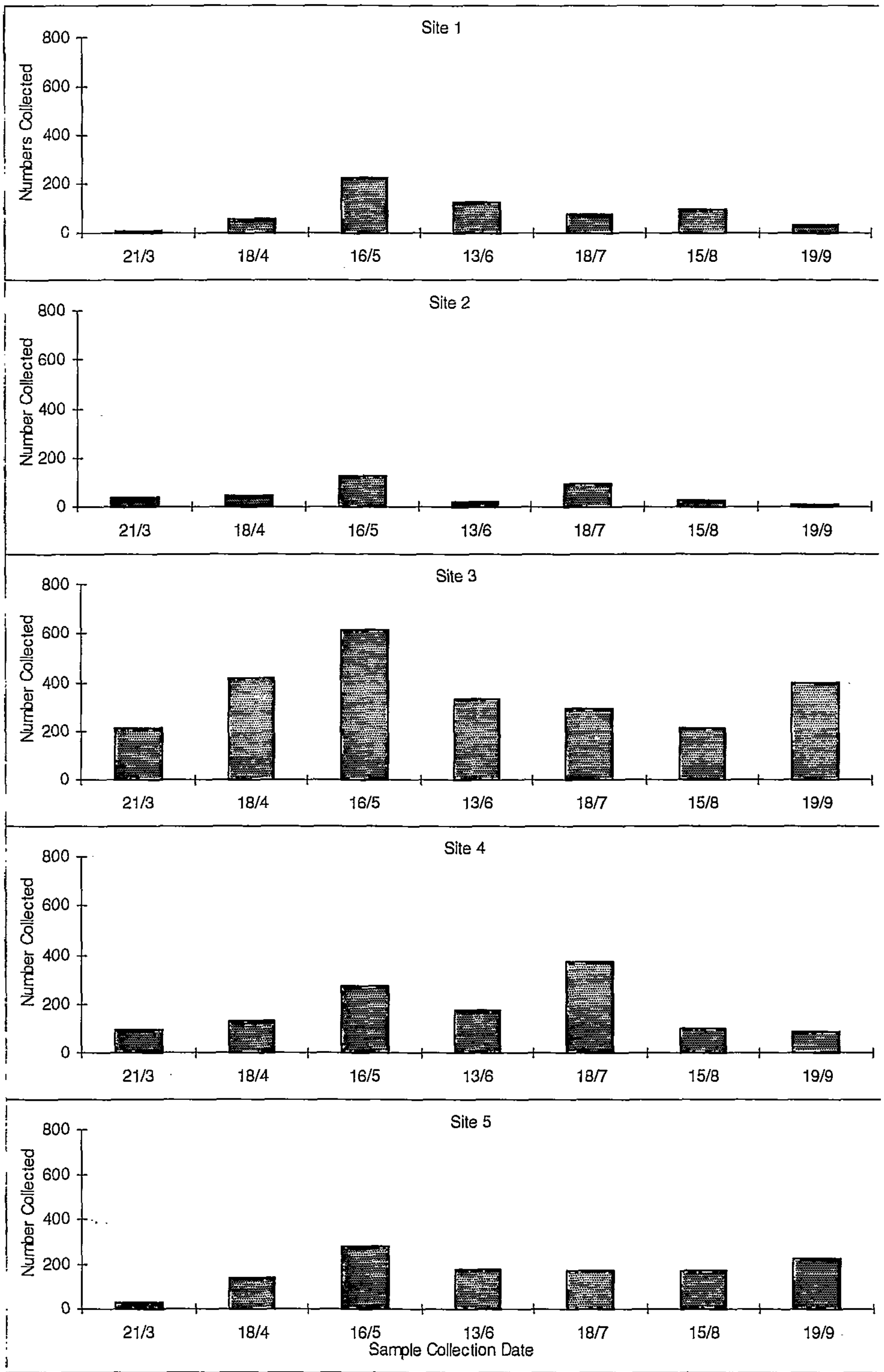


Fig 21. Total numbers of Collembola in pitfall traps at sites 1-5 during 1994.

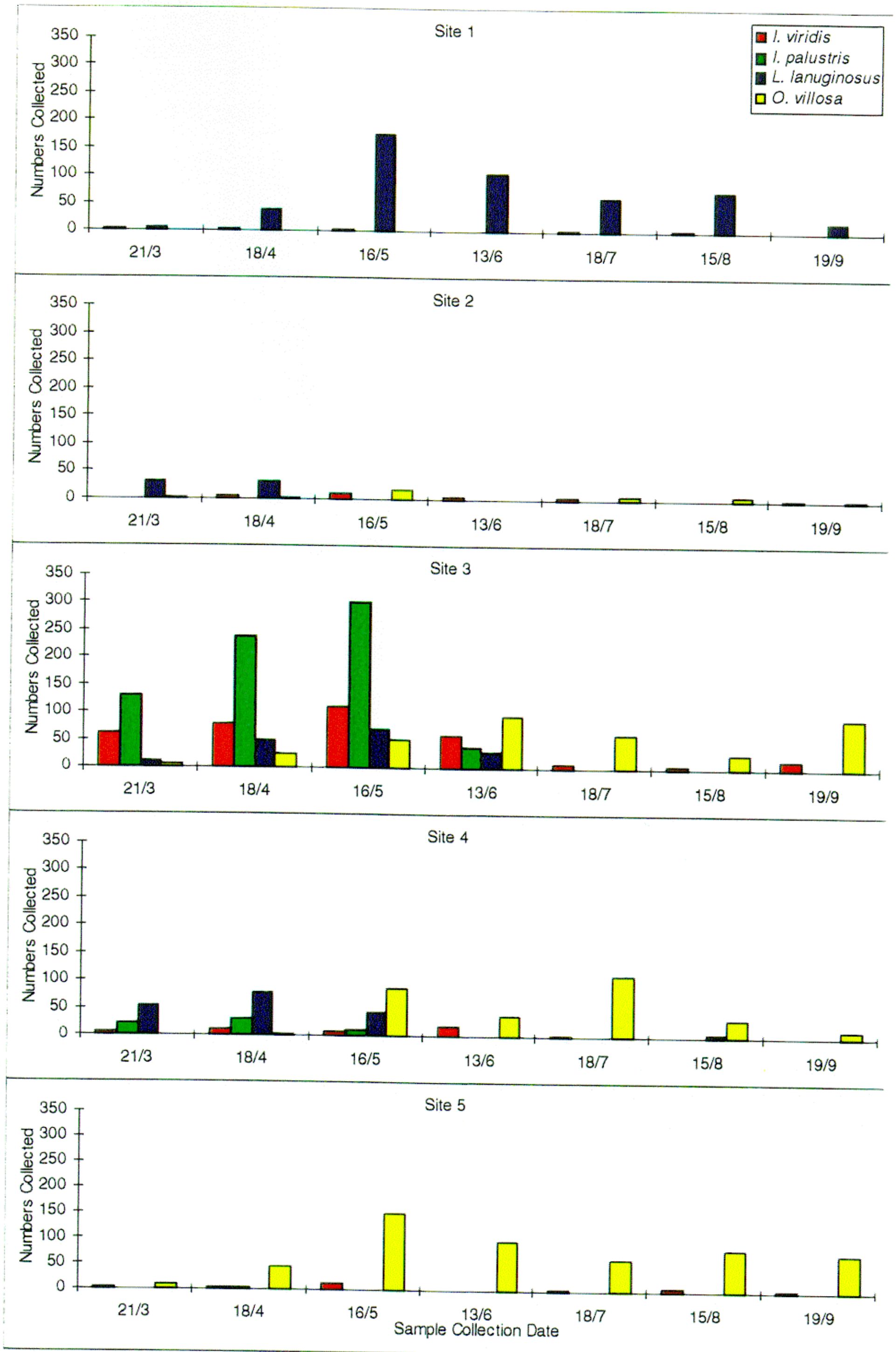


Fig 22. *Osotoma viridis, Isotomurus palustris, Lepidocyrtus, lanuginosus* and *Orchesella cincta* in pitfall traps at sites 1-5 during 1994.

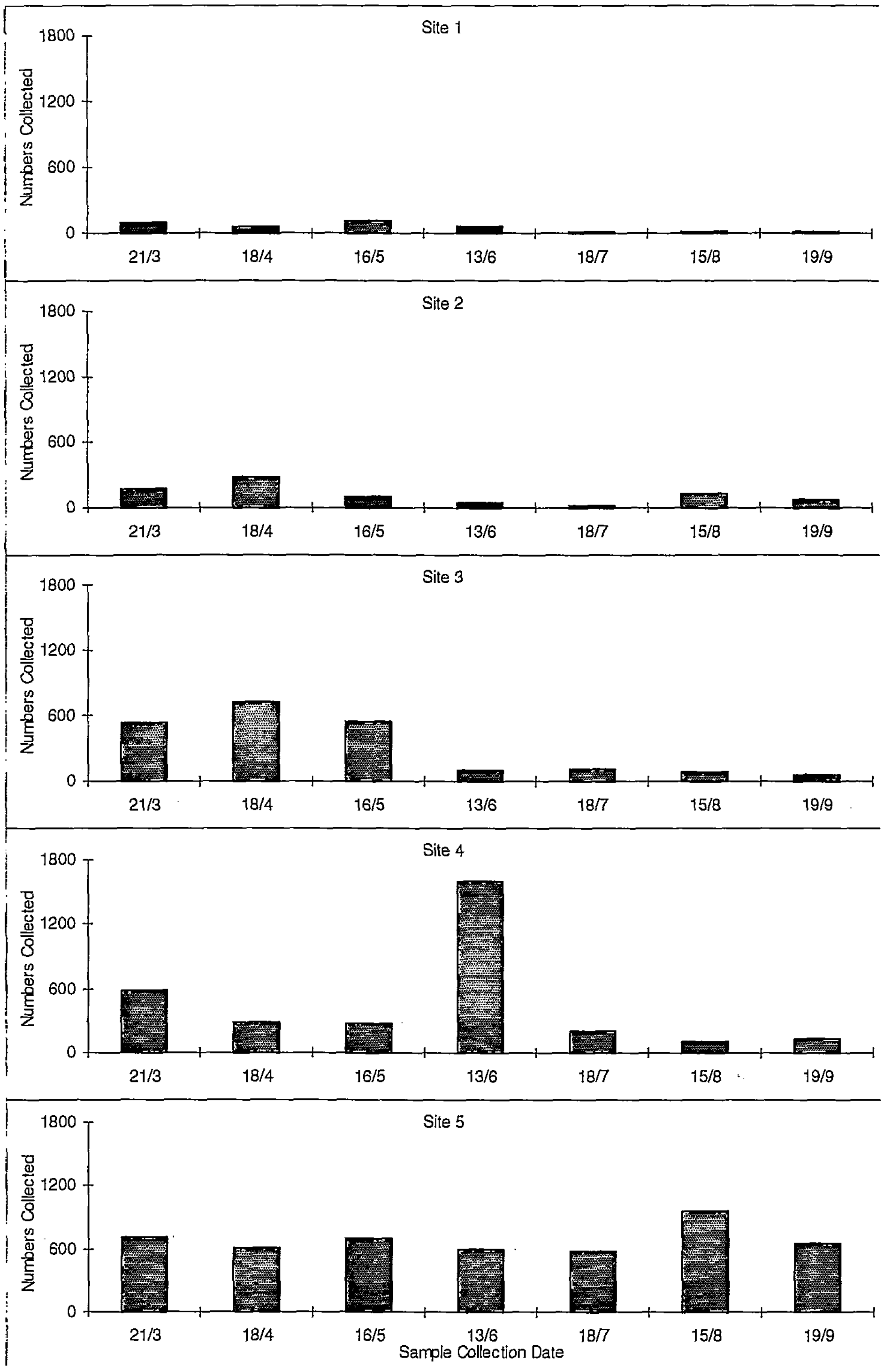


Fig 23. Total numbers of all Collembola in Tullgren funnel litter samples at sites 1-5 during 1994.

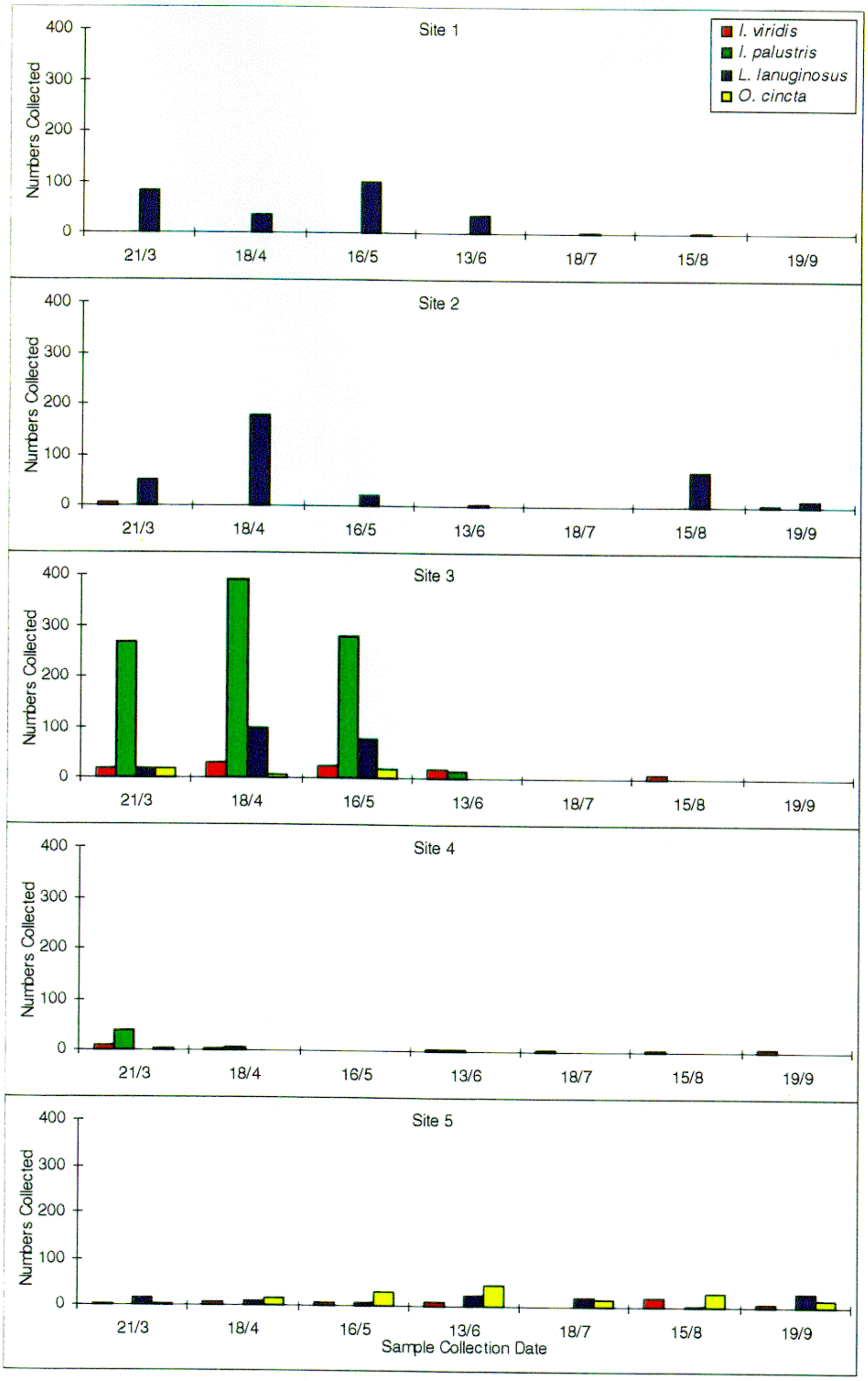


Fig 24. *Osotoma viridis, Isotomurus palustris, Lepidocyrtus, lanuginosus* and *Orchesella cincta* in funnel litter samples at sites 1-5 during 1994.

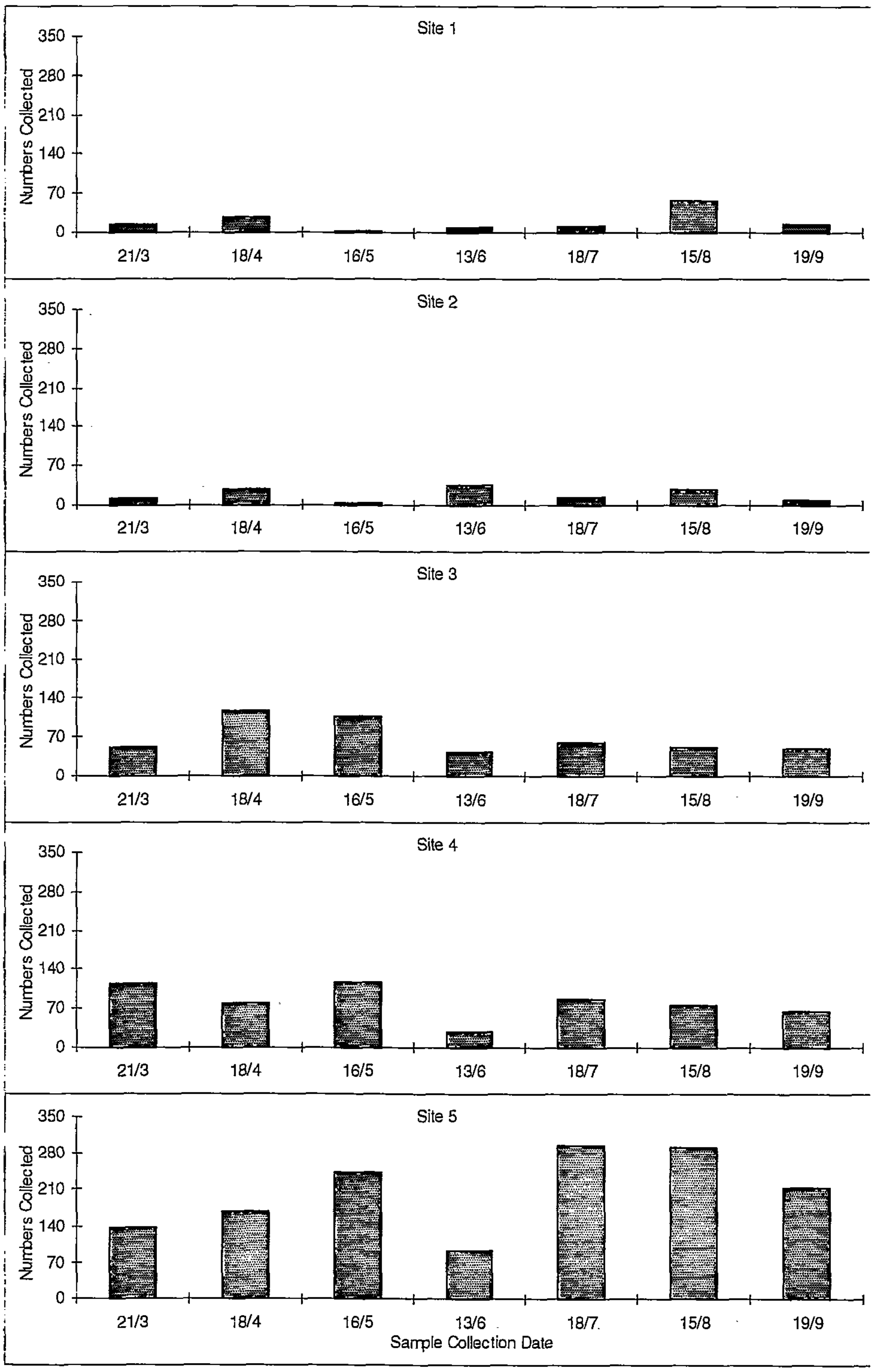


Fig 25. Total numbers of all Collembola in Tullgren funnel soil samples at sites 1-5 during 1994.

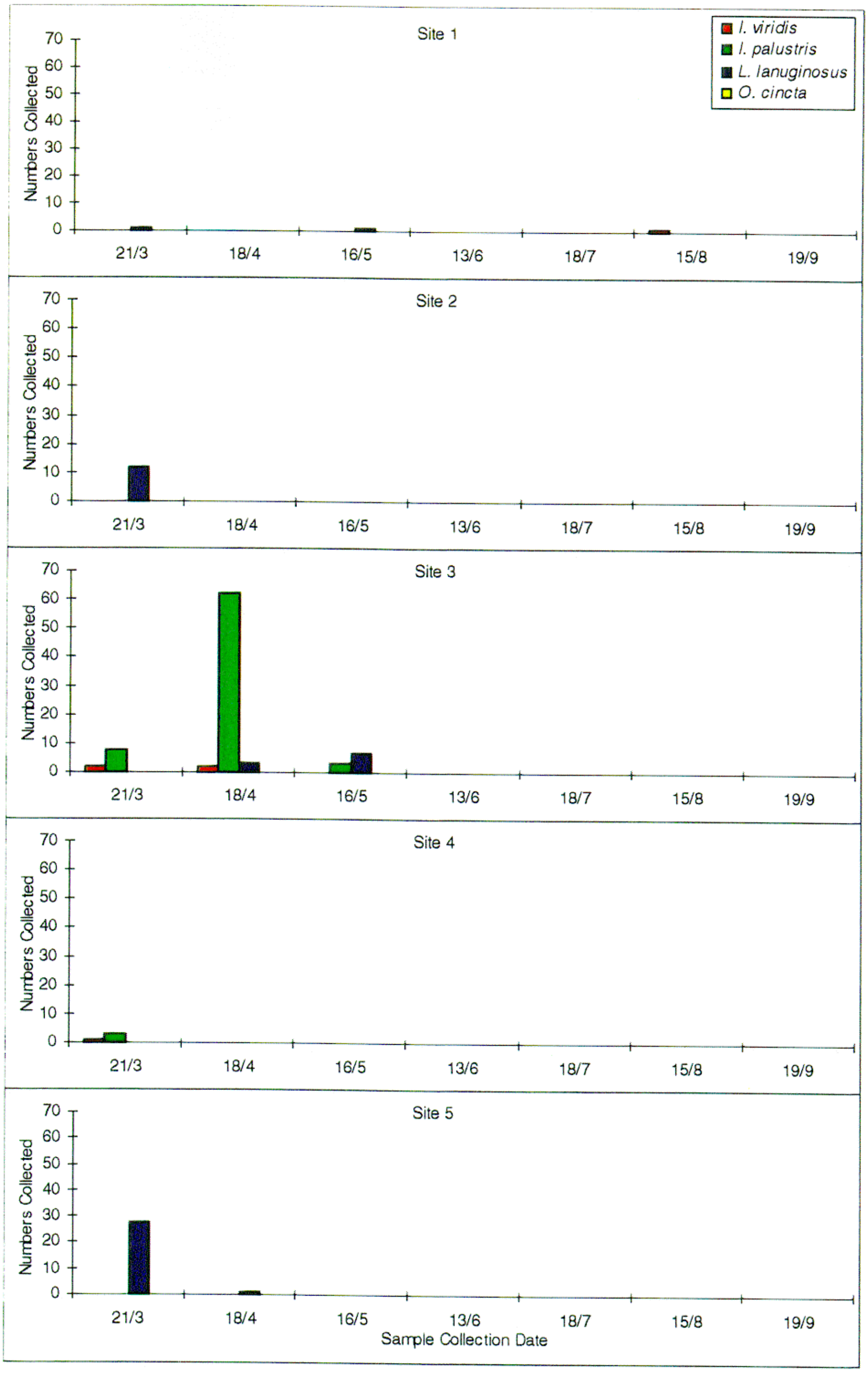
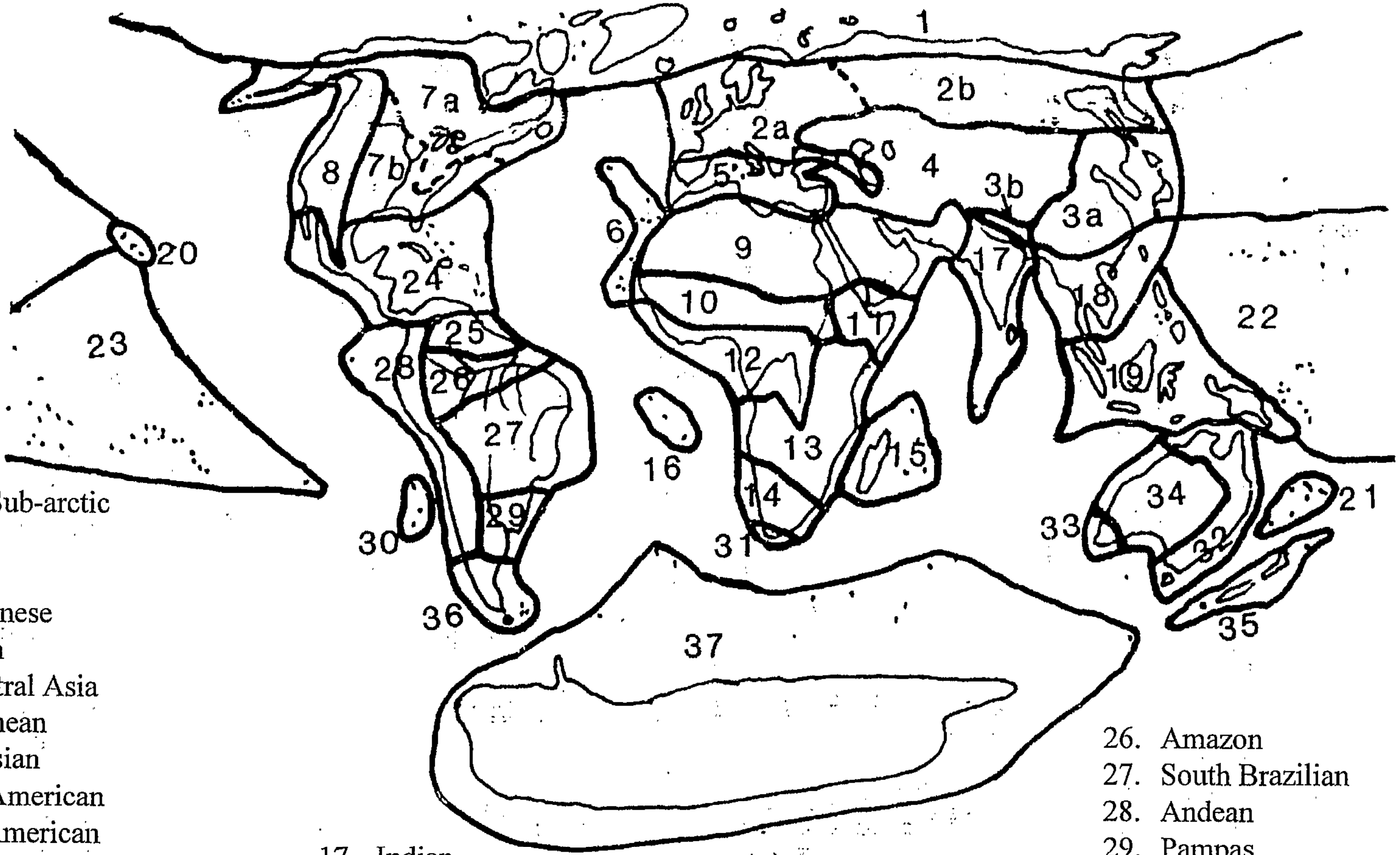


Fig 26. *Osotoma viridis, Isotomurus palustris, Lepidocyrtus, lanuginosus* and *Orchesella cincta* in funnel soil samples at sites 1-5 during 1994.

Fig 27.



1. Arctic & Sub-arctic
2a. Europe
2b. Asia
3a. Simo-Japanese
3b. Himalayan
4. W. & Central Asia
5. Mediterranean
6. Macaronesian
7a. N. North American
7b. S. North American
8. Pacific North American
9. African Indian Desert
10 Sudanese Park Steppe
11. N.E. African Highland
12. W. African Rain Forest
13. E. African Steppe
14. South African
15. Madagascar
16. Ascension & St. Helena
17. Indian
18. Continental S.E. Asia
19. Malaysian
20. Hawaiian
21. New Caledonia
22. Melanesia & Micronesia
23. Polynesia
24. Caribbean
25. Venezuela & Guiana
26. Amazon
27. South Brazilian
28. Andean
29. Pampas
30. Juan Fernandez
31. Cape
32. N. & E. Australia
33. S.W. Australia
34. Central Australia
35. New Zealand
36. Patagonian
37. Antarctic & Subantarctic

Modified GOOD (1974) biogeographic provinces

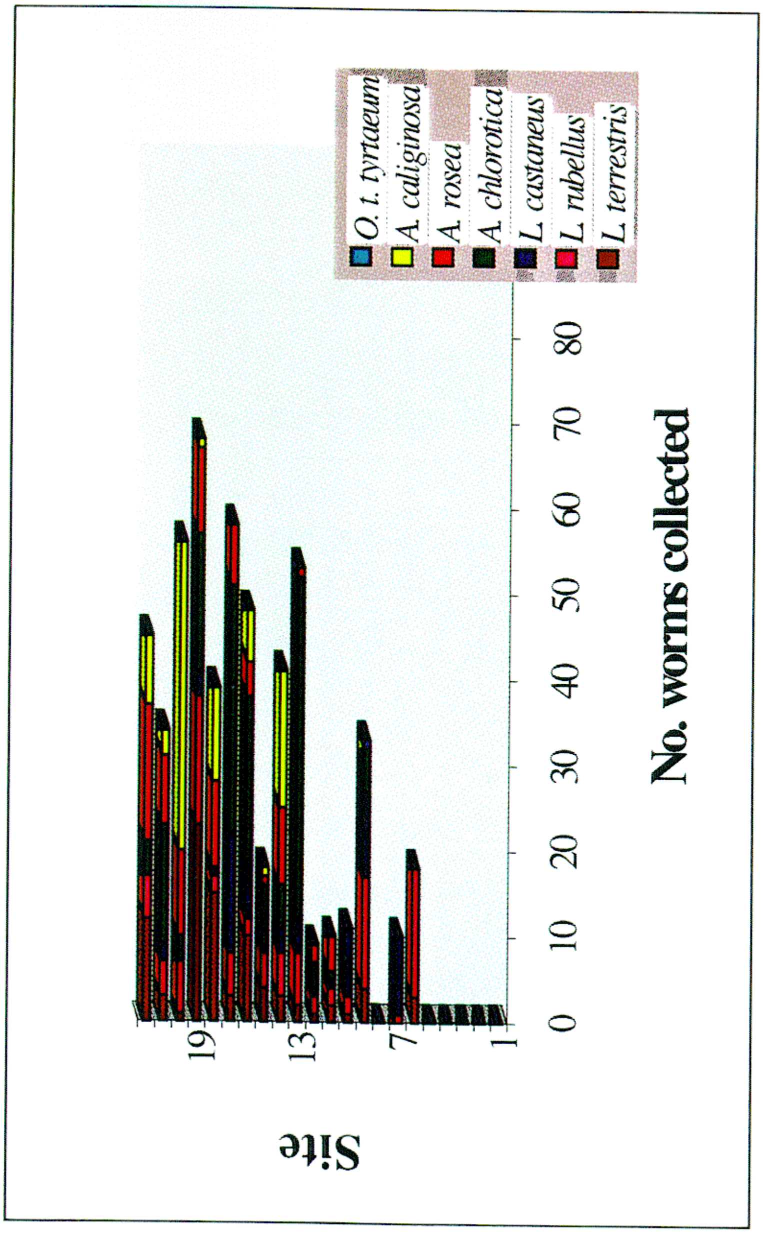


Fig 28. No. of worms collected from four 0.25 m x 0.25 m quadrats taken at the sites shown in Fig 1.

6. IS IT POSSIBLE TO CONSTRUCT ACCURATE "EXPECTED GEOGRAPHICAL DISTRIBUTION MAPS" FROM THE HISTORICAL INFORMATION CONTAINED IN SCIENTIFIC PAPERS?

Claus Svendsen, ITE Monks Wood

6.1 Introduction:

One of the key points of SOILPACS will be to predict which species one can or can not expect at a given site. The presence or absence of a species at a given location, is traditionally seen to be determined mainly by the habitat characteristics of the site (see previous sections). However, for some species there are examples of absence from suitable sites in complete geographical regions. In this section it was the specific aim to assess the robustness and quality of historical records published in scientific papers for use in creating reliable geographical distribution maps; and in that way serve to identify potential empty regions for specific species.

6.2 Data set selection:

During his research work for the *Monograph Biology of the Springtails* (Insecta: Collembola), Hopkin (1997) concluded a detailed literative search to include all papers which refer to records of Collembola in the UK. The record system (comprised of location and species recorded) resulting from this research is considered one of the most comprehensive collection of scientific papers on a single order of soil-organisms in the UK.

When the British and Irish records were isolated they contained information on 365 species of Collembola, 85 of which had been recorded more than 15 times in Great Britain. Hopkin selected six of the most relevant and important species in the context of SOILPACS based on their ecology and frequency of appearance in the published literature:

- *Anurida maritima* (Guérin, 1836) cited in 45 papers (a coastal species)

- *Isotomiella minor* (Schäffer, 1896) cited in 53 papers

- *Entomobrya nivalis* (Linnaeus, 1758 nec Lubbock, 1862) cited in 134 papers

- *Orchesella cincta* (Linnaeus, 1758) cited in 71 papers

- *Tomocerus longicornis* (Müller, 1776) cited in 66 papers

From this list, it was decided to focus on three species; *Anurida maritima* was chosen because of its distinct coastal habitat requirements and *Entomobrya nivalis* along with *Orchesella cincta* due to their general commonness and frequency of citation.

6.3 Data sorting:

In the context of the SOILPACS contract only records for England were considered. The information from the remaining records for the three species were entered into a computer spreadsheet which gave the opportunity for later sorting of the data and potential for correlating with other databases should the need arise. This data set was then sorted on the basis of reference codes. References that were not available were omitted and the examination of the rest prioritised to those that, contained information on all three species, and subsequently those which contained information on two of the three species and so on. It became clear, however, that due to the degree of cross-citation, (a vital process in the dispersion of scientific literature) the information was found to be frequently repeated. Most of the information from the papers covering only two species were already logged in the first instance when the papers covering all 3 species were examined. This point became even more pronounced when the papers covering only a single species were considered (see Table 38).

From examination of the papers the most accurate geographical location reference was noted. These place names were matched against BRC's location database to obtain grid references which resulted in suggested references for approximately 20% of the localities. Subsequently, the gazetteer (The Ordnance Survey 1987, Gazetteer of Great Britain, MacMillan Press LTD) was used to find grid references for as many of the remaining records as possible. Around half the records for *A. maritima* and about one third of the records for both *E. nivalis* and *O. cincta* were too imprecise (eg. Britain or Yorkshire) to enable the assignment of a grid reference to these records (see appendix D) and within the remaining data there was some duplication of localities.

Table 38: The results (in number of records to pass each step) of the sorting procedure can be seen in table 1.

Sorting step	*A. maritima*	*E. nivalis*	*O. cincta*
Total papers	45	134	71
UK* papers	39	119	65
Locality references	41	93	107
Different grid ref.	13	49	49

* Excluding North Ireland

6.4 Data analysis

The Countryside Information System (CIS) was used to analyze and visualize the geographical distribution of the grid references that it had been possible to derive from the scientific literature. To enable the data collected to be incorporated into the CIS, all grid references had to be converted to six figure references (one kilometre squares), the process subsequently was a straight forward import of the new data sets. Three maps were produced in this way, each as a map of GB with the 10 kilometre squares surrounding each grid reference marked (Figs 29 to 31).

6.5 Evaluation of the procedure

The major workload involved in attempting to create "expected distribution maps" in this way was clearly the literature research behind it. This is further complicated, as many of the references were too old to be included in the computer-databases on scientific literature and therefore entailed going back through the literature via the reference lists (a time-consuming laborious process). In this case this work had already been completed for a separate purpose (Hopkin, 1987) and we were still left with the task of identifying localities and corresponding grid references; a long systematic job which was hampered by the fact that a large part of the literature referred to distributions in very broad terms such as "SW-England" or at the county scale. Furthermore, there was a large inherent overlap within the literature bases because of the inbuilt citation between papers. This meant that much of this work resulted in duplicated information.

Apart from the mentioned practical problems there were three fundamental problems associated with using scientific papers in this way:

1. Records are centred geographically around the larger research establishments.

   To use records from the scientific literature naturally incurs the problem that the "sampling" to a limited extent will be centred around the research establishments with the highest activity in that particular subject group or species.

   Thus, this is likely (as it is suggested by the distributions on Figures 30 and 31) that the distribution of recorder effort is quite patchy and will have a large impact on the results obtained.

2. They only record presence and never absence.

   This means that although throughout the "Collembolan literature" there are hundreds of different localities, we can still only say that a species was present where it was reported and not that it was absent where not reported.

   Thus, the only conclusive result we can get from a map created with this procedure is a map that shows a species that has full cover (reported from all regions). A map with "holes" (empty regions) only tells us that the species have not been reported from that region and not that it is actually absent from that area.

3. Collembola have undergone substantial taxonomic revision in recent years.

   Most literative records are not supported by voucher specimens so many records will need to be confirmed by re-visiting localities and collecting fresh material.

6.6 Conclusion

It has to be concluded that the data gained from reviewing the scientific literature cannot support any SOILPACS programme in isolation. However, such data could potentially be used as a tool to assess which species are the most reported and therefore perhaps the most widespread and/or easily observable. Thus, it would provide some guidance for a large-scale survey which eventually will be necessary to obtain the data for establishing reliable "expected distribution maps" of selected invertebrate groups.

Fig 29 UK distribution maps (10 km squares) for the collembolan *Anurida maritima*, generated with data from historical records using the Countryside Information System software

Fig 30 UK distribution maps (10 km squares) for the collembolan *Entomobrya nivalis*, generated with data from historical records using the Countryside Information System software

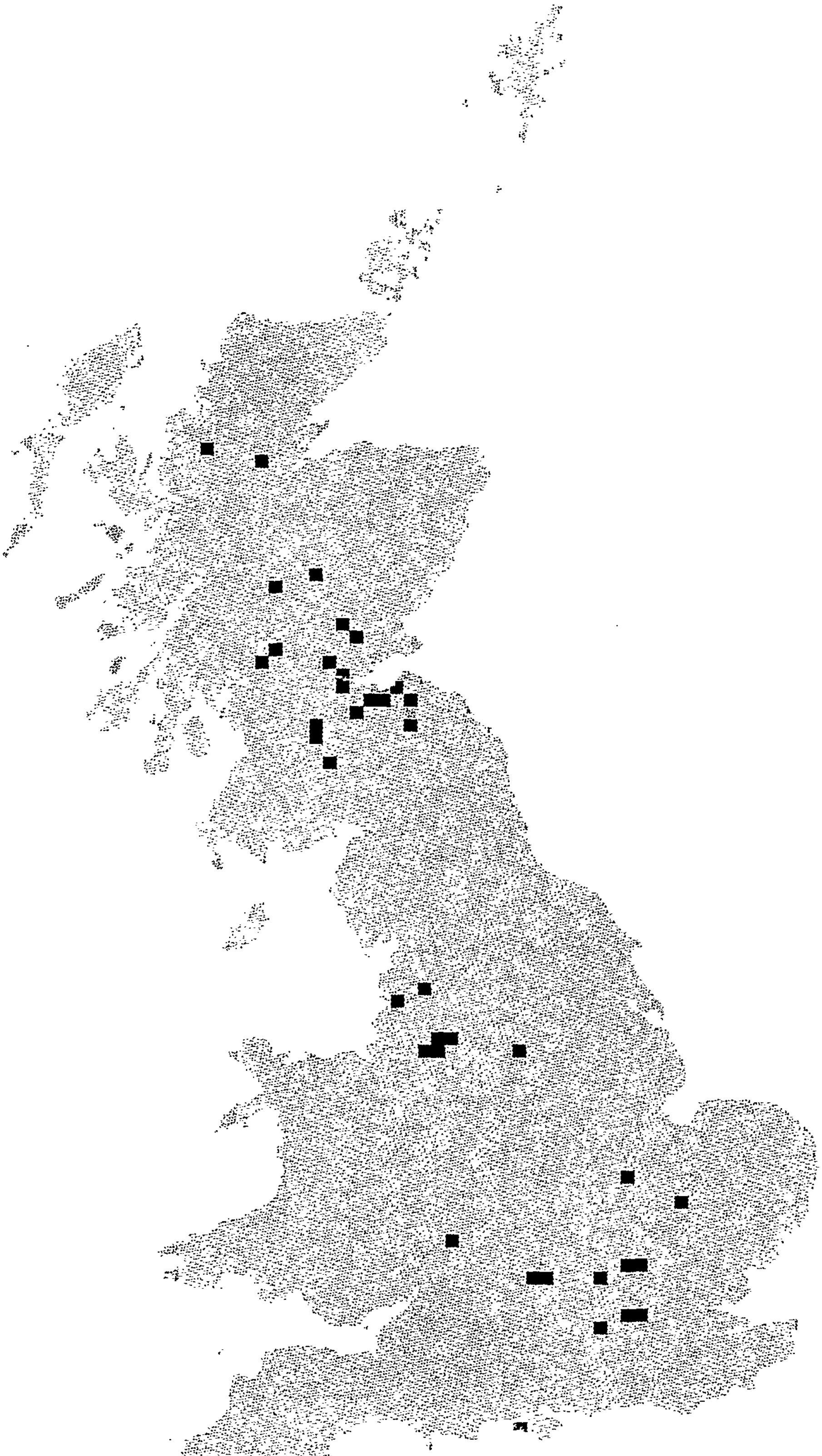
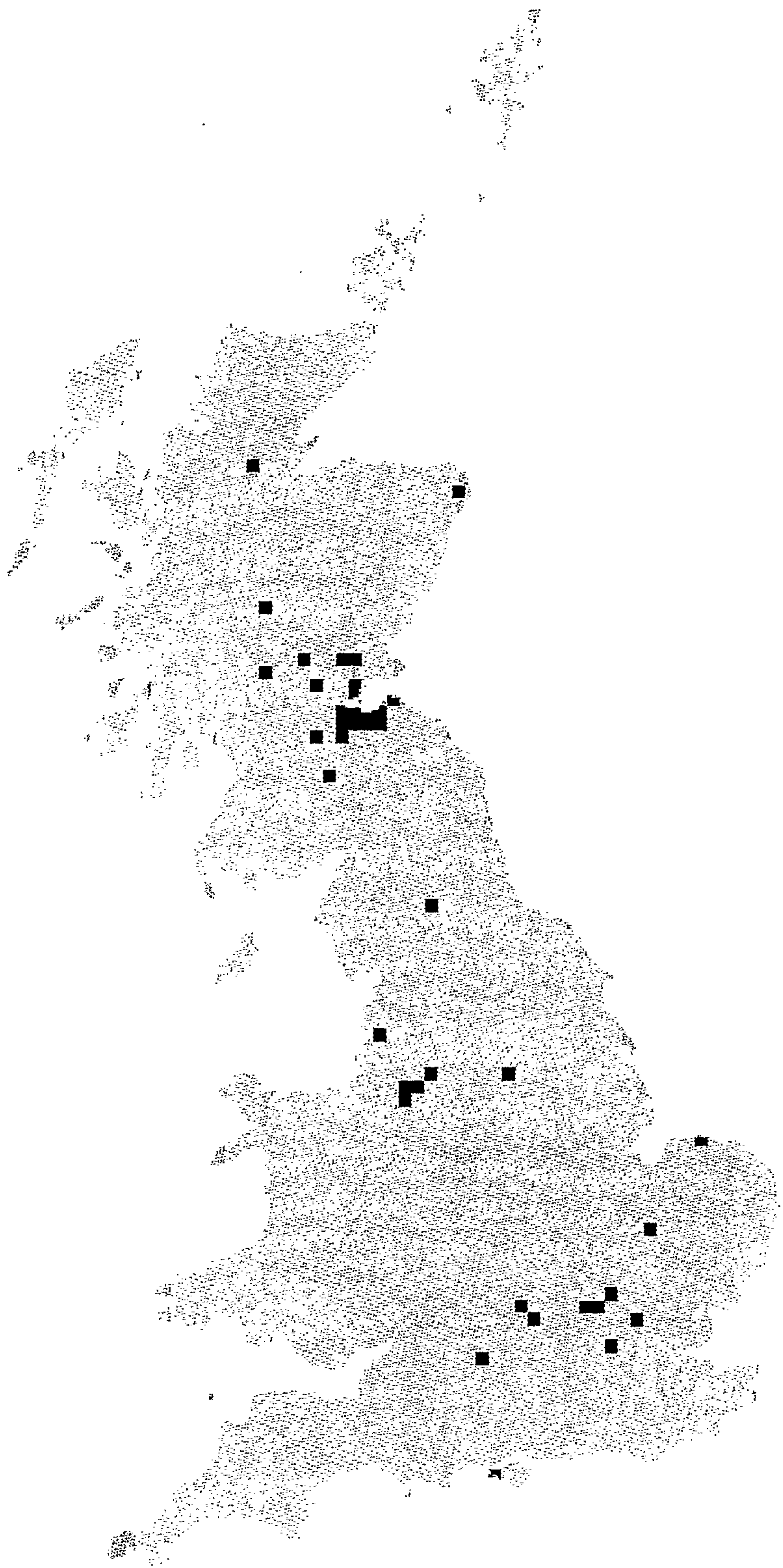


Fig 31 UK distribution maps (10 km squares) for the collembolan *Orchesella cincta*, generated with data from historical records using the Countryside Information System software



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APPENDIX A

Avonmouth Smelter Aerial Emissions of Pb, Zn and Cd (Recalculated from data supplied by Britannia Zinc Ltd)

Table A1. Smelter emissions for Jan 4th - Jan 25th 1993.

	Chimney Stack	Emissions ($kg\ hr^{-1}$)		
HMIP No.	**Sinter Plant Area**	**Pb**	**Zn**	**Cd**
1	PA Stack	0.8	0.2	0.1
2	Fine Rolls Annex Doyle Stack 6.40	0.1	0.03	0.01
3	Prop. House Doyle Stack 6.44	0.04	0.01	0.003
4	Prop. House Doyle Stack 6.48	0.002	0.003	0.001
5	I.S.F. Bins Doyle Stack 6.55	0.03	0.1	0.003
19	Cadmium Plant Stack	0.001	0.001	0.001
	Smelting Area I.S.F. Plant			
7	Hygiene Stack	0.7	1.8	0.01
8	LCV Main	0.4	1.3	0.1
9	Charge Preparation Doyle	0.1	0.1	0.01
18	Briquetting Plant Bag Filter	0.01	0.04	0.002
13	Hygiene Dust East	0.1	3.9	0.1
	Refluxer Plant			
16	Hygiene Duct West	0.1	6	0.1
21	Waste Gas Bagfilter Stack	0.003	0.02	0.003
	Site Total	2.386	13.504	0.443

Table A2. Smelter emissions for Feb 1st - Feb 22nd 1993.

	Chimney Stack	Emissions ($kg\ hr^{-1}$)		
HMIP No.	**Sinter Plant Area**	**Pb**	**Zn**	**Cd**
1	PA Stack	0.8	0.2	0.1
2	Fine Rolls Annex Doyle Stack 6.40	0.01	0.01	0.003
3	Prop. House Doyle Stack 6.44	0.01	0.02	0.003
4	Prop. House Doyle Stack 6.48	0.002	0.004	0.001
5	I.S.F. Bins Doyle Stack 6.55	0.01	0.04	0.003
19	Cadmium Plant Stack	0.001	0.003	0.001
	Smelting Area I.S.F. Plant			
7	Hygiene Stack	1.2	2.8	0.01
8	LCV Main	0.4	1	0.02
9	Charge Preparation Doyle	0.1	0.1	0.004
18	Briquetting Plant Bag Filter	0.01	0.004	0.002
13	Hygiene Dust East	0.1	0.6	0.01
	Refluxer Plant			
16	Hygiene Duct West	0.1	1.3	0.02
21	Waste Gas Bagfilter Stack	0.003	0.01	0.003
	Site Total	2.746	6.091	0.18

Table A3. Smelter emissions for Mar 1st - Mar 29th 1993.

	Chimney Stack	Emissions (kg hr^{-1})		
HMIP No.	**Sinter Plant Area**	**Pb**	**Zn**	**Cd**
1	PA Stack	0.2	0.1	0.03
2	Fine Rolls Annex Doyle Stack 6.40	0.003	0.01	0.003
3	Prop. House Doyle Stack 6.44	0.01	0.01	0.003
4	Prop. House Doyle Stack 6.48	0.002	0.002	0.001
5	I.S.F. Bins Doyle Stack 6.55	0.02	0.1	0.003
19	Cadmium Plant Stack	0.001	0.001	0.001
	Smelting Area I.S.F. Plant			
7	Hygiene Stack	1.4	2.4	0.01
8	LCV Main	0.4	1.2	0.04
9	Charge Preparation Doyle	0.1	0.1	0.004
18	Briquetting Plant Bag Filter	0.02	0.1	0.002
13	Hygiene Dust East	0.02	0.3	0.01
	Refluxer Plant			
16	Hygiene Duct West	0.3	2.6	0.1
21	Waste Gas Bagfilter Stack	0.003	0.01	0.003
	Site Total	2.479	6.933	0.21

Table A4. Smelter emissions for Apr 5th - Apr 26th 1993.

	Chimney Stack	Emissions (kg hr^{-1})		
HMIP No.	**Sinter Plant Area**	**Pb**	**Zn**	**Cd**
1	PA Stack	0.3	0.1	0.03
2	Fine Rolls Annex Doyle Stack 6.40	0.004	0.01	0.002
3	Prop. House Doyle Stack 6.44	0.004	0.01	0.002
4	Prop. House Doyle Stack 6.48	0.001	0.002	0.001
5	I.S.F. Bins Doyle Stack 6.55	0.01	0.02	0.002
19	Cadmium Plant Stack	0.001	0.003	0.001
	Smelting Area I.S.F. Plant			
7	Hygiene Stack	1.1	2	0.01
8	LCV Main	0.4	1.4	0.1
9	Charge Preparation Doyle	0.6	0.5	0.01
18	Briquetting Plant Bag Filter	0.03	0.1	0.002
13	Hygiene Dust East	0.2	0.3	0.01
	Refluxer Plant			
16	Hygiene Duct West	0.02	0.4	0.01
21	Waste Gas Bagfilter Stack	0.01	0.02	0.003
	Site Total	2.68	4.865	0.183

Table A5. Smelter emissions for May 3rd - May 24th 1993.

	Chimney Stack	Emissions (kg hr^{-1})		
HMIP No.	**Sinter Plant Area**	**Pb**	**Zn**	**Cd**
1	PA Stack	0.3	0.6	0.1
2	Fine Rolls Annex Doyle Stack 6.40	0.01	0.01	0.004
3	Prop. House Doyle Stack 6.44	0.01	0.02	0.003
4	Prop. House Doyle Stack 6.48	0.004	0.01	0.001
5	I.S.F. Bins Doyle Stack 6.55	0.04	0.01	0.003
19	Cadmium Plant Stack	0.0004	0.001	0.001
	Smelting Area I.S.F. Plant			
7	Hygiene Stack	1.5	3	0.01
8	LCV Main	0.3	1.5	0.1
9	Charge Preparation Doyle	0.1	0.1	0.01
18	Briquetting Plant Bag Filter	0.01	0.1	0.002
13	Hygiene Dust East	0.3	0.4	0.01
	Refluxer Plant			
16	Hygiene Duct West	0.1	1.8	0.04
21	Waste Gas Bagfilter Stack	0.03	0.01	0.003
	Site Total	2.7044	7.561	0.287

Table A6. Smelter emissions for May 31st - Jun 28th 1993.

	Chimney Stack	Emissions (kg hr^{-1})		
HMIP No.	**Sinter Plant Area**	**Pb**	**Zn**	**Cd**
1	PA Stack	0.5	0.1	0.04
2	Fine Rolls Annex Doyle Stack 6.40	0.004	0.02	0.004
3	Prop. House Doyle Stack 6.44	0.01	0.01	0.003
4	Prop. House Doyle Stack 6.48	0.001	0.01	0.001
5	I.S.F. Bins Doyle Stack 6.55	0.01	0.03	0.003
19	Cadmium Plant Stack	0.001	0.003	0.003
	Smelting Area I.S.F. Plant			
7	Hygiene Stack	1.1	2.4	0.01
8	LCV Main	0.3	1.3	0.04
9	Charge Preparation Doyle	0.02	0.1	0.01
18	Briquetting Plant Bag Filter	0.004	0.02	0.002
13	Hygiene Dust East	0.03	0.1	0.01
	Refluxer Plant			
16	Hygiene Duct West	0.02	0.6	0.01
21	Waste Gas Bagfilter Stack	0.003	0.01	0.003
	Site Total	2.003	4.703	0.139

Table A7. Smelter emissions for Jul 5th - Jul 26th 1993.

	Chimney Stack	Emissions (kg hr^{-1})		
HMIP No.	**Sinter Plant Area**	**Pb**	**Zn**	**Cd**
1	PA Stack	0.4	0.1	0.02
2	Fine Rolls Annex Doyle Stack 6.40	0.01	0.01	0.004
3	Prop. House Doyle Stack 6.44	0.003	0.01	0.003
4	Prop. House Doyle Stack 6.48	0.002	0.01	0.001
5	I.S.F. Bins Doyle Stack 6.55	0.02	0.03	0.003
19	Cadmium Plant Stack	0.0004	0.001	0.0004
	Smelting Area I.S.F. Plant			
7	Hygiene Stack	0.9	2.4	0.02
8	LCV Main	0.3	1.8	0.1
9	Charge Preparation Doyle	0.1	0.1	0.01
18	Briquetting Plant Bag Filter	0.01	0.1	0.002
13	Hygiene Dust East	0.03	0.2	0.01
	Refluxer Plant			
16	Hygiene Duct West	0.03	0.6	0.01
21	Waste Gas Bagfilter Stack	0.003	0.01	0.003
	Site Total	1.8084	5.371	0.1864

Table A8. Smelter emissions for Aug 2nd - Aug 23rd 1993.

	Chimney Stack	Emissions (kg hr^{-1})		
HMIP No.	**Sinter Plant Area**	**Pb**	**Zn**	**Cd**
1	PA Stack	0.3	0.4	0.02
2	Fine Rolls Annex Doyle Stack 6.40	0.01	0.01	0.01
3	Prop. House Doyle Stack 6.44	0.01	0.01	0.003
4	Prop. House Doyle Stack 6.48	0.01	0.01	0.001
5	I.S.F. Bins Doyle Stack 6.55	0.01	0.02	0.003
19	Cadmium Plant Stack	0.0004	0.001	0.0004
	Smelting Area I.S.F. Plant			
7	Hygiene Stack	0.9	2.7	0.01
8	LCV Main	0.6	2.6	0.1
9	Charge Preparation Doyle	0.1	0.1	0.01
18	Briquetting Plant Bag Filter	0.01	0.03	0.002
13	Hygiene Dust East	0.1	1.9	0.04
	Refluxer Plant			
16	Hygiene Duct West	0.03	1.5	0.02
21	Waste Gas Bagfilter Stack	0.003	0.01	0.003
	Site Total	2.0834	9.291	0.2224

Table A9. Smelter emissions for Aug 30th - Sep 27th 1993.

Chimney Stack		Emissions (kg hr^{-1})		
HMIP No.	**Sinter Plant Area**	**Pb**	**Zn**	**Cd**
1	PA Stack	0.1	0.04	0.01
2	Fine Rolls Annex Doyle Stack 6.40	0.01	0.01	0.004
3	Prop. House Doyle Stack 6.44	0.01	0.01	0.003
4	Prop. House Doyle Stack 6.48	0.002	0.004	0.001
5	I.S.F. Bins Doyle Stack 6.55	0.01	0.02	0.003
19	Cadmium Plant Stack	0.001	0.001	0.002
	Smelting Area I.S.F. Plant			
7	Hygiene Stack	2	3.6	0.01
8	LCV Main	0.4	2.8	0.1
9	Charge Preparation Doyle	0.3	0.1	0.01
18	Briquetting Plant Bag Filter	0.01	0.02	0.002
13	Hygiene Dust East	0.04	2.1	0.04
	Refluxer Plant			
16	Hygiene Duct West	0.1	7.9	0.1
21	Waste Gas Bagfilter Stack	0.01	0.01	0.003
	Site Total	2.993	16.615	0.288

Table A10. Smelter emissions for Oct 4th - Oct 25th 1993.

Chimney Stack		Emissions (kg hr^{-1})		
HMIP No.	**Sinter Plant Area**	**Pb**	**Zn**	**Cd**
1	PA Stack	0.2	0.1	0.02
2	Fine Rolls Annex Doyle Stack 6.40	0.01	0.01	0.004
3	Prop. House Doyle Stack 6.44	0.01	0.02	0.003
4	Prop. House Doyle Stack 6.48	0.002	0.01	0.001
5	I.S.F. Bins Doyle Stack 6.55	0.01	0.03	0.003
19	Cadmium Plant Stack	0.0004	0.002	0.01
	Smelting Area I.S.F. Plant			
7	Hygiene Stack	0.9	3.2	0.01
8	LCV Main	1	1.9	0.1
9	Charge Preparation Doyle	0.1	0.1	0.01
18	Briquetting Plant Bag Filter	0.1	0.02	0.002
13	Hygiene Dust East	0.03	0.5	0.01
	Refluxer Plant			
16	Hygiene Duct West	0.03	1	0.01
21	Waste Gas Bagfilter Stack	0.003	0.02	0.003
	Site Total	2.3954	6.912	0.186

Table A11. Smelter emissions for Nov 1st - Dec 13th 1993.

	Chimney Stack	Emissions ($kg\ hr^{-1}$)		
HMIP No.	**Sinter Plant Area**	**Pb**	**Zn**	**Cd**
1	PA Stack	0.04	0.6	0.04
2	Fine Rolls Annex Doyle Stack 6.40	0.004	0.01	0.004
3	Prop. House Doyle Stack 6.44	0.003	0.01	0.003
4	Prop. House Doyle Stack 6.48	0.003	0.01	0.001
5	I.S.F. Bins Doyle Stack 6.55	0.05	0.1	0.004
19	Cadmium Plant Stack	0.001	0.003	0.003
	Smelting Area I.S.F. Plant			
7	Hygiene Stack	0.8	3.5	0.01
8	LCV Main	0.3	1.8	0.1
9	Charge Preparation Doyle	0.4	2	0.003
18	Briquetting Plant Bag Filter	0.02	0.05	0.003
13	Hygiene Dust East	0.03	0.5	0.02
	Refluxer Plant			
16	Hygiene Duct West	0.04	1.2	0.04
21	Waste Gas Bagfilter Stack	0.01	0.02	0.003
	Site Total	1.701	9.803	0.234

Table A12. Smelter emissions for Dec 20th 1993 - Jan 10th 1994.

	Chimney Stack	Emissions ($kg\ hr^{-1}$)		
HMIP No.	**Sinter Plant Area**	**Pb**	**Zn**	**Cd**
1	PA Stack	0.6	0.6	0.1
2	Fine Rolls Annex Doyle Stack 6.40	0.01	0.02	0.01
3	Prop. House Doyle Stack 6.44	0.004	0.01	0.001
4	Prop. House Doyle Stack 6.48	0.01	0.01	0.001
5	I.S.F. Bins Doyle Stack 6.55	0.02	0.04	0.002
19	Cadmium Plant Stack	0.001	0.002	0.001
	Smelting Area I.S.F. Plant			
7	Hygiene Stack	0.6	2.2	0.01
8	LCV Main	0.3	1.5	0.1
9	Charge Preparation Doyle	0.2	0.5	0.01
18	Briquetting Plant Bag Filter	0.01	0.02	0.003
13	Hygiene Dust East	0.01	0.3	0.01
	Refluxer Plant			
16	Hygiene Duct West	0.01	0.2	0.01
21	Waste Gas Bagfilter Stack	0.01	0.01	0.003
	Site Total	1.785	5.412	0.261

APPENDIX B

Checklist of British and Irish Collembola (January 1997)

The numbers and lower case letters in brackets after the authorities for each name give the biogeographical regions of the world from which the species have been recorded (see Fig. 25).

Order Arthropleona

Superfamily Poduroidea (=Poduromorpha)

Family Brachystomellidae

1. ***Brachystomella parvula*** (Schäffer, 1896) (1, 2a, 2b, 3a, 3b, 4, 5, 7a, 7b, 8, 19, 20, 24, 26, 27, 28, 29, 31, 35?, 36?)

Family Hypogastruridae

<u>Subfamily Hypogastrurinae</u>

2. ***Ceratophysella armata*** (Nicolet, 1842) (1, 2a, 2b, 4?, 5, 7a, 7b?, 8?, 13?, 14?, 24?, 27?, 28?, 29?, 30?, 31?)
3. ***Ceratophysella bengtssoni*** (Ågren, 1904) (1, 2a, 5, 7a)
4. ***Ceratophysella denticulata*** (Bagnall, 1941) (2a, 2b, 5, 7a, 7b, 8, 24, 26, 28, 29, 32, 34, 37)
5. ***Ceratophysella gibbosa*** (Bagnall, 1940) (2a, 4, 5, 6, 7b, 24, 32, 34, 37)
6. ***Ceratophysella granulata*** (Stach, 1949) (2a, 4a, 5)
7. ***Ceratophysella longispina*** (Tullberg, 1876) (1)
8. *Ceratophysella rufescens* (Nicolet, 1841) (=*C. armata*)
9. ***Ceratophysella scotica*** (Carpenter & Evans, 1899) (1, 2a, 5a)
10. ***Ceratophysella sigillata*** (Uzel, 1891) (1, 2a, 5)
11. ***Ceratophysella succinea*** Gisin, 1949 (2a, 2b, 4, 5, 7a, 7b, 24, 32)
12. ***Hypogastrura assimilis*** Krausbauer, 1898 (1, 2a, 2b, 5, 7a, 7b, 8, 28, 29, 32, 34)
13. *Hypogastrura burkilli* (Bagnall, 1940) (=*H. purpurescens*)
14. *Hypogastrura elegans* (Parfitt, 1891) (=*H. purpurescens*)
15. ***Hypogastrura lapponica*** (Axelson 1902) (1, 2b, 7a, 7b)
16. ***Hypogastrura manubrialis*** (Tullberg, 1869) (1, 2a, 2b, 3a, 4, 5, 6, 7a, 8, 9, 10, 13, 14, 17, 24, 27, 28, 29, 31, 32, 34, 35, 37)
17. *Hypogastrura packardi* (Folsom, 1902) (=*H. lapponica*)
18. ***Hypogastrura purpurescens*** (Lubbock, 1867) (2a, 5, 7a, 7b, 28, 29, 31, 32, 34, 36, 37)
19. ***Hypogastrura sahlbergi*** (Reuter, 1895) (1, 2a, 2b, 4, 5, 31?)
20. ***Hypogastrura serrata*** (Ågren, 1904) (1, 2a) (Bab)
21. ***Hypogastrura socialis*** (Uzel, 1891) (1, 2a, 2b, 5)
22. ***Hypogastrura tullbergi*** (Schäffer, 1900) (1, 8?)
23. ***Hypogastrura vernalis*** (Carl, 1901) (1, 2a, 2b, 4, 5, 32, 33, 34)
24. ***Hypogastrura viatica*** (Tullberg, 1872) (1, 2a, 2b, 3a, 7a, 8, 13, 28, 29, 31?, 32, 36?, 37)

25. ***Mesachorutes libycus*** (Caroli, 1914) (2a, 4, 5, 6, 28, 31)
26. ***Schaefferia cavernicola*** (Womersley, 1930) (2a)
27. ***Schaefferia emucronata*** Absolon, 1900 (2a, 5, 24)
28. *Schaefferia pouadensis* Delamare Deboutteville, 1945 (2a) (=*S. emucronata*)
29. *Schaefferia willemi* (Bonet, 1930) (=*S. emucronata*)
30. ***Schoettella ununguiculata*** (Tullberg, 1869) (1, 2a, 2b, 3a, 5, 7a, 26)
31. ***Willemia anophthalma*** Börner, 1901 (1, 2a, 2b, 3b, 4, 5, 7a?, 8?, 29)
32. *Willemia aspinata* Stach, 1949 (=*W. denisi*)
33. ***Willemia buddenbrocki*** Hüther, 1959 (2a, 3b, 5, 6, 17, 18, 24, 29)
34. ***Willemia denisi*** Mills, 1932 (1, 2a, 2b, 5, 7a, 8)
35. ***Willemia intermedia*** Mills, 1934 (1, 2a, 2b, 5, 7a, 7b, 8, 24)
36. ***Willemia scandinavica*** Stach, 1949 (1, 2a, 5)
37. ***Xenylla acauda*** Gisin, 1947 (2a, 2b, 4, 5, 7a, 8)
38. ***Xenylla boerneri*** Axelson, 1905 (2a, 5)
39. ***Xenylla brevicauda*** Tullberg, 1869 (1, 2a, 5)
40. ***Xenylla corticalis*** Börner, 1901 (2a)
41. ***Xenylla grisea*** Axelson, 1900 (2a, 2b, 5, 6, 7a, 7b, 8, 16, 20, 21, 24, 28, 29, 32, 34)
42. ***Xenylla humicola*** (Fabricius, 1780) (1, 2a, 3a?, 5, 7a, 7b, 8, 24, 36)
43. ***Xenylla longispina*** Uzel, 1891 (2a)
44. ***Xenylla maritima*** Tullberg, 1869 (2a, 2b, 4, 5, 6, 24, 27, 28, 31, 32, 33, 34, 35)
45. ***Xenylla mucronata*** Axelson, 1903 (2a, 2b, 24?, 28?)
46. ***Xenylla welchi*** Folsom, 1916 (2a, 4, 5, 6, 7a, 7b, 8, 9, 17, 19, 20, 21, 24, 25, 28, 29, 32, 34)
47. ***Xenylla xavieri*** Gama, 1959 (2a, 5, 6)

Family Neanurinae

Subfamily Frieseinae

48. ***Friesea acuminata*** (Denis, 1925) (2a)
49. ***Friesea afurcata*** (Denis, 1926) (2a, 4, 5)
50. ***Friesea claviseta*** Axelson, 1900 (1, 2a, 2b, 4, 5, 6, 7a, 7b, 8, 9, 13, 14, 21, 23, 24, 31)
51. ***Friesea emucronata*** (Stach, 1922) (2a, 5)
52. ***Friesea mirabilis*** (Tullberg, 1871) (1, 2a, 2b, 3a, 4, 5, 6, 7a, 8, 14, 18, 24, 33, 34)
53. ***Friesea truncata*** Cassagnau, 1958 (?)

Subfamily Neanurinae

54. ***Lathriopyga longiseta*** (Caroli, 1912) (2a, 5, 6)
55. ***Monobella grassei*** (Denis, 1923) (2a, 5)
56. ***Neanura muscorum*** (Templeton, 1835) (1, 2a, 2b, 4, 5, 6, 7a, 7b, 8, 16, 17, 20, 24, 29, 31, 32)
57. ***Paranura sexpunctata*** Axelson, 1902 (2a, 2b, 3a, 8)
58. ***Yuukianura aphoruroides*** Yosii, 1953 (2a, 3a)

Subfamily Pseudachorutinae

59. ***Anurida denisi*** (Bagnall, 1939) (2a)
60. ***Anurida ellipsoides*** Stach, 1949 (2a, 5)

61. ***Anurida granaria*** (Nicolet, 1847) (1, 2a, 2b, 5, 6, 7a?, 8?, 34)
62. ***Anurida granulata*** Agrell, 1943 (2a)
63. *Anurida hibernica* (Bagnall, 1941) (=*Gastranurida denisi*)
64. ***Anurida maritima*** (Guérin, 1836) (1, 2a, 2b, 5, 7a, 7b, 8, 14, 24, 27, 28?, 31)
65. *Anurida megalops* Bagnall, 1949 (=*A. maritima*)
66. ***Anurida sensillata*** Gisin, 1953 (2a, 5)
67. ***Anurida thalassophila*** (Bagnall, 1939) (1, 2a, 5)
68. ***Anurida tullbergi*** Schött, 1891 (1, 2a, 2b, 3a, 4, 5, 7a, 7b, 8)
69. ***Anuridella calcarata*** Denis, 1925 (2a, 4, 5, 7b?)
70. *Anuridella immsiana* Bagnall, 1939 (=*A. calcarata*)
71. ***Anuridella marina*** Willem, 1906 (2a)
72. *Anuridella submarina* Bagnall, 1934 (=*A. calcarata*)
73. ***Micranurida forsslundi*** Gisin, 1949 (1, 2a)
74. ***Micranurida pygmaea*** Börner, 1901 (1, 2a, 2b, 3a, 3b, 4, 5, 6, 7a, 7b, 8, 18, 26, 29)
75. ***Pseudachorutella asigillata*** Börner, 1901 (1, 2a, 5)
76. ***Pseudachorutella clavata*** Börner, 1901 (2a)
77. ***Pseudachorutes boerneri*** Schött, 1902 (2a, 5, 24?)
78. ***Pseudachorutes corticicolus*** (Schäffer, 1896) (1, 2a, 3b, 5, 7a, 7b, 8, 24?)
79. ***Pseudachorutes dubius*** Krausbauer, 1898 (1, 2a, 3a, 4, 5)
80. ***Pseudachorutes parvulus*** Börner, 1901 (2a, 2b, 4, 5, 24, 28, 29)
81. ***Pseudachorutes subcrassus*** Tullberg, 1871 (1, 2a, 2b, 4, 5, 6)

Family Odontellidae

82. ***Odontella lamellifera*** (Axelson, 1903) (2a, 4, 5, 6, 24, 26, 29, 34)
83. ***Xenyllodes armatus*** Axelson, 1903 (1, 2a, 2b, 3a, 5, 6, 7a, 8, 24)

Family Onychiuridae

<u>Subfamily Onychiurinae</u>

84. ***Archaphorura absoloni*** (Börner, 1901) (1, 2a, 2b, 5, 6?, 7a, 8)
85. ***Archaphorura schoetti*** (Lie Pettersen, 1897) (1, 2a)
86. ***Kalaphorura bearei*** Bagnall, 1937 (2a)
87. ***Kalaphorura burmeisteri*** (Lubbock, 1873) (2a, 5, 6)
88. ***Onychiurus ambulans*** (Linnaeus, 1758) (2a, 5, 33)
89. *Onychiurus arans* Gisin, 1952 (=*Archaphorura schoetti*)
90. ***Onychiurus dissimulans*** Gisin, 1952 (2a)
91. ***Onychiurus dunarius*** Gisin, 1956 (2a)
92. ***Onychiurus fimetarioides*** Denis, 1938 (2a)
93. ***Onychiurus fimetarius*** (Linnaeus, 1767, nec 1758) *sensu* Stach, 1934 (1?, 2a, 31?, 33?, 34)
94. ***Onychiurus imperfectus*** Denis, 1938 (2a, 5)
95. ***Onychiurus jubilarius*** Gisin, 1957 (2a)
96. ***Onychiurus laminatipes*** Bagnall, 1937 (2a)
97. ***Onychiurus minutus*** Denis, 1932 (2a, 6)
98. *Onychiurus pygmaeus* Bagnall, 1937 (=*O. fimetarius*)
99. ***Onychiurus rectospinatus*** Stach, 1922 (2a, 5)

100. ***Onychiurus scotarius*** Gisin, 1954 (2a, 5)
101. ***Onychiurus sinensis*** Stach, 1954
102. ***Onychiurus stachianus*** Bagnall, 1939 (2a, 5)
103. ***Onychiurus subambulans*** Denis, 1935 (2a)
104. ***Onychiurus variabilis*** Stach, 1954 (2a, 2b)
105. ***Paronychiurus argus*** (Denis 1925) (2a)
106. ***Paronychiurus edinensis*** Bagnall, 1935 (2a)
107. ***Paronychiurus spinosus*** Bagnall, 1949 (2a)
108. ***Protaphorura alborufescens*** (Vogler, 1895) (2a, 5?)
109. ***Protaphorura arcticus*** (Tullberg, 1876) (1)
110. ***Protaphorura armata*** (Tullberg, 1869) (1, 2a, 2b, 4, 5, 7a, 7b, 8, 32, 33, 34)
111. ***Protaphorura aurantiaca*** (Ridley, 1880) (2a, 5)
112. ***Protaphorura bagnalli*** Salmon, 1959 (2a)
113. ***Protaphorura bicampata*** Gisin, 1956 (1, 2a, 2b, 4)
114. ***Protaphorura caledonica*** Bagnall, 1935 (2a)
115. ***Protaphorura campata*** Gisin, 1952 (1, 2a, 5?)
116. ***Protaphorura debilis*** (Moniez, 1890) (1, 2, 7a, 8)
117. ***Protaphorura encarpta*** (Denis, 1931) (2a, 3a, 5, 6, 7a, 7b, 8, 20, 24, 29)
118. ***Protaphorura evansi*** Bagnall, 1935 (2a)
119. ***Protaphorura fimata*** Gisin, 1952 (1, 2a, 2b, 3a, 4, 5, 6, 37)
120. *Protaphorura flavidula* Bagnall, 1939 (=*P. armata*)
121. ***Protaphorura furcifera*** (Börner, 1901) (1, 2a, 2b, 4)
122. ***Protaphorura halophila*** Bagnall, 1937 (2a)
123. *Protaphorura hortensis* Gisin, 1949 (=*P. encarpta*)
124. *Protaphorura humata* Gisin, 1952 (=*P. armata*)
125. *Protaphorura imminuta* Bagnall, 1937 (=*P. thalassophila*)
126. *Protaphorura lata* Gisin, 1956 (=*P. aurantiaca*)
127. *Protaphorura magnicornis* Bagnall, 1937 (=*P. aurantiaca*)
128. ***Protaphorura meridiata*** Gisin, 1952 (2a, 5)
129. *Protaphorura nemorata* Gisin, 1952 (=*P. armata*)
130. ***Protaphorura octopunctata*** (Tullberg, 1876) (1, 2a, 2b, 3a, 4?, 5)
131. ***Protaphorura pannonica*** Haybach 1960 (2a)
132. *Protaphorura procampata* Gisin, 1956 (=*P. campata*)
133. *Protaphorura prolata* Gisin, 1956 (=*P. aurantiaca*)
134. ***Protaphorura pseudocellata*** Naglitsch, 1962 (2a)
135. *Protaphorura pulvinata* Gisin, 1954 (=*P. meridiata*)
136. ***Protaphorura quadriocellata*** (Gisin 1947) (2a)
137. ***Protaphorura stachi*** Bagnall, 1935 (2a)
138. ***Protaphorura subaequalis*** Bagnall, 1937 (2a)
139. *Protaphorura subarmata* Gisin, 1957 (=*P. subuliginata*)
140. *Protaphorura sublata* Gisin, 1957 (=*P. aurantiaca*)
141. ***Protaphorura subuliginata*** Gisin, 1956 (2a)
142. ***Protaphorura s-vontoernei*** Gisin, 1957 (2a)
143. ***Protaphorura thalassophila*** Bagnall, 1937 (2a)
144. *Protaphorura tricampata* Gisin, 1956 (=*P. armata*)
145. *Protaphorura trinotata* Gisin 1961 (=*P. pannonica*)
146. ***Protaphorura tullbergi*** Bagnall, 1935 (2a)
147. *Protaphorura uliginata* Gisin, 1952 (=*P. aurantiaca*)

148. *Protaphorura waterstoni* Bagnall, 1937 (=*P. armata*)

Subfamily Tullbergiinae

149. ***Mesaphorura atlantica*** (Rusek, 1979) (2a)
150. ***Mesaphorura iowensis*** (Mills, 1932) (2a, 7, 8, 13, 24)
151. ***Mesaphorura krausbaueri*** (Börner, 1901) (1, 2a, 2b, 3a, 4, 5, 6, 14, 18, 19, 24, 28, 29, 30, 31, 32, 34, 35, 37)
152. ***Mesaphorura macrochaeta*** Rusek, 1976 (1, 2a, 3a, 4, 5, 7a, 7b, 8, 20, 24, 32, 34, 37)
153. ***Mesaphorura sylvatica*** (Rusek, 1971) (2a, 2b, 5)
154. *Mesaphorura thalassophila* (Bagnall, 1937) (=*M. krausbaueri*)
155. ***Metaphorura affinis*** (Börner, 1902) (1, 2a, 2b, 4, 5, 6)
156. ***Neonaphorura duboscqui*** (Denis, 1932) (2a, 2b, 5)
157. ***Neotullbergia crassicuspis*** (Gisin, 1944) (2a)
158. ***Neotullbergia ramicuspis*** Gisin 1953 (2a, 5)
159. ***Neotullbergia tricuspis*** (Börner, 1902) (2a, 5, 22)
160. ***Paratullbergia callipygos*** (Börner, 1902) (2a, 5, 6, 7a, 7b, 31)
161. *Paratullbergia carpenteri* Bagnall, 1935 (=*P. callipygos*)
162. ***Paratullbergia concolor*** Womersley, 1930 (2a)
163. ***Paratullbergia macdougalli*** Bagnall, 1936 (2a, 5)
164. *Paratullbergia womersleyi* Bagnall, 1935 (=*P. callipygos*)
165. ***Stenaphorura japygiformis*** Absolon, 1900 (2a)
166. ***Stenaphorurella denisi*** (Bagnall, 1935) (2a)
167. ***Stenaphorurella quadrispina*** (Börner, 1901) (1, 2a, 4, 5, 6, 24?, 33)

Family Poduridae

168. ***Podura aquatica*** Linnaeus, 1758 (1, 2a, 2b, 5, 7a, 7b, 8)

Superfamily Entomobryoidea (=Entomobryomorpha)

Family Cyphoderidae

169. ***Cyphoderus albinus*** Nicolet, 1841 (2a, 2b, 5, 6, 17)

Family Entomobryidae

Subfamily Entomobryinae

170. ***Entomobrya albocincta*** (Templeton, 1835) (2a, 5, 6, 20)
171. ***Entomobrya anomala*** Carpenter, 1906 (?)
172. ***Entomobrya arborea*** (Tullberg, 1871) (2a)
173. ***Entomobrya corticalis*** (Nicolet, 1841) (2a, 2b, 3a, 4)
174. ***Entomobrya fuliginosa*** (Templeton, 1835) (?)
175. ***Entomobrya intermedia*** Brook, 1884 (2a, 7a, 8)
176. ***Entomobrya lanuginosa*** (Nicolet, 1841) (1, 2a, 2b, 4, 5, 29?, 32)
177. ***Entomobrya marginata*** (Tullberg, 1871) (2a, 2b, 4, 5, 6, 18, 19?, 20?, 22, 26?, 28?, 32, 34)

178. ***Entomobrya maritima*** Reuter, 1891 (Schott 1893?) (2a, 5)
179. ***Entomobrya multifasciata*** (Tullberg, 1871) (1, 2a, 4, 5, 6, 7a, 7b, 8, 14, 17, 20, 23, 26, 28, 29, 30, 31, 32, 33, 34, 35)
180. ***Entomobrya muscorum*** (Nicolet, 1841) (2a, 2b, 4, 5, 6, 34)
181. ***Entomobrya nicoleti*** (Lubbock, 1867) (2a, 5, 32, 34)
182. ***Entomobrya nivalis*** (Linnaeus, 1758) (1, 2a, 3a?, 5, 6, 7a, 12, 14, 17, 29, 31, 32, 34, 35, 37)
183. ***Entomobrya pulchella*** (Ridley, 1881) (2a, 5)
184. ***Entomobrya schoetti*** Stach 1922 (2a)
185. ***Entomobrya superba*** (Reuter, 1876) (2a)
186. ***Entomobryoides myrmecophila*** (Reuter, 1886) (2a, 5)
187. ***Lepidocyrtus curvicollis*** Bourlet, 1839 (2a, 2b, 3a, 5, 6, 7a)
188. ***Lepidocyrtus cyaneus*** Tullberg, 1871 (1, 2a, 2b, 3a, 4, 5, 6, 7a, 7b, 8, 13, 14, 17, 31, 33, 34)
189. ***Lepidocyrtus lanuginosus*** (Gmelin, 1788) (1, 2a, 2b, 4, 5, 13, 29, 31)
190. ***Lepidocyrtus lignorum*** (Fabricius, 1781) (1, 2a, 5, 7a, 7b, 34)
191. ***Lepidocyrtus paradoxus*** Uzel, 1891 (2a, 4, 5, 6, 7a)
192. ***Lepidocyrtus ruber*** Schött, 1902 (2a)
193. ***Lepidocyrtus violaceus*** Lubbock, 1873 (1, 2a, 2b, 4, 5, 7a, 8, 20)
194. ***Mesentotoma dollfusi*** Denis, 1924 (2a, 5, 6)
195. ***Pseudosinella alba*** (Packard, 1873) (1, 2a, 4, 5, 7a, 7b, 8, 13, 16, 24, 31, 35)
196. ***Pseudosinella boneti*** Bagnall, 1941 (2a)
197. ***Pseudosinella decipiens*** Denis, 1924 (2a, 5, 24?)
198. ***Pseudosinella dobati*** Gisin, 1966 (2a)
199. ***Pseudosinella fallax*** Börner, 1903 (2a?, 5, 18?)
200. ***Pseudosinella halophila*** Bagnall, 1939 (2a)
201. ***Pseudosinella immaculata*** (Lie Pettersen, 1896) (2a, 5, 14?, 26?)
202. ***Pseudosinella maritima*** Bagnall, 1941 (2a)
203. ***Pseudosinella octopunctata*** Börner, 1901 (1, 2a, 3a, 4, 5, 6, 7a, 7b, 8, 9, 13, 14, 18, 19, 20, 24, 29, 31)
204. ***Pseudosinella petterseni*** Börner, 1901 (2a, 3a, 5, 17, 24?, 26?, 29?)
205. ***Pseudosinella sexoculata*** Schött, 1902 (2a, 5, 6, 7a, 7b, 8, 24, 29, 34, 37)
206. ***Pseudosinella subvirei*** Bonet, 1931 (2a)
207. ***Pseudosinella tarraconensis*** Bonet, 1929 (2a, 5)
208. ***Pseudosinella vandeli*** Denis, 1923 (2a)
209. ***Seira domestica*** (Nicolet, 1841) (2a, 5, 6, 24?, 28?, 29?, 34?)
210. ***Sinella coeca*** (Schött, 1896) (2a, 3a?, 4, 5, 6, 7a, 7b, 8, 18, 20, 23, 24, 26, 31, 32, 33, 34, 35)
211. ***Sinella curviseta*** Brook, 1882 (2a, 3a, 7, 8, 17, 18, 20)
212. ***Sinella humicola*** Brown 1926 (9?)
213. ***Sinella pulcherrima*** Agrell, 1939 (2a, 3, 6)
214. ***Willowsia buskii*** (Lubbock, 1869) (1, 2a, 2b, 4, 5, 7a, 7b, 8, 18, 28, 37)
215. ***Willowsia nigromaculata*** (Lubbock, 1873) (1, 2a, 2b, 3a, 4, 5, 7a, 7b, 8, 17, 18)
216. ***Willowsia platani*** (Nicolet, 1841) (2a, 4, 5, 18)

Subfamily Orchesellinae

217. ***Heteromurus nitidus*** (Templeton, 1835) (2a, 5, 6, 7a, 7b, 8, 28?, 29?, 35)
218. ***Orchesella alticola*** Uzel, 1891 (2a)
219. ***Orchesella bifasciata*** (Nicolet, 1841) (2a, 5)
220. ***Orchesella cincta*** (Linnaeus, 1758) (1, 2a, 5, 7a, 7b?, 8?, 16)

221. *Orchesella flavescens* (Bourlet, 1839) (1, 2a, 2b, 5, 8?)
222. *Orchesella quinquefasciata* (Bourlet, 1843) (2a, 5)
223. *Orchesella spectabilis* Tullberg, 1871 (2a, 5?)
224. *Orchesella villosa* (Geoffroy, 1764) (2a, 2b, 5, 7a, 7b)
225. *Verhoeffiella longicornis* (Absolon, 1900) (2a?, 5)

Family Isotomidae

226. *Agrenia bidenticulata* (Tullberg, 1876) (1, 2a, 2b, 3a, 4, 5, 7a, 7b, 8)
227. *Anurophorus laricis* Nicolet, 1842 (1, 2a, 2b, 3a, 4, 5)
228. *Anurophorus satchelli* Goto, 1956 (2a)
229. *Anurophorus unguiculus* Bagnall, 1940 (2a)
230. *Archisotoma besselsii* (Packard, 1877) (1, 2a, 5, 24?, 27?)
231. *Archisotoma megalops* Bagnall, 1939 (1, 2a)
232. *Archisotoma nigricans* Bagnall, 1939 (2a)
233. *Axelsonia littoralis* (Moniez, 1890) (2a, 5, 6, 24, 27, 32, 33, 34)
234. *Ballistura schoetti* (Dalla Torre, 1895) (1, 2a, 2b, 4, 5, 6, 7a, 8, 25, 28, 29, 31, 33, 34)
235. *Clavisotoma borealis* (Axelson, 1905) (1, 2a)
236. *Clavisotoma filifera* (Denis, 1931) (2a, 24, 26, 28, 27, 32, 34)
237. *Clavisotoma fitchi* (Denis, 1933) (2a, 5, 19, 22, 24, 27)
238. *Cryptopygus bipunctatus* (Axelson, 1903) (1, 2a, 5)
239. *Cryptopygus garretti* (Bagnall, 1939) (2a)
240. *Cryptopygus gisini* (Massoud & Rappoport, 1968) (2a, 5)
241. *Cryptopygus scalpelliferus* (Gisin, 1955) (2a, 5, 6)
242. *Cryptopygus sphagneticolus* (Linnaniemi, 1912) (1?, 2a, 2b, 4, 37?)
243. *Cryptopygus thermophilus* (Axelson, 1900) (1, 2a, 3a, 3b, 5, 6, 7a, 7b, 8, 9, 12, 17, 18, 20, 22, 23, 24, 26, 28, 29, 30, 32, 33, 34, 35)
244. *Folsomia achaeta* Bagnall, 1939 (=juvenile *Proisotoma*)
245. *Folsomia agrelli* Gisin 1944 (1, 2a)
246. *Folsomia bisetosa* Gisin, 1953 (1, 2a, 2b, 3a, 7a)
247. *Folsomia brevicauda* Agrell 1939 (1, 2a)
248. *Folsomia brevifurca* Bagnall, 1949 (2a, 4?, 17?)
249. *Folsomia britannica* Stach, 1947 (2a)
250. *Folsomia candida* Willem, 1902 (2a, 3a, 4, 5, 6, 7a, 7b, 8, 16, 19, 20, 24, 26, 27, 29, 32, 33, 34, 35, 37)
251. *Folsomia cavicola* Delamare Deboutteville, 1954 (?)
252. *Folsomia diplophthalma* (Axelson, 1902) (1, 2a, 2b, 3a, 3b, 4, 5, 7a, 7b, 8, 18, 35)
253. *Folsomia fimetaria* (Linnaeus, 1758) (1, 2a, 2b, 3a, 3b, 5, 6, 7a, 24, 29?)
254. *Folsomia fimetarioides* (Axelson, 1903) (2a, 2b, 22?)
255. *Folsomia inoculata* Stach, 1947 (2a, 2b, 3a, 4)
256. *Folsomia litsteri* Bagnall, 1939 (=*F. candida*)
257. *Folsomia manolachei* Bagnall, 1939 (1?, 2a, 5)
258. *Folsomia microchaeta* Agrell, 1939 (1, 2a)
259. *Folsomia monoculata* (Bagnall, 1949) (2a)
260. *Folsomia monophthalma* Bagnall, 1939 (2a)
261. *Folsomia montigena* Stach, (1946) (2a) (=*F. spinosa*?)
262. *Folsomia nana* Gisin, 1957 (1?, 2a, 5)

263. ***Folsomia penicula*** Bagnall, 1939 (2a, 5, 7a)
264. ***Folsomia quadrioculata*** (Tullberg, 1871) (1, 2a, 2b, 3a, 4, 5, 7a, 7b, 8, 35)
265. ***Folsomia sexoculata*** (Tullberg, 1871) (1, 2a, 3a, 5?, 7a)
266. ***Folsomia similis*** Bagnall, 1939 (2a, 7a, 7b, 8, 32)
267. ***Folsomia spinosa*** Kseneman, 1936 (2a, 2b, 4, 5) (=*F. montigena*?)
268. *Folsomia thalassophila* Bagnall, 1940 (=*F. sexoculata*)
269. ***Folsomides angularis*** (Axelson, 1905) (2a, 2b, 3b, 4, 5, 6, 14, 24?, 29?, 34?)
270. *Folsomides inaequalis* (Bagnall, 1949) (=*Proisotoma minima*)
271. ***Folsomides parvulus*** Stach, 1922 (1, 2a, 2b, 3a, 3b, 4, 5, 6, 7a, 7b, 8, 9, 13, 14, 15, 17, 19, 20, 21, 23, 24, 26, 27, 28, 29, 32, 34)
272. ***Isotoma anglicana*** Lubbock 1862 (1, 2a, 7a, 8)
273. ***Isotoma antennalis*** (Bagnall, 1940) (2a, 6)
274. ***Isotoma coeca*** Reuter, 1880 (2a)
275. ***Isotoma fennica*** (Reuter, 1895) (1, 2a, 7a)
276. ***Isotoma hibernica*** Carpenter, 1906 (2a)
277. ***Isotoma infuscata*** (Murphy, 1959) (1, 2a)
278. ***Isotoma intermedia*** Schött, 1902 (?)
279. ***Isotoma kosiana*** Bagnall, 1949 (2a)
280. ***Isotoma maritima*** (Tullberg, 1871) (1, 2a, 3a, 5?, 6?)
281. ***Isotoma nivalis*** (Carl, 1910) (2a, 5)
282. ***Isotoma notabilis*** Schäffer, 1896 (1, 2a, 2b, 3a, 4, 5, 6, 7a, 7b, 8, 16, 17, 18, 20, 24, 26, 28, 29, 30, 31, 34, 35, 36)
283. ***Isotoma olivacea*** (Tullberg, 1871) (1, 2a, 2b, 4, 5)
284. ***Isotoma poseidonis*** Bagnall, 1939 (2a)
285. ***Isotoma propinqua*** Axelson, 1902 (1, 2a, 4, 5, 7a, 8)
286. ***Isotoma tenuicornis*** (Axelson, 1903) (2a)
287. ***Isotoma violacea*** (Tullberg, 1876) (1, 2a?, 2b?)
288. ***Isotoma viridis*** Bourlet, 1839 (1, 2a, 2b, 3a, 4, 5, 6, 7a, 7b, 8, 9, 18, 24)
289. ***Isotomiella minor*** (Schäffer, 1896) (1, 2a, 2b, 3a, 4, 5, 6, 7a, 7b, 8, 10, 12, 13, 16, 17, 18, 19, 20, 22, 23, 24, 26, 27, 28, 29, 35, 36)
290. ***Isotomiella paraminor*** Gisin, 1942 (2a, 5, 6, 18?, 28?)
291. ***Isotomodes bisetosus*** Cassagnau, 1959 (2a, 5, 8)
292. ***Isotomodes productus*** (Axelson, 1906) (2a, 4, 5, 6, 7b, 8, 22, 24?, 29?, 31, 33, 34, 35)
293. ***Isotomodes templetoni*** Bagnall, 1939 (2a, 5)
294. ***Isotomodes trisetosus*** Denis, 1923 (2a, 5, 6, 18, 19, 23, 24, 26, 28, 29)
295. ***Isotomurus alticolus*** (Carl, 1899) (2a, 4, 5)
296. ***Isotomurus maculatus*** (Schäffer, 1896) (2a, 5, 6, 32?, 33?, 34?)
297. ***Isotomurus palustris*** (Müller, 1776) (1, 2a, 2b, 3a, 3b, 4, 5, 6, 7a, 8, 9, 13, 17, 20, 23, 24, 26, 27, 29, 31, 32, 33, 34, 35)
298. ***Isotomurus plumosus*** Bagnall, 1940 (1, 2a, 4, 5, 35)
299. ***Pachyotoma crassicauda*** (Tullberg, 1871) (1, 2a, 2b)
300. ***Pachyotoma sphagneticola*** Bagnall, 1940 (2a)
301. ***Pachyotoma ultonica*** (Carpenter, 1911) (2a)
302. ***Proctostephanus madeirensis*** Gama, 1959 (2a, 5, 6)
303. ***Proisotoma admaritima*** Murphy, 1953 (1, 2a)
304. ***Proisotoma buddenbrocki*** Strenzke, 1954 (1, 2a)
305. ***Proisotoma minima*** (Absolon, 1901) (1, 2a, 2b, 3a, 4, 5, 7a, 7b, 8, 24, 26)
306. ***Proisotoma minuta*** (Tullberg, 1871) (1, 2a, 2b, 3a, 4, 5, 6, 7a, 7b, 8, 9, 14, 17, 19, 20, 22,

24, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 37)
307. ***Proisotoma tenella*** (Reuter, 1895) (1, 2a, 3b, 6, 7a, 7b, 24, 27, 34)
308. ***Proisotoma vestita*** (Brown, 1923) (2a)
309. ***Pseudanurophorus alticolus*** Bagnall, 1949 (2a)
310. ***Pseudanurophorus binoculatus*** Kseneman, 1934 (1, 2a, 3a, 5, 7a, 8)
311. ***Pseudisotoma monochaeta*** Kos, 1942 (2a, 5, 7a, 8)
312. ***Pseudisotoma sensibilis*** (Tullberg, 1876) (1, 2a, 2b, 3a, 5, 6, 7a, 7b, 8, 18, 19, 20, 22)
313. ***Tetracanthella brachyura*** Bagnall, 1949 (2a)
314. *Tetracanthella britannica* Cassagnau, 1959 (=*T. brachyura*)
315. *Tetracanthella kendalli* Bagnall, 1939 (=*T. wahlgreni*)
316. *Tetracanthella lichnidis* Bagnall, 1949 (=*T. strenzkei*)
317. ***Tetracanthella pilosa*** Schött, 1891 (2a, 5)
318. ***Tetracanthella strenzkei*** Gisin, 1949 (2a, 5)
319. ***Tetracanthella wahlgreni*** Linnaniemi, 1907 (1, 2a)
320. *Uzelia oxoniensis* (Bagnall, 1914) (=*U. setifera*)
321. ***Uzelia setifera*** Absolon, 1901 (2a, 5, 7a)
322. ***Vertagopus arboreus*** (Linnaeus, 1758) (1, 2a, 3a, 5, 7a, 8, 29, 36)
323. ***Vertagopus cinereus*** (Nicolet, 1841) (1, 2a, 5)
324. ***Vertagopus montanus*** Stach, 1947 (2a, 5)
325. ***Vertagopus westerlundi*** (Reuter, 1897) (1, 2a, 2b)

Family Oncopoduridae

326. ***Oncopodura crassicornis*** Shoebotham, 1911 (2a, 3a, 5, 6, 29?)

Family Tomoceridae

327. ***Pogonognathellus flavescens*** (Tullberg, 1871) (1, 2a, 2b, 3a, 5, 6, 7a, 7b, 8, 24)
328. ***Pogonognathellus longicornis*** (Müller, 1776) (1, 2a, 5, 6)
329. ***Tomocerus minor*** (Lubbock, 1862) (1, 2a, 3a?4, 5, 6, 7a, 8, 16, 20, 24, 35)
330. ***Tomocerus minutus*** (Tullberg, 1876) (1, 2a, 2b, 3a, 4, 5)
331. ***Tomocerus vulgaris*** (Tullberg, 1871) (1, 2A, 2B, 3A?, 4, 5, 7A, 7B, 8, 32, 36?)

Order Neelipleona

Family Neelidae

332. ***Megalothorax minimus*** Willem, 1900 (1, 2a, 2b, 3a, 5, 6, 7a, 7b, 8, 10, 12, 17, 18, 19, 23, 24, 27, 31, 37)
333. ***Neelides minutus*** (Folsom, 1901) (1, 2a, 3a, 6, 7a, 7b, 8, 20, 24)
334. ***Neelus murinus*** Folsom, 1896 (2a, 5, 6, 7a, 7b, 8, 12, 17, 18, 24, 34)

Order Symphypleona

Family Sminthuridae

Subfamily Bourletiellinae

335. ***Bourletiella arvalis*** (Fitch, 1863) (2a, 3b 4, 5, 6, 7a, 8, 17, 31, 32, 33, 34, 35)
336. ***Bourletiella hortensis*** (Fitch, 1863) (1, 2a, 2b, 3a, 4, 5, 6, 7a, 7b, 8, 17, 18, 20, 32, 34, 35, 37)
337. *Bourletiella lutea* (Lubbock, 1867) (=*B. arvalis?*)
338. ***Bourletiella viridescens*** Stach, 1920 (2a, 5, 6, 32, 33, 34)
339. ***Deuterosminthurus bicinctus*** (Koch, 1840) (2a, 2b, 3a, 4, 5, 6, 35)
340. ***Deuterosminthurus flavus*** Gisin, 1946 (2a, 5, 32, 34)
341. ***Deuterosminthurus pallipes*** (Bourlet, 1843) (2a, 2b, 4, 5, 35)
342. ***Deuterosminthurus repandus*** (Ågren, 1903) (1, 2a, 2b, 4, 5, 6, 35)
343. ***Deuterosminthurus sulphureus*** (Koch, 1840) (2a, 32, 34, 35)
344. ***Heterosminthurus bilineatus*** (Bourlet, 1842) (1, 2a, 2b, 4, 5)
345. ***Heterosminthurus claviger*** Gisin, 1958 (1, 2a, 4)
346. *Heterosminthurus craggi* Murphy, 1960 (=*H. claviger*)
347. ***Heterosminthurus insignis*** (Reuter, 1876) (1, 2a, 2b, 4)
348. ***Heterosminthurus novemlineatus*** (Tullberg, 1871) (1, 2a, 2b, 3a, 5)

Subfamily Dicyrtominae

349. ***Dicyrtoma fusca*** (Lucas, 1842) (1, 2a, 2b, 5, 6, 7a, 7b)
350. ***Dicyrtomina minuta*** (Fabricius, 1783) (1, 2a, 4, 5, 6, 7, 13, 29, 31, 35)
351. ***Dicyrtomina ornata*** (Nicolet, 1841) (2a, 5, 6)
352. ***Dicyrtomina saundersii*** (Lubbock, 1862) (2a, 5, 6)
353. ***Ptenothrix atra*** (Linnaeus, 1758) (2a, 3a?, 4, 5, 7a, 7b, 8, 24)
354. ***Ptenothrix carpenteri*** (Collinge & Shoebotham, 1909) (2a)

Subfamily Katianninae

355. ***Arrhopalites bifidus*** Stach, 1945 (2a)
356. ***Arrhopalites caecus*** (Tullberg, 1871) (1, 2a, 2b, 3a, 5, 6, 7, 8, 20, 32, 33, 34, 35)
357. ***Arrhopalites cochlearifer*** Gisin, 1947 (2a, 5)
358. ***Arrhopalites principalis*** Stach, 1945 (1, 2a, 2b, 8)
359. ***Arrhopalites pygmaeus*** (Wankel, 1861) (1, 2a, 2b, 4, 5, 7a, 7b, 8, 34?)
360. ***Arrhopalites sericus*** Gisin, 1947 (2a, 5, 6)
361. ***Arrhopalites terricolus*** Gisin, 1958 (2a, 5)
362. ***Gisinianus flammeolus*** Gisin, 1957 (2a)
363. ***Sminthurinus albifrons*** (Tullberg, 1871) (2a, 2b)
364. ***Sminthurinus aureus*** (Lubbock, 1862) (1, 2a, 2b, 4, 5, 6, 24?, 35)
365. ***Sminthurinus bimaculatus*** (Axelson, 1902) (1, 2a, 2b, 4, 5, 17?)
366. ***Sminthurinus cingulatus*** Bagnall, 1921 (2a)
367. ***Sminthurinus concolor*** (Meinert, 1896) (1, 2a, 5)
368. ***Sminthurinus domesticus*** Gisin, 1963 (?)

369. ***Sminthurinus elegans*** (Fitch, 1863) (1, 2a, 4, 5, 6, 7, 8, 20, 32, 33, 34)
370. ***Sminthurinus igniceps*** (Reuter, 1881) (2a, 3a)
371. ***Sminthurinus lawrencei*** Gisin, 1963 (2a)
372. ***Sminthurinus niger*** (Lubbock, 1867) (1, 2a, 4, 5, 6, 16, 31, 32, 33, 34)
373. *Sminthurinus trinotatus* (Axelson, 1905) (=*S. bimaculatus*?)

Subfamily Sminthuridinae

374. ***Jeannenotia stachi*** (Jeannenot, 1955) (1, 2a, 4, 5, 6, 7a, 32, 34)
375. ***Sminthurides aquaticus*** (Bourlet, 1843) (1, 2a, 3a, 4, 5, 7, 8?, 32?, 33?, 34?)
376. ***Sminthurides assimilis*** (Krausbauer, 1898) (2a, 2b, 5, 6)
377. ***Sminthurides cruciatus*** Axelson, 1905 (2a)
378. ***Sminthurides malmgrenii*** (Tullberg, 1876) (1, 2a, 2b, 3a, 5, 6, 7a, 7b, 8)
379. ***Sminthurides parvulus*** (Krausbauer, 1898) (2a, 5, 6, 17)
380. ***Sminthurides pseudassimilis*** Stach, 1956 (1, 2a, 5)
381. ***Sminthurides schoetti*** (Axelson, 1903) (1, 2a, 5, 6)
382. ***Sminthurides signatus*** (Krausbauer, 1898) (1, 2a)
383. ***Sphaeridia pumilis*** (Krausbauer, 1898) (1, 2a, 2b, 4, 5, 6, 7, 8, 9, 12, 13, 17, 24, 26, 28, 29, 32, 33, 34)
384. ***Stenacidia violacea*** (Reuter, 1881) (1, 2a, 3b, 5, 6, 17, 32, 33?)

Subfamily Sminthurinae

385. ***Allacma fusca*** (Linnaeus, 1758) (1, 2a, 2b, 5, 6)
386. ***Caprainea marginata*** Schött, 1893 (2a, 5)
387. ***Disparrhopalites patrizii*** (Cassagnau & Delamare Deboutteville, 1953) (2a, 5, 6)
388. ***Lipothrix lubbockii*** (Tullberg, 1872) (2a, 5, 6)
389. ***Sminthurus multipunctatus*** (Schäffer, 1896) (2a, 4, 5)
390. ***Sminthurus nigromaculatus*** (Tullberg, 1872) (1, 2a, 5, 6, 9)
391. ***Sminthurus viridis*** (Linnaeus, 1758) (1, 2a, 2b, 3a, 4, 5, 6, 9, 17, 28, 29, 31, 32, 33, 34, 35)
392. ***Sphyrotheca multifasciata*** Reuter, (1881) (2a, 3a, 5, 33)

APPENDIX C

Notes on species of *Brachystomella*, *Ceratophysella* and *Hypogastrura* (Collembola) recorded from Britain and Ireland

Introduction

Accurate checklists of records of species for particular geographical regions are important because if annotated, they give some indication of rarity and allow international comparisons to be made. The new checklist prepared for this report (Appendix B) is a simple list which is difficult to interpret without additional notes on the species. As an illustration of the taxonomic problems that exist within the Collembola in Britain and Ireland, a detailed literature search was conducted on the first 24 species on the list in the genera *Brachystomella, Ceratophysella* and *Hypogastrura.* Species within these genera are common in soils and leaf litter but specific identification is difficult as there is no up-to-date key for the species in our region which takes account of recent taxonomic studies

1. ***Brachystomella parvula*** (Schäffer, 1896)

Distribution : A widespread and locally common species first recorded on 'puddles in the lane' from Wicken Fen under the name *Chondrachorutes wahlgreni* Denis by Jackson (1928) (the list of British genera of Shoebotham (1917*a*) includes *Chondrachorutes* Wahlgr. from Berkhamsted but no other details). Recorded from mountains 'above 2000 feet' in Wales (Davies 1934), 'among seaweed at the head of Loch Long' in Scotland (Bagnall 1939), 'surface soil of grassland, Silwood Park' (Goto 1955*a*), an 'old wheat stack near Monks Wood' (Gilbert 1961), 'common in beds near flamingoes' in Buckingham Palace Gardens (Lawrence 1963*a*) and various sites in Ireland (Bolger 1986; Lawrence 1961*b*). Also recorded by Davis (1963), Hale (1963), Lawrence (1973), Milne (1962), Parr (1978), Sheals (1957), Wood (1967). In the checklist of Turk (1933), this species appears as *Chondrachorutes tuberculata* (Nic.).

Taxonomic notes : Many records should be treated with care, for example Greenslade & Najt (1987) have shown that records for *B. parvula* in Australia are in fact *B. platensis* Najt & Massoud 1974.

Conclusions : Specimens of '*B. parvula*' need to be carefully checked in the light of Greenslade & Najt's comments noted above. At present it seems reasonable to include this species on the UK/Eire list.

2. ***Ceratophysella armata*** (Nicolet, 1842)

Distribution : Apparently a widespread, common and locally abundant species (but see taxonomic notes below) first recorded by Lubbock (1868) as *Achorutes armatus* Nicolet, and subsequently as Plate 40 in Lubbock (1873). Frequently found in large numbers on rotting vegetable matter (Carpenter 1905; Carpenter & Evans 1899), fungus (Collinge & Shoebotham 1910; Gough 1972), dung (Evans (1901*b*) and as a minor 'pest' of plants (Carpenter 1914, 1931; Collinge 1909, 1911; Theobald 1910). Baweja (1939) found that this species increased its normal density by about 20 times following colonisation of sterilized soil at Rothamsted. Also recorded by Bagnall (1910), Bolger (1986), Brown (1918, 1925*a*), Carpenter (1913), Carr (1916), Collinge (1910), Dhillon & Gibson (1962), Edwards 1929), Evans (1901*a*), Gilbert (1961, subsequently re-assigned to *C. denticulatus* by Gilbert 1963), Jackson (1928), Lawrence (1961*b*, but see taxonomic note below), Miles (1958), Morris (1920), Salt *et al.* (1948), Shoebotham (1914, 1917*b*), Thompson (1924), Turk (1933), Womersley (1923, 1925, 1926, 1927*a*, 1927*b*, 1930*b*, 1930*c*), and from caves by Carpenter (1897) and Lawrence (1959).

Taxonomic notes : Lawrence (1963*b*) stated 'I have yet to see a British specimen of *armata* and the numerous records of this species may often apply to *denticulata*'. Similar confusion has occurred in Australia (Greenslade 1994). Fjellberg (1980) said 'Earlier authors considered this species to be common, but usually it was confused with other species. I have not yet seen Norwegian specimens'. Christiansen & Bellinger (1980) considered that 'All nearctic records of this species are suspect'. For a modern description see Babenko *et al.* (1994).

Conclusion : The presence of this species in UK/Eire is by no means certain. It does not appear on Fjellberg's (1996) Norwegian checklist and specimens should be carefully checked with reference to Babenko *et al.* (1994) before being assigned to *C. armata.*

3. ***Ceratophysella bengtssoni*** (Ågren, 1904)

Distribution : First recorded from Wicken Fen 'on puddles in the lane' by Jackson (1928). Apparently recorded under the names *Ågreniella angularis* sp.n. ('three examples from an Edinburgh field') and *Ågreniella collingei* sp.n. ('in countless numbers on the golden pulp of a rotten garden marrow' in Warwickshire) by Bagnall (1949). Bagnall (1940) listed several records including 'in some plenty in moles' nests' of specimens taken in 1910 to 1912. One specimen was found by Lawrence *et al.* (1967) at Kew Gardens in a 'heap of decaying leaves, Herbarium Experimental Ground'. Also extracted from 'approx. one tea cup full of bat guano' (30 specimens) from the Hyena Den of Wookey Hole in Somerset by Lawrence (1959), and recorded from Mouse Hole in the Avon Gorge by Hazelton (1968*c*). The record of Lawrence (1961*a*, see below) is listed by Bolger (1986) as the only record for Ireland.

Taxonomic notes : Specimens of this species collected by Lawrence (1961*a*) from the Burren were 'not typical of the species and show some of the characters of the closely related *sigillata*' (see under *C. sigillata* below). For a modern description see Babenko *et al.* (1994).

Conclusion : The inclusion of this species on the UK/Eire list relies on a few scattered records, all made prior to 1970 and before recent revisions of the genus. It is probably present somewhere but all specimens need to be re-examined (especially with reference to *C. sigillata*) using Babenko *et al.* (1994).

4. ***Ceratophysella denticulata*** (Bagnall, 1941)

Distribution : Described as *Achorutes denticulatus* sp.n. by Bagnall (1941) from a wide variety of English, Scottish and Irish localities in collections dating back to 1910. Common 'in cut grass' in Buckingham Palace gardens (Lawrence 1963*a*) and on sewage filters (Lawrence 1970). Numerous records for Ireland are cited in Bolger's (1986) checklist. Also recorded by Blackith (1974), Bolger & Curry (1980), Curry (1969, 1971), Davis (1963), Edwards & Lofty (1974), Frampton (1988), Gilbert (1963), Goto (1955*b*, repeated by Waterston 1981), Greenslade & Fletcher (1986), Hale (1963, 1965), Hutson (1980*a*, 1980*b*), Lasebikan (1973), Lawrence (1973), Longstaff (1976), Miles (1975), Milne (1962), Nelson (1981 as *Hypogastrura* species cf. *denticulata-scotica*), Purvis (1982), Sheals (1957), Wood (1967), and from caves and mines by Hazelton (1972*a*, 1972*b*) and Moseley (1970).

Taxonomic notes : Gough (1971) collected a number of immature specimens from Skokholm in which 'there was much variation in the form of the empodium which was variously distorted or reduced. The form differed even on different legs of the same individual'. Numerous specimens were found on *Agaricus* sp. on Shetland by Harris & Goto (1982) who stated 'This species is probably much more widely distributed than exisiting records would seem to indicate. It has been confused with *H. armata* and probably others'. For a modern description see Babenko *et al.* (1994).

Conclusion : There seems little doubt that this is a widespread and common species in the region. Specimens should be carefully checked with reference to the description in Babenko *et al.* (1994).

5. ***Ceratophysella gibbosa*** (Bagnall, 1940)

Distribution : Described as *Achorutes gibbosus* sp.n. by Bagnall (1940) from a wide variety of English, Scottish and Irish localities dating back to 1908. Also recorded by Bagnall (1941). Found on a manure heap by Gilbert (1963), in a glasshouse in Buckingham Palace gardens by Lawrence (1963*a*, one specimen only), and in 'anemone corms', rotten leaves and fungus by Lawrence (1962). Bagnall's Irish record is the only mention of this species in Bolger's (1986) checklist.

Taxonomic notes : Lawrence (1962) discussed possible synonymy between *C. gibbosa* and *C. denticulata* although this now seems unlikely. For a modern description see Babenko *et al.* (1994).

Conclusion : Apart from Bagnall's specimens, there are very few recent records for *C. gibbosa*. Confusion with other *Ceratophysella* species is a distinct possibility.

6. ***Ceratophysella granulata*** (Stach, 1949)

Distribution : Recorded from the Outer Hebrides as 'New to the British Isles' by Goto (1955*b*, repeated by Waterston 1981) who said that he had unpublished records of this species 'from various parts of England'. Some of these were published in Goto (1955*a*). Also recorded by Delaney (1956), Gough (1972), Harris & Goto (1982), Miles (1958 as 'probably'). A couple of unpublished Irish records made by Lawrence are listed in Bolger's (1986) checklist.

Taxonomic notes : Goto (1955*b*) said that 'It is probable that at least some of the earlier records of *H. armata* from many parts of the British Isles actually refer to *C. granulata*'. For a modern description see Babenko *et al.* (1994).

Conclusion : There are few records for this species in the region. It is possible that it could have been confused with others in the past. Specimens should be carefully checked with reference to the description in Babenko *et al.* (1994).

7. ***Ceratophysella longispina*** (Tullberg, 1876)

Distribution : Carpenter and Evans (1899) found '*Achorutes longispinus* Tullb., var. *scoticus*' near Edinburgh but *scoticus* is now considered to be a species in its own right (see below, species no. 10). Carpenter (1905) reported this species as damaging bean seedlings in a Dublin garden (record repeated by Theobald 1910). Carpenter (1934) listed this species as 'abundant in *Narcissus* bulbs in Manchester). A huge swarm of several million individuals of '*Achorutes longispinus*' was reported by Sankey (1952) on an exposed chalkface in a road cutting in Surrey. Also recorded by Bagnall (1910), Brown (1918), Carpenter & Phillips (1922), Carr (1916), Turk (1933) and Womersley (1930*c*). The Carpenter (1913) record is the only one listed for Ireland in Bolger's (1986) checklist (as *sp. dub.*).

Taxonomic notes : Several authors mention that this is a typically 'Arctic species'! Fjellberg (1994) regarded it as 'circumpolar'. For a modern description see Babenko *et al.* (1994).

Conclusion : Fjellberg (1980) reported this species as 'common on Spitsbergen' and his view (Fjellberg 1985) that this is a 'Northern Holarctic' species calls the British and Irish records into question. Specimens should be carefully checked with reference to Babenko *et al.* (1994). At present, the presence of this species on the UK/Eire list is by no means certain.

8. ***Ceratophysella rufescens*** (Nicolet, 1841) (=*C. armata*)

Distribution : First recorded as 'common in winter among dead leaves' by Lubbock (1868), a record repeated in him in Lubbock (1873). Also recorded by Bagnall (1910), Carpenter & Evans (1899), Collinge & Shoebotham (1910), Turk (1933), Womersley (1923) and as a pest of mushrooms by Theobald (1910).

Taxonomic notes : Listed as *sp. dub.* by Kloet & Hinks (1964). Gisin (1960) regarded *C. rufescens* as a **junior synonym** of *C. sigillata* (Uzel). No other recent descriptions are available.

Conclusion : This 'species' must be considered as a colour variety of another *Ceratophysella* but it is impossible to say which unless specimens can be found to support the records cited above. Thus it should be **removed** from the UK/Eire checklist and listed as a probable synonym of *C. armata*.

9. ***Ceratophysella scotica*** (Carpenter & Evans, 1899)

Distribution : Described by Carpenter & Evans (1899) as *Achorutes longispinus*, Tullb., var. *scoticus* nov. from 'a dozen specimens' from wet *Sphagnum* at Bavelaw Moss, near Balerno (Midlothian) (record repeated by Waterston 1981). There appear to be no other records until Bagnall (1940) who reported several localities for this species from collections made since 1910. Also recorded by Blackith (1974), Goto (1957), Hale (1963), Lasebikan (1973), Murphy (1960 as *Hypogastrura (Ceratophysella) gotoi* nom. nov. regarded as a junior synonym of *C. scotica* by Goto & Lawrence (1964)), Pomeroy (1977) and in the Irish checklist of Bolger (1986).

Taxonomic notes : For a modern description see Babenko *et al.* (1994).

Conclusion : Although there are relatively few records for this species, it seems to be fairly well-characterised and is probably widespread in the Northwest of our region, especially in bogs and mountains.

10. ***Ceratophysella sigillata*** (Uzel, 1891)

Distribution : This species does not appear on the list of Kloet & Hinks (1964), or in Fjellberg's (1996) checklist for Norway, but is included here as there is a possibility that it has been confused with others in the past (e.g. see Taxonomic notes for *C. bengtssoni* above).

Taxonomic notes : For a modern description see Babenko *et al.* (1994).

Conclusion : There are no published records for this species in UK/Eire but the probability that it is present should be borne in mind when members of *Ceratophysella* are being examined.

11. ***Ceratophysella succinea*** Gisin, 1949

Distribution : The only record for this species in our region is that of Purvis (1982) from a dune edge at Carnsore Point in Southeast Ireland listed in the checklist of Bolger (1986) (as *Hypogastrura ?succinea* Gisin).

Taxonomic notes : Included in Fjellberg's (1996) checklist for Norway. For a modern description see Babenko *et al.* (1994).

Conclusion : It is quite probable that this species occurs in several localities in our region. Indeed there may be specimens hidden in museum collections among other species of *Ceratophysella.*

12. ***Hypogastrura assimilis*** Krausbauer, 1898

Distribution : The only definite record for this species appears to be that of Greenslade & Fletcher (1986) who found it in small earthworm culture boxes at Rothamsted among a variety of other species. There is also an old record reported by Womersley (1923) of '*H. ? assimilatus* Nic.' recorded by Marquand 'as occurring plentifully in a beer cellar in November'. This is probably the source of the record for this species in the checklist of Turk (1933) but it is not clear which species is involved. Possibly found among cultivated mushrooms by Austin (1937).

Taxonomic notes : For a modern description see Babenko *et al.* (1994).

Conclusion : This species has formerly been regarded as a subspecies of *Hypogastrura manubrialis* (Tullberg, 1869) so it is likely that *H. assimilis* occurs here, and even more likely that there are specimens of *H. assimilis* in reference collections of *H. manubrialis.*

13. ***Hypogastrura burkilli*** (Bagnall, 1940) (=*H. purpurescens*)

Distribution : Described as new to science by Bagnall (1940) who said 'this exceptionally large species has only been found in the woodlands of the Thames area'. He gives records from several counties. No other records exist for our region.

Taxonomic notes : Lawrence (1962) concluded that 'No immature specimens of *burkilli* are known and *purpurescens* occurs around the type locality. It seems possible that *burkilli* may be rare and exceptionally large specimens of *purpurescens.*' This view is accepted here. Babenko *et al.* (1994) list *H. burkilli* as a **junior synonym** of *H. purpurescens.*

Conclusion : This species should be removed from the checklist as a junior synonym of *H. purpurescens.*

14. ***Hypogastrura elegans*** (Parfitt, 1891) (=*H. purpurescens*)

Distribution : The only record for this 'species' is the original description made by Parfitt (1891). As it does not appear in any recent publications, it is safe to assume that this is a junior synonym of another *Hypogastrura* species, probably *H. purpurescens*.

Taxonomic notes : Listed as *sp. dub.* by Kloet & Hincks (1964).

Conclusion : This 'species' should be removed from the checklist as a junior synonym of *H. purpurescens.*

15. ***Hypogastrura lapponica*** (Axelson 1902)

Distribution : The only record for this species (as *Hypogastrura packardi* var. *dentata*) is a 'single example found in sphagnum on the slopes of Cairngorm at over 3,000 feet, vii08. First and only British record' by Bagnall (1939).

Taxonomic notes : Bagnall (1939) says that his specimen 'is the *A. lapponicus* of Axelson whose description was published within a month or so after Folsom's publication'. For a modern description see Babenko *et al.* (1994).

Conclusion : If Bagnall's specimen still exists, it clearly needs to be checked against the most recent description by Babenko *et al.* (1994). If the specimen is lost then someone needs to return to the Cairngorms to attempt to rediscover it! *H. lapponica* should remain on the checklist for the present as it is possible that it exists somewhere in our region, probably in Scottish mountains.

16. ***Hypogastrura manubrialis*** (Tullberg, 1869)

Distribution : This is a widespread and quite common species first recorded by Brook (1883) from crevices in sun dried clay on the beach at Thanet. Found 'in multitudes on the surface of running water in a ditch at Corsiehill, near Perth' (Carpenter & Evans 1904), and on 'water in a cart rut' in Berkhamsted by Collinge & Shoebotham (1910). Regarded as 'injurious' to plant life by Collinge (1909) and Theobald (1910). Also recorded by Austin (1937), Bagnall (1940, and 1941 as *Achorutes mucronalis* sp.n., see Lawrence 1962 for synonymy), Bolger (1986), Carpenter & Evans (1899), Collinge (1910), Collinge & Shoebotham (1909 as *Achorutes neglectus*), Evans (1908), Goto (1955*a*), Hutson (1980*a*, 1980*b*, 1981), Lawrence (1963*a*, 1970, 1983), Lawrence *et al.* (1967), Miles (1958), Morris (1920), Shoebotham (1914, 1917*b*), Turk (1933), and Womersley (1930*c*).

Taxonomic notes : For a modern description see Babenko *et al.* (1994).

Conclusion : This seems to be a widespread, fairly common and well-characterised species which should appear on the checklist although specimens should be carefully checked with reference to Babenko *et al.* (1994).

17. ***Hypogastrura packardi*** (Folsom, 1902) (=*H. lapponica*)

See entry under 15. *Hypogastrura lapponica* above. *H. packardi* is a **junior synonym** of *H. packardi* and should not appear on the checklist.

18. ***Hypogastrura purpurescens*** (Lubbock, 1867)

Distribution : Described as sp.n. by Lubbock (1868) from specimens collected 'on a hotbed and under branches of trees' but no locality data is given. Listed as damaging cabbages by Theobald (1910). Also recorded by Bagnall (1910, 1940 as *Achorutes britannicus* sp.n., Bagnall 1949 as *Lubbockiella* sp.), Bolger (1986), Brook (1879), Brown (1918, 1919, 1923*a*, 1925*a*), Bull (1964), Cameron (1913), Carpenter & Evans (1899, 1904 as *Achorutes propinquus* sp.nov.), Collinge & Shoebotham (1910), Davies (1934), Evans (1901*a*, 1908), Goto (1953), Hazelton (1968*a*, 1968*b*, 1970*a*, 1970*b*, 1972*a*, 1972*b*, 1974*a*, 1974*b*, 1974*c*), Hazelton & Glennie (1946), Jackson (1928), Lawrence (1959, 1961*a* 1970, 1973), Lawrence *et al.* (1967) Maxwell (1967), Miles (1975), Morris (1927), Moseley (1970), Shoebotham

(1914, 1917*b*), Thompson (1924), Turk (1932, 1933), Womersley (1923, 1924, 1925, 1928 and 1930*c* as *H. pseudo-purpurascens*, 1930), Wood (1967).

Taxonomic notes : For a modern description see Babenko *et al.* (1994).

Conclusion : There seems little doubt that this widespread and common species should be on the checklist. As always, specimens should be checked with reference to Babenko *et al.* (1994).

19. ***Hypogastrura sahlbergi*** (Reuter, 1895)

Distribution : The first record which may be this species from 'Hertfordshire' is that of Shoebotham (1911) as *Achorutes schäfferi*, Carl 1901, although no further details are given. Brown (1923) described *Achorutes strenuus* sp.n. from Beachy Head but this was suspected by (Gisin (1949), and shown conclusively by Goto & Lawrence (1964) to be a junior synonym of *H. sahlbergi.* Ambiguous records of '*H. strenuus*' from SouthWest England were also made by Womersley (1925, 1926); these were repeated in the checklist of Turk (1933). Also recorded under the correct name of '*sahlbergi*' by Bagnall (1940) from 'Durham' 'in a manure heap' and 'Scotland, amongst rotting seaweed at Stranraer' 'and in the Kyles of Bute' but his text is ambiguous and it is not clear whether he ever saw any specimens! ('I hope to secure specimens with a view to studying the species'). Lawrence *et al.* (1967) found a few specimens of this 'black species belonging to a distinctive group' at Kew Gardens and stated 'previously found in Britain only on the cliffs at Eastbourne', presumably a reference to Brown (1923).

Taxonomic notes : For a modern description see Babenko *et al.* (1994).

Conclusion : The only reasonably certain records for this species are those of Brown (1923) from the Beachy Head/ Eastbourne area, and Kew Gardens by Lawrence *et al.* (1967). Thus it seems reasonable to include it on the checklist. It must surely be present in many more localities.

20. ***Hypogastrura serrata*** (Ågren, 1904)

Distribution : The only record for this species is that of Shoebotham (1911) who states the location as 'Staffordshire' with 'Identification confirmed by Dr. Ågren'.

Taxonomic notes : Babenko *et al.* (1994) mention this species under *H. tianshanica* Martynova 1970 but it is not clear whether this refers to probable synonymy (text in Russian!).

Conclusion : This species appears on Fjellberg's (1996) checklist so he clearly regards it as a good species. However, whether it has ever occurred in our region is open to question. The fact that Shoebotham's specimen(s?) were checked by Ågren would support inclusion of *H. serratus* on the checklist but its presence clearly needs to be confirmed from recent material.

21. ***Hypogastrura socialis*** (Uzel, 1891)

Distribution : First recorded by Bagnall (1935) 'I first found this species on the slopes of Cheviot in 1912 and in 1925 rediscovered it on Ben More'. These records are repeated in Bagnall (1939) under *H. nivicola* which is now regarded as a **junior synonym** of *H. socialis.*

Taxonomic notes : For a modern description see Babenko *et al.* (1994).

Conclusion : The records by Bagnall from Scottish mountains appear to be the only ones for our region. This is a fairly distinctive species and should be looked for in upland areas throughout. It can remain on the checklist for the present as a 'needs confirming' entry.

22. ***Hypogastrura tullbergi*** (Schäffer, 1900)

Distribution : Recorded as *Achorutes browni* sp.n. by Bagnall (1940, 1949), and also as *Lubbockiella aureus*, and *L. litoralis* by Bagnall (1949) from a wide variety of localities. A Bagnall record from London is repeated by Lawrence *et al.* (1967). The *purpurascens* of Womersley (1930*c*) recorded from Ireland is probably this species. Bagnall's and Womersley's Irish records are repeated in the checklist of Bolger (1986). This may be the *Achorutes dubius* of Templeton (1835) and Lubbock (1873) who found it 'in great numbers on a sandbank at Alum Bay in December'. Also recorded by Hazelton (1968*a*, 1968*b*, 1970*a*, 1970*b*) and Lawrence (1962).

Taxonomic notes : Fjellberg (1985) in his monograph on Alaskan Collembola stated 'The *tullbergi* of most recent workers - the form without antennal spines - is a mixture of several forms/species. One of these, present in the high Arctic, is described below as *H. concolor* Carpenter.' Najt *et al.* (1984) considered *H. tullbergi* to be an Arctic species, and this view was accepted by Arbea & Jordana (1991) who described *H. boldorii* Denis, 1931 *sensu* Gisin, 1961 as a senior 'synonym' of *H. tullbergi.* Thus we may have to rename 'our' specimens at some point in the future. For a modern description see Babenko *et al.* (1994).

Conclusion : All specimens of '*H. tullbergi*' from Britain and Ireland need to be checked against modern descriptions to determine to which species they should be assigned. The status of *H. tullbergi* as British or Irish needs confirmation.

23. ***Hypogastrura vernalis*** (Carl, 1901)

Distribution : First recorded by Womersley (1930*a*) who said 'This a well-known European form, but does not appear to have been previously recorded from this country. A large number of specimens were found along with *Arrhopalites caecus*, Tlbg., infesting decayed tulip bulbs in the Entomological Dept. of the Imperial College, South Kensington, Feb. 1930. The bulbs came from Wimborne, Dorset, which probably is the real locality'. This is presumably the source of the record for this species in the checklist of Turk (1933). The only other record is from Kew Gardens by Lawrence *et al.* (1967) as '*H. (H.)* cf. *vernalis* (Carl). Under cut grass and dead leaves in garden near Palace, 31.vii.1960'.

Taxonomic notes : For a modern description see Babenko *et al.* (1994).

Conclusion : The very small number of records for this species is suprising given its apparent wide geographical distribution. *H. vernalis* can remain on the checklist for the present but its status as British needs confirming.

24. ***Hypogastrura viatica*** (Tullberg, 1872)

Distribution : This is probably the *Achorutes dubius* of Templeton (1835) who recorded it from 'Cranmore, on water', the *Achorutes murorum*, Bourlet included in Lubbock (1868), and the *Achorutes similatus* Nicolet of Brook (1879). First recorded under *viaticus* by Reuter & Reuter (1880) from Scotland 'very numerous', 'creeping on the bark of ash trees'. Large 'swarms' have been found on several occasions on sewage filters and elsewhere e.g. Carpenter (1913), Carpenter (1931), Carpenter & Evans (1899), Collinge (1910), Collinge & Shoebotham (1910), Carpenter (1913), Lawrence (1961*b*, 1970), Turk (1932), Womersley (1923, 1924, 1930*c*). Also recorded by Bagnall (1910, 1940, 1949), Bolger (1986), Brown (1921, 1923, 1925*b*), Bull (1964), Cameron (1913), Carpenter & Phillips (1922), Carr (1916), Elton (1934), Evans (1901*a*), Gisin (1967), Green (1953), Green (1980), Imms (1906), Lloyd (1944), Shoebotham (1914), Turk (1933), Waterston (1981). The *Achorutes subviatus* and *A.pseudoviaticus*, and subspecies thereof of Bagnall (1941), are **junior synonyms** of *H. viatica.*

Taxonomic notes : For a modern description see Babenko *et al.* (1994).

Conclusion : *H. viatica* is often associated with decaying vegetation and manure, and is frequent on sewage filter beds. There seems little doubt that this species is widespread and common in our region.

General Conclusions

Of the 24 species under consideration, the following six can be regarded as being definitely present in our region.

1. ***Brachystomella parvula***
4. ***Ceratophysella denticulata***
9. ***Ceratophysella scotica***
16. ***Hypogastrura manubrialis***
18. ***Hypogastrura purpurescens***
24. ***Hypogastrura viatica***

The following four species are probably present but specimens need to be checked before the records can be confirmed.

2. ***Ceratophysella armata***
3. ***Ceratophysella bengtssoni***
12. ***Hypogastrura assimilis***
19. ***Hypogastrura sahlbergi***

The following ten are species recognised by Babenko *et al.* 1994) but their presence in Britain and Ireland needs to be confirmed.

5. ***Ceratophysella gibbosa***
6. ***Ceratophysella granulata***
7. ***Ceratophysella longispina***
10. ***Ceratophysella sigillata***
11. ***Ceratophysella succinea***
15. ***Hypogastrura lapponica***
20. ***Hypogastrura serrata***
21. ***Hypogastrura socialis***
22. ***Hypogastrura tullbergi***
23. ***Hypogastrura vernalis***

The following four species are synonyms and should be removed from the checklist.

8. *Ceratophysella rufescens* (=*C. armata*)
13. *Hypogastrura burkilli* (=*H. purpurescens*)
14. *Hypogastrura elegans* (=*H. purpurescens*)
17. *Hypogastrura packardi* (=*H. lapponica*)

Appendix D.

The appendix lists the raw data files used within the study described in section 6. Species no. - the species number assigned by Dr S Hopkin in his British checklist for Collembola (See Appendix B). Species - the Latin species name. Ref. Code - a code relating to the original paper reference in Hopkin's archive. Location and General location - the locations as they were given in the original paper. BRC locality - the matching locating names from BRC's location database. CIS East and CIS North - the 3 digit east and north grid reference that corresponds to the location names.

Species No	Species	Ref Code	Location	General Location	BRC Locality	CIS East	CIS North
64	Anurida maritima	b258	Clare I	Ireland		120	100
64	Anurida maritima	c189	Clare I	Ireland		120	101
64	Anurida maritima	l100	Burren	Burren		127	211
64	Anurida maritima	g229	Stokholm	Stokholm		173	205
64	Anurida maritima	m1002	Bardsey (I)	Bardsey Island	215	325	
64	Anurida maritima	p1001	Bardsey (I)	Bardsey Island	215	326	
64	Anurida maritima	a1000	Bardsey Island	Bardsey Island	215	327	
64	Anurida maritima	m1001	Plymouth	Plymouth	245	055	
64	Anurida maritima	m1003	Plymouth	245	055		
64	Anurida maritima	g1002	Anglesey	Anglesey	249	385	
64	Anurida maritima	k127	Swansey	264	194		
64	Anurida maritima	c187	Dublin	Ireland	Dublin	316	227
64	Anurida maritima	c183	Aberlady	Scotland	Aberlady	346	675
64	Anurida maritima	c183	St. Andrews	Scotland	351	716	
64	Anurida maritima	c183	North Berwick	Scotland	356	685	
64	Anurida maritima	c183	Fife (Lubbock)	Scotland	363	709	
64	Anurida maritima	g117	St. Leonards; Sussex	Britain	579	109	
64	Anurida maritima	n1000	Whitstable	Whitstable	611	165	
64	Anurida maritima	c240	Dale Fort (St Ann's Head to Hook Quay)				
64	Anurida maritima	c187	Lambay I				
64	Anurida maritima	e71	Peaton (Loch Long)	Scotland			
64	Anurida maritima	t1000	Swarning				
64	Anurida maritima	b361	"swarms" Yorkshire				
64	Anurida maritima	b168	Britain				
64	Anurida maritima	b258	Britain				
64	Anurida maritima	g1000	Britain				
64	Anurida maritima	g1001	Britain				
64	Anurida maritima	l120	Britain				
64	Anurida maritima	t77	Britain				
64	Anurida maritima	b360	England				
64	Anurida maritima	f1001	England				
64	Anurida maritima	l1001	England				
64	Anurida maritima	m1000	England				
64	Anurida maritima	p1000	England				
64	Anurida maritima	b353	Ireland				
64	Anurida maritima	l1000	Ireland				
64	Anurida maritima	w140	Ireland				

Species No	Species	Ref Code	Location	General Location	BRC Locality	CIS East	CIS North
64	Anurida maritima	c276	Lancashire				
64	Anurida maritima	f1000	Outer Hebrides				
64	Anurida maritima	g135	Outer Hebrides				
64	Anurida maritima	w181	Outer Hebrides				
64	Anurida maritima	b1000	Scotland				
64	Anurida maritima	e72	Scotland				
64	Anurida maritima	w133	SW-England				
64	Anurida maritima	w136	SW-England				
64	Anurida maritima	w198	SW-England				
64	Anurida maritima	b1001					
64	Anurida maritima	c1000					
64	Anurida maritima	i1000					
182	Entomobrya nivalis	c189	Clare I	Ireland	120	100	
182	Entomobrya nivalis	l100	Burren	Burren	127	211	
182	Entomobrya nivalis	g117	Kinlochewe	Britain (Middlesex)	Kinlochewe	200	860
182	Entomobrya nivalis	e81	Comrie	Scotland	Comrie	241	855
182	Entomobrya nivalis	c183	Duchray (Sterling)	Scotland		248	699
182	Entomobrya nivalis	e81	Callander	Scotland	Callander	250	750
182	Entomobrya nivalis	c183	Aberfoyle	Scotland	Aberfoyle	252	701
182	Entomobrya nivalis	e81	Aberfoyle	Scotland	Aberfoyle	252	702
182	Entomobrya nivalis	e71	Fiddler Gill	Scotland	Fiddler Gill	280	640
182	Entomobrya nivalis	e71	Douglas	Scotland	Douglas	283	630
182	Entomobrya nivalis	e81	Blair-Atholl	Scotland	287	765	
182	Entomobrya nivalis	e71	Cleghorn	Scotland	Cleghorn	289	645
182	Entomobrya nivalis	c183	Dollar	Scotland	Dollar	290	690
182	Entomobrya nivalis	e71	Elvanfoot	Scotland	Elvanfoot	296	616
182	Entomobrya nivalis	e81	Methven	Scotland	Methven	302	726
182	Entomobrya nivalis	c183	Uphall	Scotland	Uphall	306	671
182	Entomobrya nivalis	c183	Dunfermline	Scotland	Dunfermline	307	686
182	Entomobrya nivalis	c183	Pentland Hills Above Ba	Scotland	Pentland Hills	310	650
182	Entomobrya nivalis	c183	Pentland Hills Above Cu	Scotland	Pentland Hills	310	650
182	Entomobrya nivalis	e81	Glen Farg	Scotland	Glen Farg	315	713
182	Entomobrya nivalis	l73	Dublin (beach wood)		Dublin	316	227
182	Entomobrya nivalis	c183	Braid Hills	Scotland	Braid Hills	320	665
182	Entomobrya nivalis	c183	Mortonhall (Midlothian)	Scotland		20	660
182	Entomobrya nivalis	c183	Torduff Hill	Scotland	320	667	
182	Entomobrya nivalis	c183	Colinton Dell	Scotland	321	668	
182	Entomobrya nivalis	c183	Dalhousie	Scotland	Dalhousie	330	660
182	Entomobrya nivalis	c276	Grange-over-Sands	Lanceshire	Grange-over-Sands	344	420
182	Entomobrya nivalis	c183	Aberlady (Elothian)	Scotland	Aberlady	346	675
182	Entomobrya nivalis	c183	Yester (E lothian)	Scotland	Yester	350	660
182	Entomobrya nivalis	c183	Lauder	Scotland	Lauder	352	647

Species No	Species	Ref Code	Location	General Location	BRC Locality	CIS East	CIS North
182	Entomobrya nivalis	c276	Ribchester	Lanceshire	Ribchester	360	430
182	Entomobrya nivalis	c276	Warington	Lanceshire	Warrington	360	380
182	Entomobrya nivalis	c276	Rostherne	Lanceshire	Rostherne	370	380
182	Entomobrya nivalis	c276	C. Ashton-on-Mersey	Lanceshire		378	392
182	Entomobrya nivalis	c183	Hillend (Pentlands)	Scotland	Hillend	381	238
182	Entomobrya nivalis	c276	L. Manchester	Lanceshire	383	398	
182	Entomobrya nivalis	b302	Isle of Wight	Isle of Wight	430	080	
182	Entomobrya nivalis	b261	Sheffield	Sheffield	435	385	
182	Entomobrya nivalis	b266	Cumnor	Berkshire	Cumnor	446	203
182	Entomobrya nivalis	e1001	Wythamwoods		446	209	
182	Entomobrya nivalis	m1004	Oxford	Oxford	455	204	
182	Entomobrya nivalis	f1002	Oxford Meadow	Oxford	455	204	
182	Entomobrya nivalis	g117	Silwood Park	Berks.	Silwood Park	494	168
182	Entomobrya nivalis	c192	Berkhamsted	Berkhamsted		499	207
182	Entomobrya nivalis	b144	Rothamsted	Rothamsted		513	214
182	Entomobrya nivalis	e80	Rthamsted			513	214
182	Entomobrya nivalis	m1006	Rothamsted			513	214
182	Entomobrya nivalis	m1007	Rothamsted			513	214
182	Entomobrya nivalis	g117	Boston Manor	Britain (Middlesex)	Boston Manor	516	179
182	Entomobrya nivalis	c192	Kimpton			517	218
182	Entomobrya nivalis	l85	KEW	Kew		518	177
182	Entomobrya nivalis	l81	Monks wood (woodland)	Monks Wood		519	280
182	Entomobrya nivalis	c192	Welwyn	Welwyn		523	216
182	Entomobrya nivalis	l97	Buckinham palace			529	179
182	Entomobrya nivalis	j79	Wicken Fen	Wicken Fen		550	265
182	Entomobrya nivalis	g118	Carmortheshire				
182	Entomobrya nivalis	l1003	Cranmore	Ireland	Cranmore		
182	Entomobrya nivalis	g123	Huntingdonshire				
182	Entomobrya nivalis	b266	Jersey	Jersey			
182	Entomobrya nivalis	b266	Jersey				
182	Entomobrya nivalis	e71	Peaton	Scotland			
182	Entomobrya nivalis	c183	Rosslyn	Scotland			
182	Entomobrya nivalis	b308	Ireland (blanket bog)				
182	Entomobrya nivalis	b266	Britain				
182	Entomobrya nivalis	s1001	Scotland (flourmill)				
182	Entomobrya nivalis	h1001	England (fungus)				
182	Entomobrya nivalis	d1001	SW-England (heaths)				
182	Entomobrya nivalis	b254	Britain				
182	Entomobrya nivalis	b266	Britain				
182	Entomobrya nivalis	d1000	Britain				
182	Entomobrya nivalis	d171	Britain				
182	Entomobrya nivalis	h1000	Britain				
182	Entomobrya nivalis	l1002	Britain				
182	Entomobrya nivalis	t77	Britain				
182	Entomobrya nivalis	c1004	Cheshire				

Species No	Species	Ref Code	Location	General Location	BRC Locality	CIS East	CIS North
182	Entomobrya nivalis	m1005	Cheshire				
182	Entomobrya nivalis	b1002	England				
182	Entomobrya nivalis	b363	England				
182	Entomobrya nivalis	c1001	England				
182	Entomobrya nivalis	c1002	England				
182	Entomobrya nivalis	c1003	England				
182	Entomobrya nivalis	l1000	England				
182	Entomobrya nivalis	l1002	England				
182	Entomobrya nivalis	p1000	England				
182	Entomobrya nivalis	r1000	England				
182	Entomobrya nivalis	s1000	England				
182	Entomobrya nivalis	n1001	Ireland				
182	Entomobrya nivalis	s255	Ireland				
182	Entomobrya nivalis	t1001	Ireland				
182	Entomobrya nivalis	t1001	Ireland				
182	Entomobrya nivalis	t1001	Ireland				
182	Entomobrya nivalis	w140	Ireland				
182	Entomobrya nivalis	r1001	orkney				
182	Entomobrya nivalis	g132	outer hebrides				
182	Entomobrya nivalis	g135	outer hebrides				
182	Entomobrya nivalis	e1000	Scotland				
182	Entomobrya nivalis	r1001	Scotland				
182	Entomobrya nivalis	w133	sw-England				
182	Entomobrya nivalis	w133	sw-England				
182	Entomobrya nivalis	w136	sw-England				
182	Entomobrya nivalis	m60	wales				
182	Entomobrya nivalis	c181					
220	Orchesella cincta	c189	Clare I	Ireland	Clare	120	100
220	Orchesella cincta	l100	Burren	Burren		127	211
220	Orchesella cincta	b1004	Lundy I	Britain	Lundy	213	144
220	Orchesella cincta	w138	Lundy I	Devonshire	213	144	
220	Orchesella cincta	e81	Comrie	Scotland	Comrie	241	855
220	Orchesella cincta	e81	Callander	Scotland	250	750	
220	Orchesella cincta	c183	Aberfoyle	Scotland	Aberfoyle	252	701
220	Orchesella cincta	e81	Aberfoyle	Scotland	Aberfoyle	252	702
220	Orchesella cincta	e81	Muthill	Scotland	Muthill	280	710
220	Orchesella cincta	e71	Cleghorn Glen	Scotland	Cleghorn	289	645
220	Orchesella cincta	c183	Dollar	Scotland	Dollar	290	690
220	Orchesella cincta	e71	Elvanfoot	Scotland	Elvanfoot	296	616
220	Orchesella cincta	c183	Uphall	Scotland	Uphall	306	671
220	Orchesella cincta	e81	Bridge of Earn	Scotland	Bridge of Earn	310	710
220	Orchesella cincta	c183	Kirknewton	Scotland	Kirknewton	310	660
220	Orchesella cincta	c183	Pentland Hills above S	Scotland	Pentland Hills	310	650
220	Orchesella cincta	e81	Glenfarg	Scotland	315	713	
220	Orchesella cincta	c183	Ratho	Scotland	Ratho	315	670
220	Orchesella cincta	c183	Balerno	Scotland	Balerno	316	666
220	Orchesella cincta	l73	Dublin (beach wood)		Dublin	316	227
220	Orchesella cincta	c183	Cullalo	Scotland	318	688	

Species No	Species	Ref Code	Location	General Location	BRC Locality	CIS East	CIS North
220	Orchesella cincta	c183	Braid burn	Scotland	320	665	
220	Orchesella cincta	c183	Braid Hills	Scotland	320	665	
220	Orchesella cincta	c183	Burntisland	Scotland	Burntisland	320	680
220	Orchesella cincta	c183	Comiston	Scotland	Comiston	320	670
220	Orchesella cincta	c183	Mortonhall	Scotland	Mortonhall	320	660
220	Orchesella cincta	c183	Penicuik	Scotland	Penicuik	320	655
220	Orchesella cincta	c183	Fairmilehead	Scotland	325	668	
220	Orchesella cincta	c183	Arniston	Scotland	Arniston	330	655
220	Orchesella cincta	c183	Vogrie	Scotland	337	662	
220	Orchesella cincta	c183	Longniddry	Scotland	Longniddry	343	670
220	Orchesella cincta	c276	Grange-over-	Lanceshire Sands	Grange-over-	344 Sa	420
220	Orchesella cincta	c183	Luffness	Scotland	Luffness	347	681
220	Orchesella cincta	c276	C. Delamere	Lanceshire	Delamere	356	369
220	Orchesella cincta	c183	N. Berwick	Scotland	North Berwick	356	685
220	Orchesella cincta	c276	Warrington	Lanceshire	360	380	
220	Orchesella cincta	c276	Rostherne	Lanceshire	370	380	
220	Orchesella cincta	b358	Teesdale	Teesdale	380	520	
220	Orchesella cincta	c276	Didsbury	Lancashire	Didsbury	384	390
220	Orchesella cincta	c183	Arthur's Seat	Scotland	404	837	
220	Orchesella cincta	w1001	Savernake Forest		422	166	
220	Orchesella cincta	b1003	Isle of Wight		430	080	
220	Orchesella cincta	b302	Isle of Wight		430	080	
220	Orchesella cincta	b261	Sheffield		435	385	
220	Orchesella cincta	e1001	Wythamwoods		446	209	
220	Orchesella cincta	m1004	Oxford	England	Oxford	455	204
220	Orchesella cincta	m64	Oxford	England	Oxford	455	204
220	Orchesella cincta	m149	Oxford (etc.)	Oxford		455	204
220	Orchesella cincta	c192	Berkhamsted	Berkhamsted		499	207
220	Orchesella cincta	c192	Berkhamsted	Berkhamsted		499	208
220	Orchesella cincta	b144	Rothamsted			513	214
220	Orchesella cincta	c192	Kimpton			517	218
220	Orchesella cincta	c192	Kimpton			517	219
220	Orchesella cincta	l85	KEW			518	177
220	Orchesella cincta	c192	Welwyn	Welwyn		523	216
220	Orchesella cincta	c192	Welwyn	Welwyn		523	216
220	Orchesella cincta	w196	Epping Forest	Epping Forest		541	197
220	Orchesella cincta	j79	Wicken Fen			550	265
220	Orchesella cincta	g117	Holkham (Norfolk)	England	Holkham	586	344
220	Orchesella cincta	c183	Bucklyvie	Scotland			
220	Orchesella cincta	l1003	Cranmore	Ireland	Cranmore		
220	Orchesella cincta	l1003	Cranmore	Ireland	Cranmore		
220	Orchesella cincta	c187	Lambay I	Ireland			
220	Orchesella cincta	e71	Peaton	Scotland			
220	Orchesella cincta	c183	Rosslyn	Scotland			
220	Orchesella cincta	c181	"injurious"				
220	Orchesella cincta	t80	"injurious"				
220	Orchesella cincta	b308	Ireland (blanket bog)				
220	Orchesella cincta	h1001	England (fungus)				

Species No	Species	Ref Code	Location	General Location	BRC Locality	CIS East	CIS North
220	Orchesella cincta	w1002	England (lake district)				
220	Orchesella cincta	m66	Berkshire				
220	Orchesella cincta	h1000	Britain				
220	Orchesella cincta	j1000	Britain				
220	Orchesella cincta	t77	Britain				
220	Orchesella cincta	t77	Britain				
220	Orchesella cincta	g118	Carmorthenshire				
220	Orchesella cincta	h204	Caves				
220	Orchesella cincta	c1004	Cheshire				
220	Orchesella cincta	l81	common				
220	Orchesella cincta	b363	England				
220	Orchesella cincta	c1003	England				
220	Orchesella cincta	f1001	England				
220	Orchesella cincta	l1002	England				
220	Orchesella cincta	m1000	England				
220	Orchesella cincta	n1001	England				
220	Orchesella cincta	p1000	England				
220	Orchesella cincta	s1000	England				
220	Orchesella cincta	g123	Huntingdonshire				
220	Orchesella cincta	b353	Ireland				
220	Orchesella cincta	g1003	Ireland				
220	Orchesella cincta	s255	Ireland				
220	Orchesella cincta	t1001	Ireland				
220	Orchesella cincta	w1000	Ireland				
220	Orchesella cincta	w140	Ireland				
220	Orchesella cincta	c190	Midland Plateau				
220	Orchesella cincta	h228	Northumberland				
220	Orchesella cincta	r1001	Orkney				
220	Orchesella cincta	b1000	Scotland				
220	Orchesella cincta	r1001	Scotland				
220	Orchesella cincta	w133	SW-England				
220	Orchesella cincta	w136	SW-England				
220	Orchesella cincta	w136	SW-England				
220	Orchesella cincta	b254					
220	Orchesella cincta	c1005					
220	Orchesella cincta	f2					
220	Orchesella cincta	l118					
220	Orchesella cincta	l119					
220	Orchesella cincta	t1002					